QUALITY MANAGEMENT IN KINEMATIC LASER SCANNING APPLICATIONS

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ABSTRACT:

Sophisticated mobile mapping technology is used for a growing number of applications. Precise road or railway corridor survey methods require sensors with complementary measurement characteristics. The Mobile Road Mapping System (MoSES) combines photogrammetric stereo cameras and a number of laser scanners on a calibrated measurement platform. External orientation to georeference the collected data of all objects is provided by a multisensor module combining IMU, DGPS and odometer measurements of high accuracy. Nevertheless practical trajectory determination for scanning applications needs additional control algorithms, which frequently check for after filtering quality weaknesses like position drifts or consistency problems. The exact calibration of the multisensor system itself is derived using certain system specific methods. During practical survey projects special quality management procedures guarantee the integrity of the system. Results show, that the laser scanner data accuracy reaches 3-4 mm even for a combination of different scanners. Stereo-photogrammetric measurements fit to the laser scanner data within their measurement accuracy of below 0,05 m. The combination of cameras and laser scanners enables the determination of digital road surface models for reconstruction purposes, tunnel surveys or 3d-mapping of bridges. Application examples show the success of this multisensor mapping approach.

1. INTRODUCTION

Mobile mapping systems based on a land vehicle have been increasingly applied for a broad range of applications throughout the last years. The tasks covered by kinematic survey methods grow more and more complex. High precision applications rely on an IMU based trajectory and a multisensor survey system. For example the Mobile Road Mapping System (MoSES) combines stereo photogrammetric cameras and laser scanners as complementary sensors to capture the road corridor (figure 1). The aim of system design for MoSES was to create a mapping system capable of serving multiple tasks. Since the year 2000 the MoSES system has been successfully applied for projects. The preconditions for an integrated use of cameras and laser scanners are careful calibration and sophisticated quality management. Various steps to guard quality have proved to be necessary to guarantee result reliability to customers. The first quality management step is the analysis of the IMU based trajectory. Secondly the results of camera and scanner measurements have to be controlled by independent methods. The years of project experience led to the definition of a general multisensor system qualification process valid for any kind of accuracy range. For the MoSES system this process enables high precision applications like the survey of digital road models or the kinematic digitalisation of tunnels or bridges. The MoSES is capable to compete with static survey methods and accuracy.

2. THE MOBILE ROAD MAPPING SYSTEM (MOSES)

2.1 System concept

The MoSES has been designed to capture road related data in a cost-effective way without obstruction of the traffic flow. The sensors cover a corridor of 20 m width on both sides of the route travelled (figure 2). The system has been described in detail in previous articles (Gräfe, 2001; Heister, 2004). The sensor combination is flexible. In general the architecture is modular and consists basically of two subsystems:

- trajectory subsystem and
- object acquisition subsystem.

Figure 1. Mobile road Mapping System (MoSES).

The MoSES system currently combines 4 sensor modules.

2.2 Trajectory subsystem

The trajectory module forms the core of each high end mapping system. An Inertial Measurement Unit (IMU), aided by

embedded differential GPS, odometer and other sensors if necessary, e.g. a digital barometer, provides continuously the full 3D kinematic state of the vehicle. Sensor orientation requires the determination of 3D position as well as roll, pitch and heading of the vehicle. Depending on the specification of the inertial components highly sophisticated software achieves position accuracies ranging from 0,02 m to 0,5 m and angular accuracies ranging from 0,005° to 0,02°. The trajectory is provided in real-time with reduced accuracy and with high accuracy after post mission processing (Gräfe, 2001).
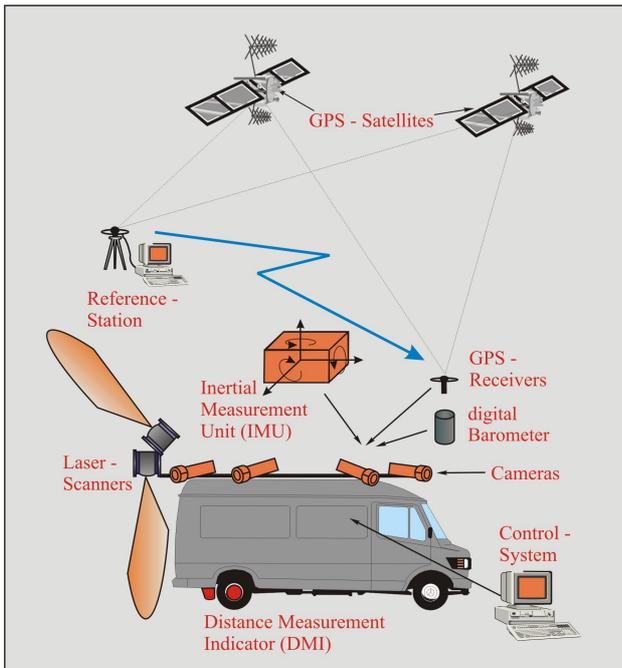

Figure 2. System concept of MoSES.

2.3 Object acquisition subsystem

To guarantee full sensor coverage of the road corridor a variable number of digital cameras for documentation and photogrammetric measurement purposes and two laser scanners have been integrated into a hybrid measurement system.

2.3.1 Module Image Documentation

The image documentation module allows parallel image acquisition of multiple high resolution cameras to guarantee consistent documentation of the surrounding space and all relevant objects in sight. The standard configuration consists of two cameras documenting the road corridor and one camera pointing downward to allow road surface analysis. Exact time synchronization enables the assignment of 3D coordinates and orientation angles to each image. The georeferenced imagery can be handled flexibly using a viewing software or may be integrated into a Geo-Information-System (GIS) as additional source of information.

2.3.2 Module Stereo Photogrammetry

The photogrammetry module consists of at least one pair of stereo cameras. The module has been designed for 3D photogrammetric survey of the road corridor (figure 3). Depending on the type of camera objects may be determined with a standard deviation < 0.1 m, relative measurements with < 0,03 m. The processing software allows efficient object

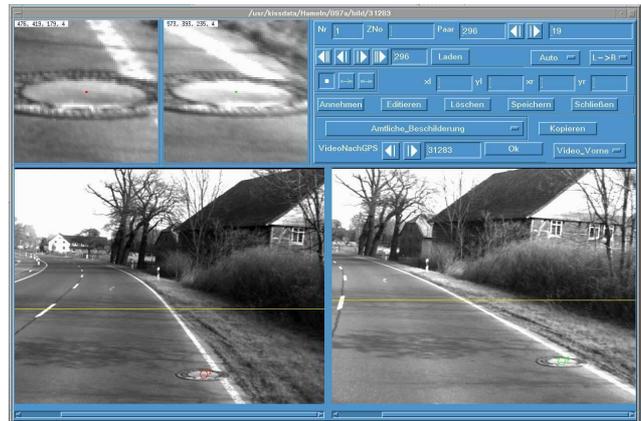measurement, attribution and transfer to CAD und GIS applications.

Figure 3. Stereo-photogrammetric software.

2.3.3 Module Scanner

The scanner module offers kinematic survey capabilities using laser scanners based on time of flight measurements. The main feature of scanner technology is the full digital coverage of the road area. The resulting point clouds are used for road condition determination, digital road surface modelling, bridge- or tunnel surveys or 3D city model data. The resolution of the standard scanner lies within the mm-range. If the specific MM-calibration procedure is applied, height accuracies of 0.005 m will be obtained.

2.4 Sensor integration

Each module is controlled by a PC, which logs all sensor data for post-mission processing and performs real-time integrity checks and accuracy estimations. All modules are linked by a specially designed multi purpose synchronisation system. Precise time synchronization of all sensors to the trajectory is the prerequisite for high accuracy results.

2.5 System calibration

Direct georeferencing of sensor measurements with high precision requires sophisticated sensor analysis and careful geometric system calibration. 3D lever arms and mounting angles for each sensor in the vehicle coordinate system have to be determined accurately to enable direct combination of stereo photogrammetric measurements with laser scanner coordinates without significant differences. By means of high precision engineering survey methods the geometric calibration parameters of both stereo cameras and laser scanners can be determined with sufficient accuracy. The calibration methods are described in detail in (Gräfe, 2007).

3. TRAJECTORY QUALITY MANAGEMENT

The trajectory is used as exterior orientation for all sensors. The quality of the mapping results is directly related to the trajectory. Common mapping project results should fulfil the following requirements:

- All results within the required absolute accuracy range, which may be 0,5 m for position and height.
- The road itself must be homogenous, which means, that 3D distances along the road regularly have to be determined with an accuracy below 1 ‰.

- High accuracy in the same range is also required for longitudinal or cross slope information.
- If road planning parameters like curvature or slope are derived from the measurement data, the trajectory has to be geometrically smooth in position and height.

All these requirements normally have to be met for a whole road network regardless whether topography allows full GPS coverage or not. Even in high mountain regions, large forests or within tunnels the specifications of a survey project have to be met. For this reason only trajectory subsystems based on an 3D IMU as the core of the system have been used for the MoSES. The experiences of the last years with different systems and software packages showed, that even an IMU based trajectory system has to be watched carefully to maintain quality.
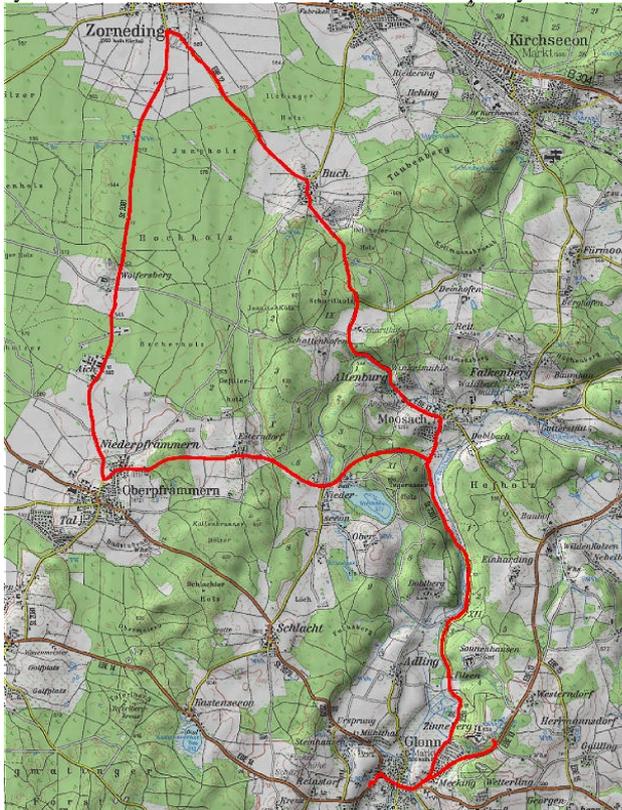

Figure 4. Trajectory system quality test track.

3.1 Absolute accuracy check

Trajectory determination systems should allow both the use of a realtime solution and additional post-processing. In realtime accuracy is naturally degraded, but the trajectory should also fulfil the requirements stated above. For the MoSES system commonly the trajectory raw data is post processed using forward and backward filtering and smoothing to derive a blended solution of high accuracy. The stability of a trajectory solution is normally judged by the accuracy after a complete DGPS outage of certain length, e.g. 120 seconds (Gräfe, 2001). For practical projects the situation mostly is a little different. A long outage with no satellite reception at all is quite a rare case, but periods with very poor GPS quality may regularly be encountered for several minutes. Poor GPS quality may result into systematic shifts or sudden jumps in position or height, e.g. along alleys. The IMU data based trajectory has to be robust against systematic DGPS shift influence or sudden changes. To judge the trajectory quality under difficult conditions, a

reference route of 26 km length has been defined (figure 4). Each new trajectory module or new trajectory post-processing software package is evaluated along the track, which allows all requirements to be checked. The track includes open fields, villages and deep forests as well as flat road sections and sections with quite steep slope. The absolute accuracy is evaluated by ground control points, which cover the whole route. Well defined common objects like manholes or signs have been determined by tachymetric survey methods. The corresponding object coordinates are measured by MoSES using stereo-photogrammetric methods (see section 2.3.2). The differences of the measurements to the control point coordinates allow the direct analysis of trajectory absolute accuracy and robustness.
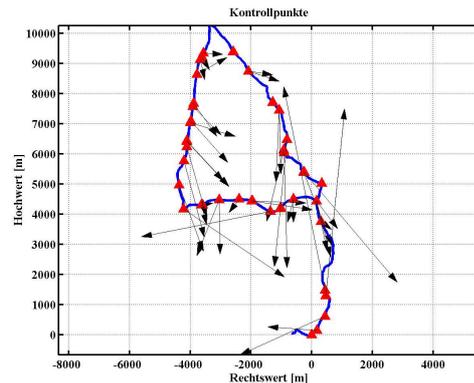

Figure 5. Discrepancies at 86 ground control points along the test track.

Control Point Residuals	Easting [m]	Northing [m]	Height [m]
Minimum	-0.93	-1.51	-2.63
Maximum	0.77	1.35	1.34
Standard deviation	0.34	0.50	0.97
Estimated trajectory RMS (post-processing)	0.21	0.22	0.32

Table 6. Statistic analysis of the discrepancies shown in figure 5

Figure 5 and table 6 show the results of a post processed trajectory analysed along the test track. The ground control points prove, that this trajectory system achieves an accuracy of below 0.5 m for each position component and below 1 m for height. Compared with the difficulties of the test track, the result is acceptable. Table 6 additionally contains the trajectory RMS estimated by the trajectory post processing software package. The accuracy estimation is much too optimistic, which is a common experience with a lot of software packages. Especially in inner city areas or even along highway noise barriers sometimes trajectories encounter large systematic shifts combined with too optimistic accuracy estimations, which may lead to wrong results.

3.2 Trajectory integrity analysis

The relative accuracy requirements of the trajectory are regularly met if an IMU is used as core of the system. The inertial measurement data normally should guarantee the integrity of the solution. Sometimes or with some trajectory processing software packages the integrity gets lost. Simple checks may be performed in two ways:

- Trajectory integrity check in time space or
- geometric trajectory integrity check.

Figure 7 contains the analysis of a trajectory as a time series. The IMU determines accelerations and angular rate with high frequency, e.g. with 200 Hz, which equals a time resolution of 0.005 seconds. The changes from each trajectory epoch to the next should be very small. Figure 7 shows a sudden height change of 10 cm per 0.005 seconds maximum corrupting the trajectory. A behaviour like this rules out the corresponding trajectory from further use for slope determination or laser scanner data processing.
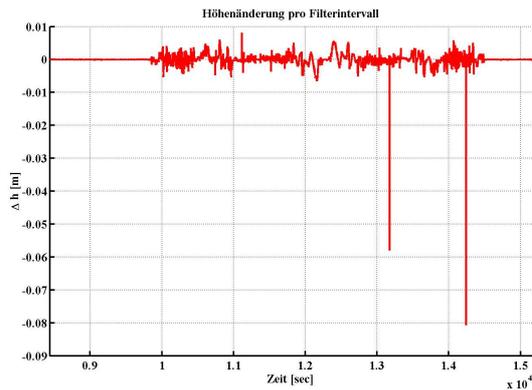

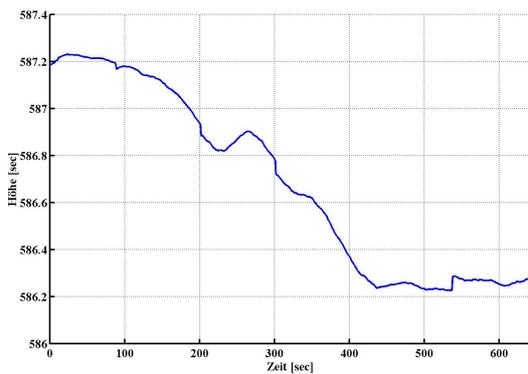Figure 7. Trajectory analysis in time space showing jumps.

Figure 8. Geometric trajectory analysis showing height drift.

Figure 8 contains the analysis of the geometric trajectory stability. The dynamic filter model for land vehicle trajectories has to make sure, that the trajectory is not subject to sudden changes or drifts within static periods. A vehicle will regularly be static, e.g. at traffic lights or in a traffic jam. Road curvature parameters or slope results still have to be reliable for those missions. Figure 8 shows a trajectory drifting 1 m in height within 10 minutes. A behaviour like this also may rule out the corresponding trajectory system from further use.

4. SCANNER DATA QUALITY MANAGEMENT

Laser scanner are widely used for many applications. The MoSES system contains laser scanners since 1999. Kinematic applications for laser scanners require careful quality management. Prerequisites for successful scanner applications are strict time synchronisation and exact sensor calibration (Gräfe 2007). Especially the sensor calibration is a critical issue, which is often ignored. Most scanners are influenced by sunlight. Scanners may also show systematic discrepancies in

the cm-range depending on the measurement angle and surface reflectivity. To verify the laser scanner quality of the MoSES system, the results are regularly checked along different test routes.

Figure 9. A reference track for laser scanner quality control along an underpass .
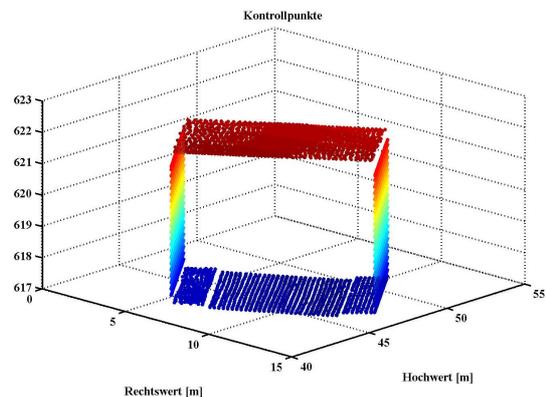

Figure 10. Reference survey point cloud of the underpass in figure 9 to check the laser scanner data.

The quality management for laser scanner results controls the whole scanner data processing chain, including sensor and system calibration, time synchronisation and trajectory determination (Gräfe, 2005). The analysis of the control tracks for the MoSES system regularly leads to height accuracy results of 3-4 mm, which is very acceptable compared with static survey precision.

5. PROJECT EXAMPLE

Kinematic mapping technology offers methods to acquire road data for large survey areas in fairly short time (figure 11). For the project shown in fig. 11, the road network including curvature and slope and all relevant objects in the road corridor were determined with the MoSES van. The results achieved by mobile systems are only reliable, if the quality management described in chapter 3 is applied on any mission dataset. If this is not the case, mobile mapping becomes inefficient, because only e.g. 80% of the survey area are covered with sufficient accuracy. The rest of the roads would have to be mapped by different technologies. For this reason, the MoSES system software includes a specialised quality management chain to ensure integrity and precison for the whole measurement area.

All systems, especially the trajectory module, are frequently checked for quality, so that homogenous results for the whole survey area can be guaranteed.
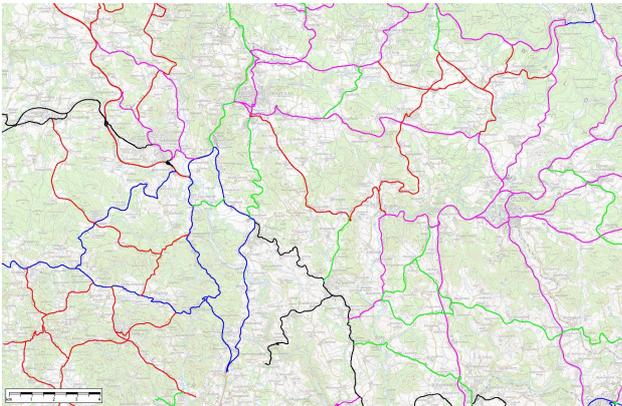

Figure 11. Example for a road network survey in Bavaria.

6. LASER SCANNER APPLICATIONS

The laser scanner module of the MoSES consists of 2 scanners with a 180° field of view for each sensor. The scanners emit a pulsed laser beam, which is moved in a plane by a prism rotating with 75 Hz. Results are transversal profiles with a resolution of 1° and an accuracy of below 5 mm for each measured distance. Additionally a signal intensity value provides information about the reflectivity of the surface at each target point. The orientation of the two scanners is flexible, so that even a 360° view is possible to allow 3D tunnel surveys. The density of the profiles in driving direction varies with driving speed. At a speed of about 60 km/h a profile every 20 cm is stored. The spacing of points along each profile varies between 35 mm and 65 mm for a corridor width of 8 m. This amounts to nearly 150 points per square meter on the road surface. Projects that require higher profile density are driven with reduced speed. Since the absolute orientation of each laser beam is precisely known by applying the trajectory, each measurement can be transformed from the system coordinate frame into the global WGS-84 coordinate frame. Results are point clouds for both laser scanners representing the digitised survey corridor (Graefe, 2005).

6.1 Determination of Geometric Road Parameters

The generation of digital road surface models requires geometric knowledge about the roadway itself. Geometric road survey is one of the key features of the MoSES system and is a standard mobile mapping task with the following steps (Gräfe, 2005):

- Survey of the roadway edges and road lanes by using automatic laser scanner edge detection or photogrammetric stereo image measurements.
- Semi-automatic generation of the road axis in 3D curvature parameters together with attribute data like road width, lane structure and lane width.
- The road axis is the necessary basis to generate the model grid coordinates. The geometric roadway parameters, especially the roadway edges, lane structure and lane width are used to define the processing area of the digital surface model (fig. 12).
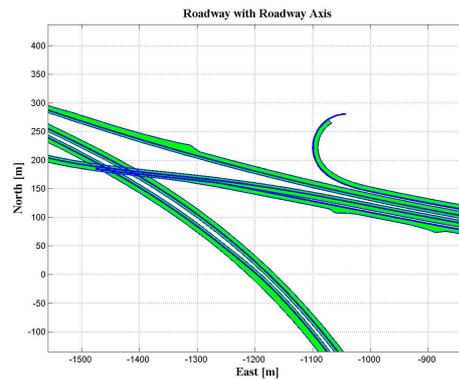

Figure 12: Roadway axes (green) for a part of a highway intersection surveyed with MoSES with transversal profiles along the road axis.

6.2 Processing of Digital Road Surface Models

The generation of 3D digital surface models based on laser scanner measurements with MoSES requires robust model determination and sophisticated quality control (compare chapter 4):

1. The regular grid for the road model is orientated along the road axis. The grid is based on transversal profiles in regular distance and with regular spacing between the points within each profile (fig. 12). This method of generating the grid was chosen, because the results can easily be integrated into standard road planning software packages, that organize their data in the same way. The width of each profile depends on the task and is limited by the edge of the roadway. The grid density is flexible. Surface models of a length between 0,5 to 40 km with a point spacing between 0,02 m and 0,50 m have been processed.
2. The road edges define the area for digital surface model processing. Data organisation varies with each task and is based on the road lane structure.
3. The point clouds of both laser scanners normally show large overlapping areas. Redundant surface measurements are used to ensure quality. Based on redundant measurements, systematic differences between both scanners are determined to control, that both scanners form one homogeneous point cloud.
4. The scanner coordinates within the area of interest are used to process the digital surface model of the road. A best-fit multi dimensional surface function for each grid coordinate is determined using robust estimation techniques. The estimation is based on the surrounding scanner measurements and used to calculate the smoothed height for the grid point.
5. Robust estimation techniques allow sophisticated quality control for each generated height value. In case of insufficient scanner data distribution or for grid coordinates along the roadway edge, estimation may not be possible.
6. Especially for highway survey tasks the combination of multiple missions may be necessary. Due to methods to generate homogeneous datasets out of independent missions along the same roadway, the combination of multiple digital surface models along the same road is possible without significant loss of accuracy (Gräfe, 2007).

7. Transformation of all grid points to a local coordinate system is typically required for road pavement reconstruction tasks. A local coordinate system is always needed at a building site. The necessary coordinate shifts of the digital surface model to the local coordinate frame vary slightly with time due to trajectory determination. The survey of the coordinate corrections is based on ground control points along the road that are automatically measured within the laser scanner data. Using this method the shifts can be determined with accuracy below 3 cm in position and 3 mm in height.
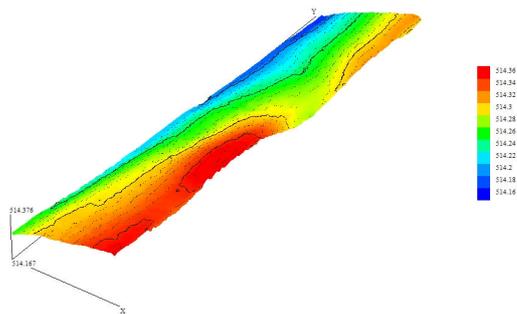

Figure 13. Example for a digital road surface model. The heights are colour coded.

Digital road surface models derived from MoSES data are used especially for road surface reconstruction tasks along highways. The method directly competes traditional static surveys offering comparable accuracy at higher speed, lower costs, much higher grid resolution and – most important – at much lower security risks (fig. 13). Digital road surface models may also be used for applications in the car industry, e.g. as reference data for development and testing. Additional interpretations of digital road surface models allow new applications, e.g. the precise coordinate based analysis of the water flow or rut depth for accident analysis tasks.

6.3 Bridge and tunnel survey applications

Another laser scanner application for the MoSES van is the survey of 3D buildings along the road like bridges or tunnels.
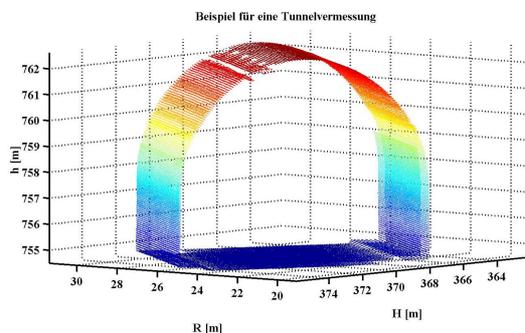

Figure 14. Example for a digital tunnel model. The heights are colour coded.

The point clouds are quality managed and free of statistical outliers, so that digital surface models of bridges or tunnels can easily be derived. Figure 14 shows an example for a tunnel survey result.

7. CONCLUSIONS

Quality management of both the trajectory data and the sensor measurements is the prerequisite for reliable results derived from mobile mapping data. To meet the requirements sophisticated quality control methods have been developed for the MoSES system. This effort opened the way to new kinematic survey applications. The determination of digital road surface models based on kinematic survey data acquired with MoSES has proved to be a reliable survey method and has been widely used over the last years.

8. REFERENCES

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