The Department of Geodesy and Geoinformatics

Stuttgart University

2008

editing and layout:
volker walter, friedhelm krumm, martin metzner, wolfgang schöller

Dear friends and colleagues,

It is our great pleasure to present to you this annual report[1] on the 2008 activities and academic highlights of the Department of Geodesy & Geoinformatics of Universität Stuttgart. The Department consists of the four institutes:

- ▷ Institute of Geodesy (GIS),
- ▷ Institute of Photogrammetry (ifp),
- ▷ Institute of Navigation (INS),
- ▷ Institute of Applications of Geodesy to Engineering (IAGB).

Research

This annual report documents our research contributions in many diverse fields of Geodesy & Geoinformatics: from satellite and physical geodesy through navigation, remote sensing, engineering surveying and telematics to photogrammetry, geographical information systems and location based services. Detailed information on projects and research output can be found in the following individual institutes' sections.

Teaching

With our German Geodesy & Geoinformatics curriculum we have a vigorous programme with a total enrolment of about 130 students. Diversity is one of the programme's strengths: the female student population is about 35%, whereas foreign students account for nearly 50%. Great changes lie before us, though. In the course of the so-called Bologna process, the Diploma curriculum is transformed into the Bachelor-Master structure. Preparations for starting the new BSc-program in Winter Semester 2009/2010 are well underway.

Now in its third year of existence and with an ever increasing enrolment, our international Master Programme Geomatics Engineering (GEOENGINE[2]) is firmly established. We attract the GEOENGINE student population from such diverse countries as China, Iran, Indonesia, India, Pakistan, Poland and Great-Britain.

Beyond these two core curricula, the institutes are involved in a host of other programmes around campus.

Nico Sneeuw
Associate Dean (Academic)
sneeuw@gis.uni-stuttgart.de

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[1] A version with colour graphics is downloadable from http://www.ifp.uni-stuttgart.de/publications/jahresberichte/jahresbericht.html
[2] http://www.geoengine.uni-stuttgart.de/

Institute for Applications of Geodesy to Engineering

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Head of Institute

Prof. Dr.-Ing. Ulrich Rott, (Provisional Director)
Dr.-Ing. Martin Metzner, Akad. Rat

Secretary

Christel Schüler (till 29.02.2008), Elke Rawe (since 01.05.2008)

Emeritus

Prof. Dr.-Ing. Dr.sc.techn.h.c. Dr.h.c. Klaus Linkwitz

Scientific Staff

Dipl.-Ing. Alexander Beetz	Sensor Integration
Dr.-Ing. Renate Czommer	Map Matching
Dipl.-Ing. Ralf Laufer	Quality assurance
Dipl.-Ing. Ralf Schollmeyer (till 15.03.2008)	Kinematic positioning
MSc Rainer Schützle (since 01.04.2008)	Information Quality
Dipl.-Ing. Jürgen Schweitzer (since 01.05.2008)	Kinematic Positioning
PD Dr.-Ing. Volker Schwieger	Engineering Geodesy
Dipl.-Ing. Christian Waese (till 29.02.2008)	Geodata and GIS Applications
Dipl.-Ing. Matthias Wengert	Geodata and GIS Applications
Dr.-Ing. Thomas Wiltschko (till 31.03.2008)	Traffic Information Techniques

Technical Staff

Niklaus Enz (till 31.08.2008)
Ruping Hua (till 31.10.2008)
Martin Knihs
Lars Plate
Doris Reichert

External teaching staff

Dr.-Ing. Max Mayer - Landesamt für Flurneuordnung

General View

After the death of Prof. Möhlenbrink, until then head of the institute, Prof. Rott provisionally in charge of the institute on his behalf. The work of the appointments committee on the new professorship is being continued throughout the year 2008. Besides, in 2008 the Institute for Applications of Geodesy to Engineering has become member of the faculty „Aerospace Engineering and Geodesy“. Furthermore, IAGB is still member of FOVUS (Traffic research Centre of the University of Stuttgart) and thus continues the close collaboration with the faculty „Civil and Environmental Engineering“.

The institute’s main tasks in education and research reflect on engineering geodesy, geodetic measurement techniques, data processing, and traffic information techniques. The daily work is characterised by intensive co-operation with other engineering disciplines, especially with aerospace engineering, civil engineering, traffic engineering, and construction management. Co-operations also exist with other university institutes as well as with the construction and automobile industry, and various traffic services.

In education, the institute is responsible for the above-mentioned fields within the curricula for „Geodesy and Geoinformatics“ as well as for „Geomatics Engineering“. In addition to the education in Surveying for Architects and Surveying for Civil Engineers, lectures on Acquisition and Management of Planning Data are presented to the diploma course of Technique and Economy of Real Estate. Furthermore, lectures are given to students of Geography and Traffic Engineering as well as two lectures in English within the master course Infrastructure Planning. Finally, eLearning modules are applied in different curricula e.g. for geodetic measurement techniques or for cartographic animations. The current research is reflected in most lectures and in diploma theses.

Research and development

Positioning by mobile phones

The project Do-iT (data optimisation for integrated telematic) deals with the acquisition and forecast of traffic state on the basis of multiple trajectories generated from anonymous mobile phone data. Two principally different methods of data acquisition are used.

In the first case (Abis-Data) the signal strength observations of the serving and six neighbouring GSM antennas received at the mobile phone are recorded in the GSM network. Positions are estimated with a frequency of 2Hz by matching these signal strength observations onto a signal strength map available for every GSM antenna. Different filter algorithms identify participants in the GSM network as pedestrian, cyclist, individual or public traffic participant. Kalman filtered positions of one identified participant are generating a kind of corridor based on the uncertainties of the position estimation. Within this corridor, data of the road network are extracted from the digital map. Most probable trajectories are derived on the basis of shortest path algorithm. Since 12th November 2008 trajectories are calculated online using this method for two Location Areas in Karlsruhe. At the moment approximately 2000 trajectories can be produced per diem in real time. Overall more than 5000 trajectories per diem can be produced depending on phoning behaviour of participants and computer capacity.

Since Abis-data are only available during communication or connection the project Do-iT should also analyse the usability of A-data available at Mobile Switching Centers (MSC), which provide, in case of active connection, the change of one radio cell to another (handover). In stand by mode only the old and new location area and the new radio cell is available.

Until now trajectory determination with A-data is done in the following steps

- ▷ Mobile phones are identified as moving, if there are more than 8 different handovers or location area changes.
- ▷ Since there are more reasons for a handover, than the changed position of mobile phones, the handover sequence is corrected due to multiple see-saw switching.
- ▷ Possible sojourn area of mobile phone is estimated by time difference between successive handovers and maximum occurring speed of those road segments which intersect the borderlines of both handovers.
- ▷ These single sojourn areas are joined together to form a corridor limiting the digital road map.
- ▷ Possible routes are generated by shortest path algorithms between nodes at the first and last handover
- ▷ The most common part of all possible routes is chosen as most probable route.
- ▷ Path-time diagram is calculated with regard to the chosen route.

Figure 1 presents the result of one long telephone call during a journey from Stuttgart to Karlsruhe compared to GPS as reference.

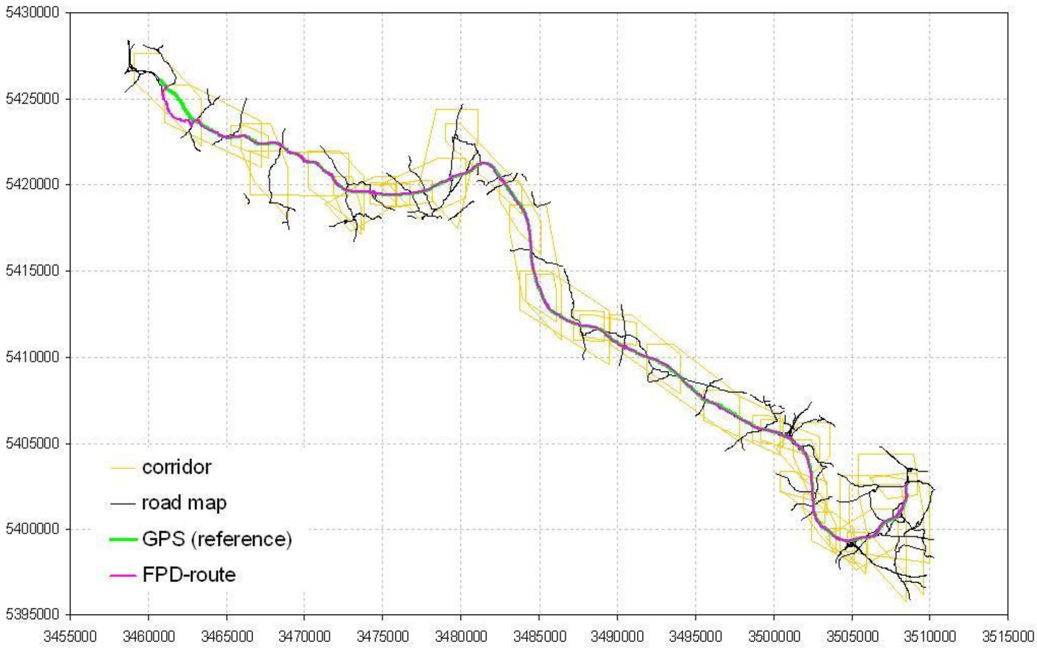

Fig. 1: Route derived from floating phone data (A-data)

Quality Management for Traffic State Acquisition using Mobile Phone Positioning

A process accompanying quality management will be implemented in the Do-iT project. By means of a permanent monitoring of the process development, an adequate quality model to describe the trajectories calculated from mobile phone traffic (FPD-trajectories) could be developed and implemented within the processes. Hence, a number of quality parameters for the evaluation of data quality is available. However, a part of these parameters can only be determined exemplarily using adequate reference data. While online, operation data from stationary traffic data acquisition systems (SAS) provided by the project partners are used as reference. Within development of the algorithms and right after their finishing additional test runs with GPS were done. For evaluation of the trajectories, GPS as reference is normally not available in general and therefore can not support quality assurance in the future.

To evaluate the quality of trajectories, in particular the following parameters have been selected from the comprehensive quality model:

- ▷ failure rate of FPD-server in [%]
- ▷ rate of coverage of project network in [%]
- ▷ saturation (part of traffic which can be detected) in [%]
- ▷ correlation of diurnal cycles of traffic volume from FPD and SAS
- ▷ correlation of diurnal cycles of mean velocity from FPD and SAS

As can be seen in figure 2, almost the whole project network can be covered with trajectories generated from mobile phone traffic. The traffic flows on highways and main traffic arteries in particular can be mapped using this method. Outside the grey covered area no mobile traffic data are available for calculating the trajectories by using the presented method, therefore the coverage of the project network ends there (thin, black lines).

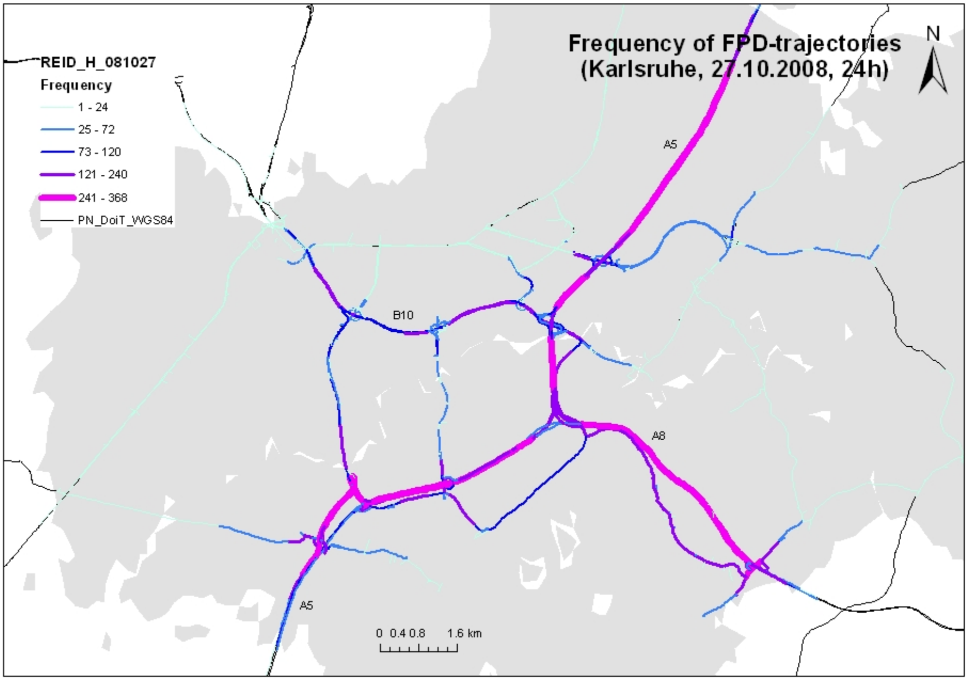

Fig. 2: Frequency of calculated trajectories within a day (for example: October 27th 2008 in Karlsruhe)

The following figure 3 shows an exemplary comparison with selected SAS. The saturation in percent showing the ratio between calculated FPD-trajectories and the detected traffic volume as well as the absolute number of trajectories meeting a single SAS location, are given next to the highlighted road elements.

Resulting from research and analysis of surveys concerning mobile phone habits as well as the recent market allocation, a saturation of 1 % is almost the maximal reachable value. The reasons therefore among others are the fact, that only one network provider is involved into the project and the used method basing on active mobile phones.

In addition, a protocol software has been implemented, enabling the comparison of statistical indicators like number, length and duration of trajectories. By doing so, different days can be compared as well as single hours. This enables the learning of regular variations of the indicators following diurnal and weekly cycles as well as detecting critical changes, indicating problems within data processing. Based on this failure recognition and by developing an adequate catalogue of countermeasures a failure management and thus a comprehensive quality assurance within the online operation can be built up.

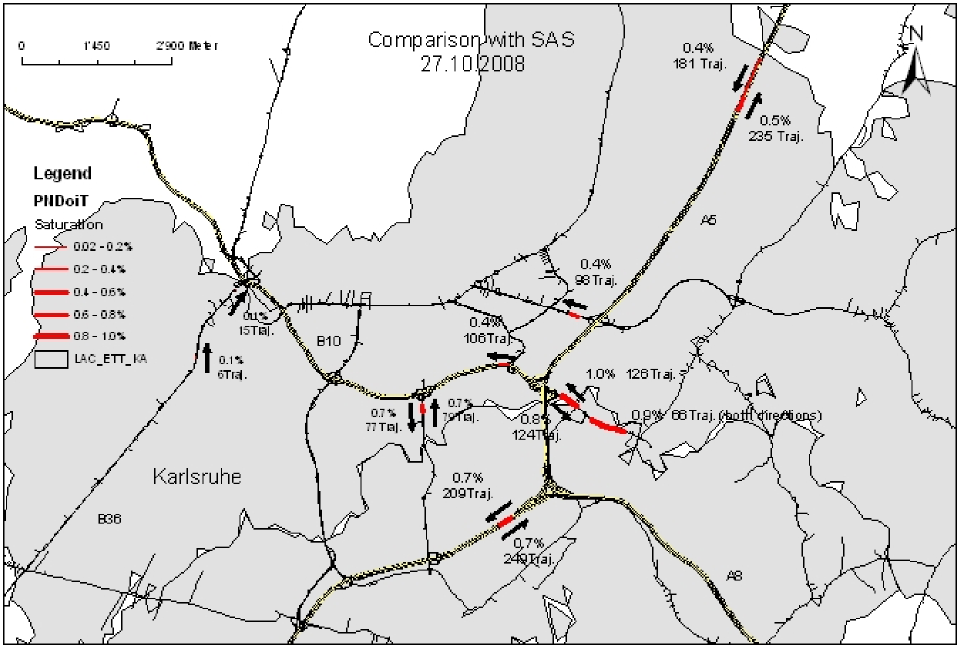

Fig. 3: Comparison with SAS, illustration of saturation (for example: October 27th 2008 in Karlsruhe)

For which traffic related application FPD-trajectories with defined and assured quality are suitable will be investigated within the demonstrators of the project partners. The data are used for traffic state acquisition and traffic management in real time as well as for traffic planning.

Modular System for Construction Machine Guidance

The modular system for construction machine guidance (PoGuide), which was developed at the institute, is subject to continuous improvement. The core of PoGuide is a simulator for Hardware-in-the-Loop simulations. It consists of a remote control, model truck, robot tachymeter and an interface between a PC and the remote control (shown in figure 4).

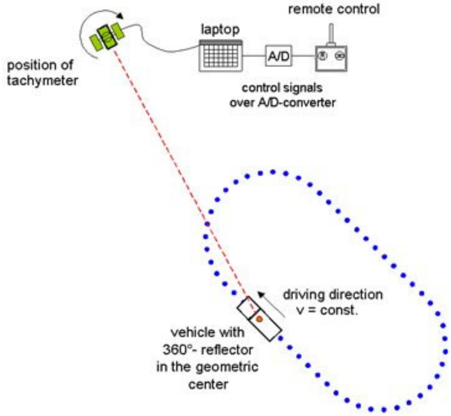

Fig. 4: PoGuide - Simulator

Along with the implementation of an enhanced Kalman filter based on the geometric single track model, different controllers have been integrated into the system and adapted to the simulator for optimal operation. The controllers are 3-point-controller, P-, PI-, PD- and PID-controller. By combining of the PID-controller and the enhanced Kalman filter one could achieve a control quality of 2,4 mm (as control quality the RMS of the lateral deviations for each driven round is taken). Figure 5 shows the lateral deviations for one driven round. One of the future research objectives will be the reduction of the recurrent systematic effects.

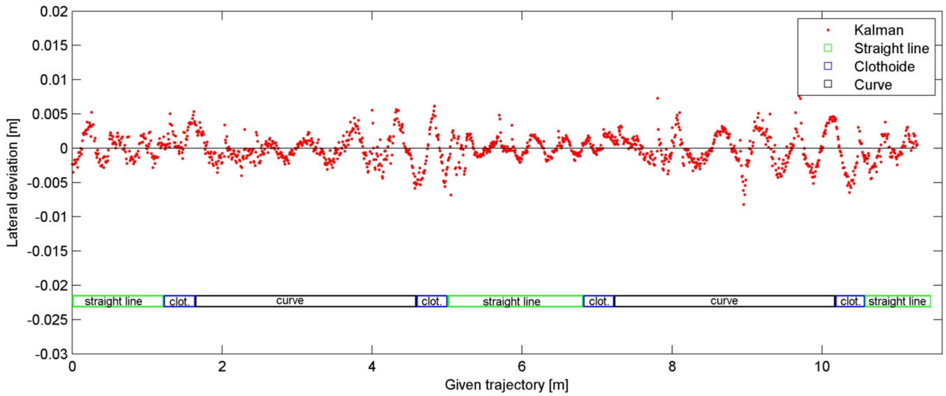

Fig. 5: lateral deviations for one driven round

Further more it's intended to add a caterpillar model to the simulator. For the implementation of this vehicle in the simulator it is essential to develop a new vehicle model. In addition, the test vehicles have to be equipped with complementary sensors. Thus it is possible to make a state control und use adaptive filter techniques.

Accurate Positioning by High-Sensitivity GPS Receivers

High-Sensitivity GPS receivers are characterised by cost clearly below 100 Euro. Additionally a sensitivity better -150 dBm with respect to attenuated and reflected signals is given. The second characteristic predispose these receiver type for navigational use in shadowed areas like urban canyons. The instruments use phase-smoothed code measurements for positioning.

For recent investigations at IAGB the u-blox AEK-4T Evaluation Kit was used, since this receiver shows the possibility to readout phase data. Figure 6 shows the ANN-MS-antenna and the respective adaüter constructed at IAGB. The processing is realised in post-processing. For this task the software TEQC is used for decoding of the raw data. The software Wa1 is utilised for processing the decoded data and position determination. For a user-friendly program control, the new software GPS tools was developed at IAGB.

Fig. 6: Adapter and ANN-MS-antenna for u-blox AEK-4T

The usage of default processing parameters leads to an average 3D-RMS of 2.4 cm for 30 minutes observation period. If environments as far as possible without shadowing and multipath effects are chosen, the average 3D-RMS is 2.0 cm for 20 minutes observation period. In this case the solutions are 100 % reliable and correct. These results are valid for baselines up to 7.7 km length.

The potential of these very cost-effective GPS receiver type seems to be very high and may lead to geodetic post-processing accuracy levels, if the processing software will be further adapted. It remains ambiguous, whether a real time solution may be reached. More probable is quasi real time positioning, that may deliver positions within a few minutes. A typical application would be monitoring measurements. Here the cost-effectiveness leads to the possibility to use a huge number of GPS receivers and therefore to built up sensor networks. Accuracy and reliability as well as object resolution may be improved.

Kinematic GPS-Measurements for Evaluation of TanDEM-X Data

In the last year the IAGB investigated different evaluation methods for kinematic GPS-measurements with respect to accuracy and efficiency. The aim was to acquire in a short time a 3D-track as long as possible with an RMS of 50 cm. The computed GPS-positions should be taken for evaluation of a Digital Elevation Model, which will be created with the satellite mission TanDEM-X.

Based on this analysis in the middle of the last year a project was started in cooperation with the „Deutsches Zentrum für Luft- und Raumfahrt“ (DLR). It contains the evaluation of 30 000 km kinematic GPS-Tracks using the method Precise Point Positioning (PPP).

PPP is a GPS evaluation method, where a position determination can be done on the base of continuous dual frequency data without using reference stations or reference station networks directly. The accuracy of kinematic measurements may reach decimetre level. For the evaluation is used on the one hand „GIPSY-OASIS (GOA II)“, an open source software package from Jet Propulsion Laboratory (JPL), which is installed locally on an Red Hat Linux operation system and on the other hand an online evaluation service called „CSRS-PPP Online Service“, which is supported by the Natural Resources Canada (NRCan). The results of the two products were averaged in position and in height.

The first track from Munich to the border of Hungary and Ukraine has a total length of 2000 km (forward and backward). The measurements were recorded by DLR staff using a car and a dual frequency GPS receiver (Leica GX1230) and a measurement frequency of 10 Hz. To achieve the point density of 25 points / 100 m the velocity of 120 km/h should not be exceeded.

Fig. 7: Cut-out of track1 from Munich to Ukraine

In figure 7 a short part of the results of the first track is visualized. The red marked GPS positions show the course with driving direction from left to right. The trajectory has short gaps, which occurs often after bridges, big traffic signs or tunnels. This issue can be explained as follows: after loosing the GPS signal the receiver needs an amount of time to recompute the position as well as to fix the ambiguities again. As expected there were computed in average 61 % (availability rate) of the maximum possible positions of a track. The next step is the evaluation of the tracks from Munich to Sao Martinho (Portugal) and Beijing to Urumqui (China).

Positioning variants for map-based intermodal transport control systems

Together with an industrial partner alternative positioning methods for map-based intermodal transport control systems (ITCS) have been investigated. Based on Logical Positioning using a speedometer, alternative methods have been searched for. It should be easy to realize a later conversion to a map-based control system.

The following topics are of particular interest:

The so far used Logical Positioning (fig. 8) is based on the determination of the driveway between two stops. The accuracy of Logical Positioning depends on the distance measurement on the one hand, and on the accuracy of the actual stop position on the other hand. To increase accuracy, an algorithm has been developed using GPS.

Furthermore, IAGB has developed an algorithm which fits the size of the stop-interval dynamically. Using the dynamic stop-interval, the Logical Positioning also works in areas where the distance between two stops is very long.

The data basis for the newly developed Support-Point-Based Positioning (fig. 9) is line-based. Unlike the method without support points (Logical Positioning), the data of the routes including the whole geometry are available in a global coordinate system. Thus, a vehicle can be located at any time by using GPS and a speedometer. The only precondition is that the vehicle has to be on a predefined route. The main advantages in comparison to the Logical Positioning can be outlined as follows:

- ▷ It is possible to detect a deviation of the vehicle from the scheduled route.
- ▷ The beacons so far used to influence the traffic lights are not needed anymore.
- ▷ The driver can use guidance commands.
- ▷ Deviations from the time schedule can be predicted more precisely.

The main difference compared to the Map-Based Positioning (fig. 10) is the fact that not the entire road network is available. The applications are linked to the defined routes and are therefore not route-flexible.

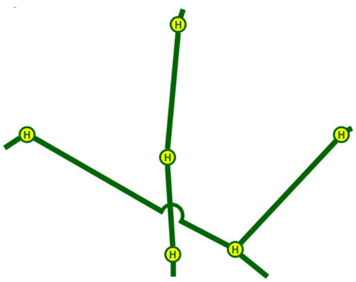

Fig. 8: Logical Positioning

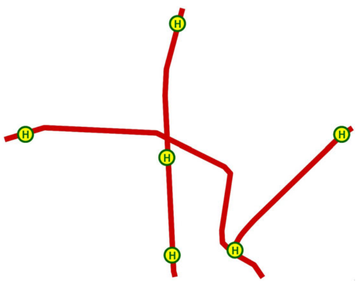

Fig. 9: Interpolation-Point-Based Positioning

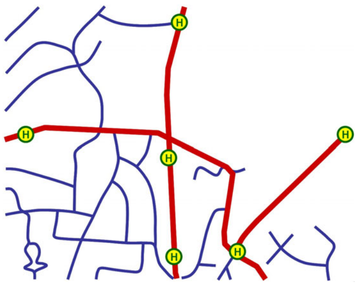

Fig. 10: Map-Based Positioning

Quality assured exchange of road safety attributes

Accurate and up-to-date safety related road network attributes are particularly important for safe driving along the European road network. Digital maps play an important role in many advanced driver assistance systems (ADAS) applications. With such systems becoming technically and commercially feasible, high quality map content becomes a prerequisite for their success. Today, map database updates are typically delivered as full map updates, e.g. once every quarter on CD or DVD. In the future this is expected to evolve towards instantaneous incremental updating, which means that changes to the map database are provided by subscription broadcast in real-time. When this becomes reality, also the provision of incremental updates to the map providers (and other users of such data) would be required, especially of safety related road attributes that concern traffic regulations and traffic signs. As public authorities are creating the changes of these road attributes, they would also be the most efficient source of such changes.

The European research project ROSATTE aims at establishing an efficient and quality ensured data supply chain for relevant core geographical data from public road authorities to commercial map providers with regards to safety related road content. The data provision chain addressed by ROSATTE concerns the flow of relevant attribute data from the road authorities via a standardized data exchange infrastructure to data users like the commercial map providers as shown in fig.11.

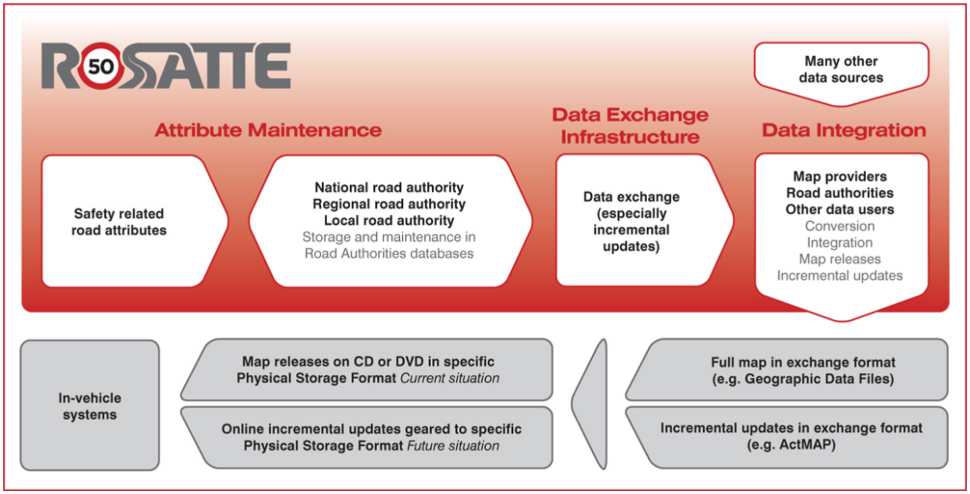

Fig.11: ROSATTE project structure

In order to be able to describe the user requirements on the quality of the ROSATTE update information, the IAGB quality model is to be used. It consists of 6 inherent quality characteristics, namely availability, up-to-dateness, completeness, consistency, correctness and accuracy. These characteristics are to be represented by quality parameters. Having defined the user quality requirements with the help of the quality parameters, all processes for data acquisition, data exchange and final data integration have to be evaluated regarding their effect on data quality. In case the requirements are not met, the processes have to be improved by quality assurance measures.

All partners concerned most likely work with different versions of digital maps or even with maps of different providers. Therefore the update objects can only be spatially referenced using location referencing techniques such as AGORA. This means in practice that locations in the source database may deviate from those finally integrated in the map providers' database. One possibility to keep the databases consistent would be the so-called feedback loop. Here, the map providers send a feedback message to the local authorities, that contains information about the status of the update integration. This can be a successful integration, an integration failure or some indicators showing the probability of a successful integration or the reason for the failure. This would help the local authorities to find errors and finally to get all their updates integrated in the target database.

Currently the ROSATTE metadata model is to be developed. Special attention is put on the conformity with the European INSPIRE directive (Infrastructure for Spatial Information in the European Community). The core element is the definition of a metadata catalogue which helps the member states to provide their spatial information in a common way in the future, so that people or institutions have a common way to find and use public spatial data.

Analysis of accident hotspot

The analysis of accident hotspots already carried out at the IAGB have been continued within two projects. Both projects had the purpose of identifying systematically the causes of accident and to support them by figures.

Topographical and topological description of accident hotspots

The purpose of this study was to obtain a topographical and topological description of traffic junctions in order to be able to identify the causes leading to accidents. The topographical and topological description was based on a model developed by IAGB. The core of the data model is a reference frame consisting of four layers build on each other: traffic junction, roadway, traffic lane and manoeuvre. By using the reference frame a systematic description of all relevant elements and their relationships can be made. The data model has been extended, so that roundabouts can be described, too.

Based on the data model the data of eleven selected traffic junctions out of the rural districts of Böblingen and Esslingen have been acquired. Mainly official data sources as the DSK5 and traffic lights plans have been used as data base. The official data sources have been completed and verified by an on-site acquisition. Regarding the event of accident the accident database of the IAGB has been taken as data source. Altogether 154 accidents have been taken into account for the analysis.

The collected data could be analysed and visualised in the geographical information system (figures 12 - 14). With regard to the topographical and topological description the identification of accident characteristics proved to be difficult. Anyhow the analysis showed that most of the accidents occurred due to line-of-sight obstructions. Another important accident cause is the exceeding of the speed limit. This applies particularly to urban roads where the construction entices the driver to exceed the speed limit.

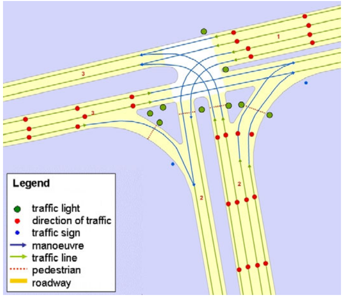

Fig. 12: Overview Map

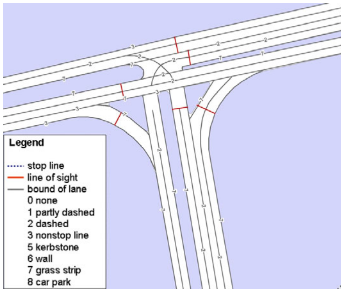

Fig. 13: Lane boundary

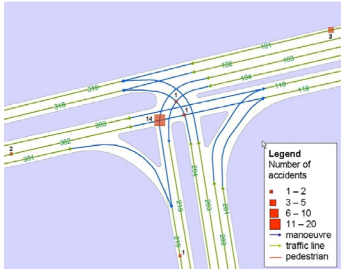

Fig. 14: Distribution of accidents

Investigation of accident risks at traffic junctions

Previous analysis of accident hotspots at the IAGB showed the relationship between the number of conflict issues within a manoeuvre and the accident frequency. A conflict item is the intercept point between two manoeuvres. A generic model has been developed to analyse the traffic junctions according to the initial suspicion. By means of the model, typical traffic junctions (fig. 15) could be classified and manoeuvres (fig. 16) as well as conflict points (fig. 17) could be described. This has been done for 53 traffic junctions with a total of 384 accidents and accident costs of nearly 1.7 million Euro.

By means of the study the one could demonstrate that the accident frequency actually increases with the number of conflict points within a manoeuvre. Furthermore, it became evident that the traffic junction type „crossing“ is much more critical than the traffic junction types „threading“ or „unthreading“. In addition, it could be shown that the accident frequency is nearly the same at traffic light controlled and traffic sign controlled traffic junctions. However, the accident costs are more than twice as much at traffic light controlled traffic junctions than at traffic sign controlled traffic junctions.

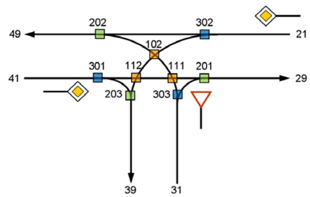

Fig. 15: Example for an arrangement of traffic junctions

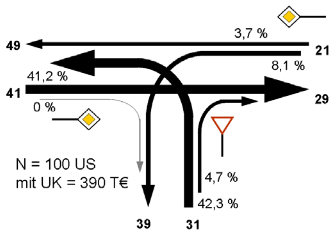

Fig. 16: Distribution of accident costs in total per manoeuvre

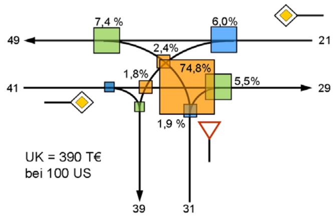

Fig. 17: Distribution of accident costs in total per conflict issue

Activities of Prof. Dr.-Ing.Dr.sc.techn.h.c.Dr.h.c. Klaus W. Linkwitz in 2008

Formfinding of Lightweight Surface Structures

The two-hour-lecture „Analytic Formfinding of Lightweight Surface Structures“ was incorporated into the 4-Semester Master Course “Computational Mechanics of Materials and Structures (COMMAS)“ for foreign students. It was given as a 32-hour compact course in the summer semester 2008. The additional appertaining practical computer exercises were performed on windows-XP-computers of the CIP-pool of the course „Water Resource Engineering and Management (WAREM) of the department “Civil- and Environment Engineering“ in the University Campus Pfaffenwald. The exercises were intensified, as a final, formally rated, project-work was demanded from the students.

Further lectures of K. Linkwitz

As part of the obligatory course „Engineering Geometry and Design“ given to civil engineers in their first semester by the Institute of Construction and Design II, two lectures on the subject „Typical examples of computer-aided geometric design“ were held.

Publications

Beetz, A., Schwieger, V. Integration of Controllers and Filter Algorithms for Construction Machine Guidance. 1st International Conference on Machine Control and Guidance, Zürich, Schweiz, 24.-26.06.2008.

Gläser, A., Möhlenbrink, W., Schwieger, V. A Contribution to Construction Machine Automation. Journal of Applied Geodesy, Walter de Gruyter, Berlin - New York, Volume 2, Heft 2, 2008.

Laufer, R. Usage of a quality management concept for data exemplified with stationary traffic data acquisition systems. Proceedings on 4th International Symposium Networks for Mobility, Stuttgart, 25. - 26.09.2008.

Linkwitz, K. Entwurf, Formfindung und Vorfertigung von Holzdächern mit Holzleimbindern. Vortrag auf Einladung des Department of Geoinformatics and Geodesy der Universität Donezk an der Nationale Technische Universität Donezk.

Ramm, K., Schwieger, V. Mobile Positioning for Traffic State Acquisition. Journal of Location Based Services. Taylor & Francis, London, UK, 2008.

Schwieger, V. Generierung von Verkehrsdaten auf Basis verfügbarer Mobilfunkdaten innerhalb der GSM-Netzinfrastruktur. Beiträge zur Fachkonferenz „Verkehrsmanagement und Verkehrstechnologien“ des BMWi, Halle, 20.- 21. Mai 2008.

Schwieger, V., Hemmert, J. Integration of a Multiple Antenna GNSS System and Supplementary Sensors. 1st International Conference on Machine Control and Guidance, Zürich, Schweiz, 24.-26.06.2008.

Schwieger, V. High-Sensitivity GPS - an availability, reliability and accuracy test. Proceedings on FIG Working Week, Stockholm, Schweden, 14.-19.06.2008.

Wiltschko, T., Schwieger, V Floating Phone Data - Ein Ansatz zur Generierung von Verkehrsdaten aus Mobilfunkdaten. Berichte zur HEUREKA 08, Stuttgart, 5.-6. März 2008.

Diploma Thesis

Baumstark, Eduard: Qualitätsbeurteilung von Mobilfunkdaten auf Abis-Ebene zur Positionsbestimmung

Buhai, Adrian: Präzise statische Positionsbestimmung mit High-Sensitivity GPS-Empfängern

Mao, Junyu: Analyse und Vergleich von Vermessungsreflektoren

Master Thesis

Kebede, Tadesse Tafesse: Development and Implementation of Filter Algorithms and Controllers for a Construction Machine Simulator

Schützle, Rainer: Estimation of the vehicle EgoMotion

Study works

Ju, Hui: Bestimmung von Positionsschwerpunkten auf Basis von Positionsfolgen aus Mobilfunkortung

Karrer, Katrin: Untersuchung der Qualität von stationären Erfassungssystemen am Beispiel der Autobahn A81

Lu, Bei: Migration eines Geodatenbestandes in die Software Geomatics Suite der Fa. SierraSoft

Tu, Tao: Vergleichende Genauigkeitsuntersuchungen zur Deformationsbestimmung eines Hochspannungsmastes

Education

Surveying I, II for Civil Engineers (Czommer, Laufer)	3/1/2/0
Acquisition and Management of Planning Data (Metzner, Wengert)	2/1/1/0
Geodetic Measurement Techniques I, II (Metzner, Wengert)	4/2/0/0
Statistics and Error Theory I, II (Schwieger, Laufer, Wengert)	2/2/0/0
Basic Geodetic Field Work (Beetz, Wengert)	5 days
Integrated Field Work (Schwieger, Laufer)	10 days
Surveying (Czommer, Schweitzer)	2/1/0/0
Surveying Engineering I, IV (Czommer)	4/2/0/0

Surveying Engineering II, III (Schwieger, Beetz)	4/2/0/0
Multisensor Systems for Terrestrial Data Acquisition (Schwieger, Schweitzer)	1/1/0/0
Causes and Impacts of Deformations in Structures (Metzner)	2/0/0/0
Geodetic Seminar I, II (Fritsch, Keller, Kleusberg, Schwieger, Sneeuw)	0/0/0/4
Thematic Cartography (in German) (Czommer, Schützle)	1/1/0/0
Thematic Cartography (Metzner, Schützle)	1/1/0/0
Transport Telematics (Metzner, Czommer)	2/1/0/0
Transport Telematics (in German) (Czommer, Schweitzer)	2/1/0/0
Reorganisation of Rural Regions (Mayer)	1/0/0/0
Terrestrial Multisensor Data Acquisition (Schwieger, Schützle)	2/1/0/0
Kinematic Measurements and Positioning (Schwieger, Beetz)	2/1/0/0

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ARDALAN A, Prof. Dr., Tehran/Iran (1.1.-29.2./4.8.-29.9.)
BORKOWSKI A, Prof., Wroclaw/Poland (21.10.-24.10.)
GHITAU D, Prof., Bucharest/Rumania (16.7.-4.9.)
HASHEMI-FARAHANI H, Tehran/Iran (1.1.-10.3.)
JIANG W, Prof. Dr., Wuhan/China (9.7.-25.9.)
KARIMI R, Tehran/Iran (1.1.-23.3.)
KUHN M, Dr., Perth/Australia (5.1.-15.1.)
LI J, Prof. Dr., Wuhan/China (4.8.-28.8.)
LIN Y, Dr., Tongji/China (1.1.-28.4.)
MIRA S, Prof. Dr., Bandung/Indonesia (16.12.-31.12.)
PEDZICH P, Dr., Warsaw/Poland (13.2.-23.2.)
SHARIFI M, Prof. Dr., Tehran/Iran (5.8.-14.10.)
TSOULIS D, Ass. Prof. Dr., Thessaloniki/Greece (3.3.-12.8.)
VARGA P, Prof. Dr., Budapest/Hungary (30.9.-30.10.)
WANG Z, Dr., Wuhan/China (30.6.-25.9.)
WU J, Prof. Dr., Tongji/China (3.3.-31.12.)
ZHANG X, Prof. Dr., Wuhan/China (30.6.-25.9.)
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SCHÖNHERR H, Präsident Dipl.-Ing., Landesamt für Geoinformation und Landentwicklung Baden-Württemberg, Stuttgart

Honorary Professors

HINTZSCHE M, Prof. Dipl.-Ing., Fellbach (†6.8.)

Research

Ice mass balance over Greenland

Research on the mass balance of the Arctic and Antarctic ice shields is of prime importance in order to understand past, present and future impacts of global warming on the complex system Earth. As secular deglaciation manifests as water influx into the oceans, i.e. sea level rise, ice ablation rates are more than only of scientific concern. In fact, they are accompanied by extensive political and socio-economical discussions.

So far there exists a variety of methods to determine mass variations in the cryosphere. Besides altimetry and interferometric synthetic aperture radar (InSAR) measurements, gravimetric studies gained interest in the last few years. Due to the launch of the twin-satellite mission GRACE (Gravity Recovery And Climate Experiment) in 2002. Since more than six years the spacecraft have been providing science data. The mission observations are typically analyzed in monthly intervals, leading to so-called monthly solutions of the Earth's gravitational field. Gravity field residuals, taken with respect to long-term averages, allow secular spatio-temporal mass changes to be monitored. Prominent negative signals occur over Greenland, Alaska and Antarctica. The greatest secular trend can be observed over Greenland, showing this area to be one of the most affected by global climate change.

A major challenge to deriving reliable mass change rates from GRACE is the correction for leakage effects. Basically, spectral leakage occurs when high-frequency signals or errors are mapped into lower frequencies, thus introducing artificial low-frequency signals that are not present in reality. In the spatial domain leakage manifests as signals spreading spatially, thus not being concentrated directly over the area of mass variation, but also leaking to the surrounding region, theoretically over the whole globe, cf. Figure 1.

As highlighted in Figure 1, leakage affects the determination of mass change rates over Greenland in two different ways. On the one hand, mass change over Greenland converts into a signal spreading out over the land mass area. From the Greenland point of view the signal leaks out, hence we refer to it as leakage-out signal. It has to be restored back into the region of interest. On the other hand, mass change at a location outside Greenland, e.g., over the Canadian Shield, also propagates into a signal spreading over the whole globe, and hence has an impact on the mass change estimation process over Greenland. From the Greenland point of view, the signal leaks in, thus we refer to it as leakage-in signal. It has to be reduced from the region of interest. The reliability of mass change estimates depends mainly on the ability to identify, quantify and remove these leakage effects.

We developed and applied a robust four-step procedure to derive ice mass rates over Greenland, which accounts for both leakage-out and leakage-in effects. It is characterized by the combination of extended spatial filters, followed by „calibration“ in terms of comparison with forward gravitational modeling results. In order to quantify the overall mass variation budget over Greenland, we consider the major gravitational signals in the Artic region as seen by GRACE. They are located over Greenland, Alaska, the Canadian Shield and Fennoscandia, cf. Figure 2. The latter two have to be attributed to the continuing response of the Earth's crust and upper mantle due to past-glacial loads, referred to as glacial isostatic adjustment (GIA). Together with the signal over Alaska, they constitute the strongest leakage-in signals into the Greenland area.

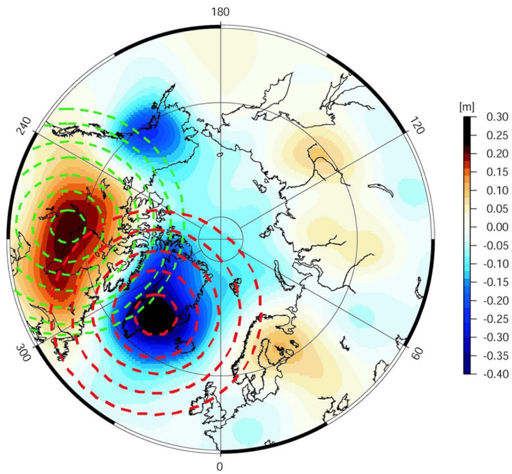

Figure 1: Nature of leakage-out (dashed red lines) and leakage-in (dashed green lines) signals from the Greenland point of view.

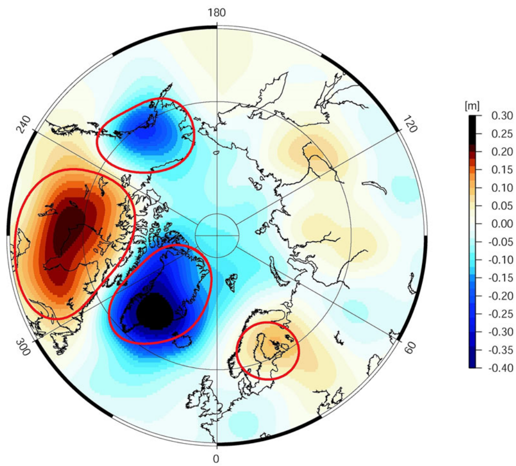

Figure 2: GRACE-derived equivalent water thickness variations from August 2002 to July 2008 over the Arctic region. Red lines enclose the areas of main mass-variation.

Table 1 summarizes our findings for the ice volume balance over Greenland when analyzing monthly gravity fields from August 2002 to July 2008. We investigated release four (RL04) GRACE-only gravity field estimates provided by (i) the Centre for Space Research (CSR), University of Texas at Austin (ii) the GeoForschungsZentrum (GFZ) Potsdam, and (iii) the Jet Propulsion Laboratory (JPL), hence three independently operating data processing centres.

Table 1: GRACE-derived ice volume variations from August 2002 to July 2008, dependent on the GRACE data processing centre.

Monthly gravity fields taken from	Annual ice volume loss [km^3/yr]
CSR	-242 $\pm$ 14
GFZ	-194$\pm$ 24
JPL	-96 $\pm$ 23
average	-177 $\pm$ 12

Analysis of the gravity field solutions provided by CSR, GFZ and JPL exhibit a significant spread. As long as the discrepancies among the various GRACE solutions can be explained, we recommend averaging the individual results, finally yielding the ice volume decline to become -177$\pm$$km^3$/yr. Despite the rather large spread of the results among GRACE processing centres, our results are in general agreement with the findings of alternative GRACE analysis methods. Nevertheless the values reveal that, so far, there is no clear consensus about the magnitude of present ice mass decline over Greenland.

Improving time-variable GRACE gravity field by data assimilation

The satellite gravity field mission, GRACE, has been providing a wealth of time-variable gravity field information since its launch in 2002 with which surface mass changes can be inferred. The most prominent of the discernible surface mass changes come from continental hydrology and the ocean. However, due to the observation geometry and modelling inadequacies, the mass changes derived from GRACE cannot be used without filtering as one can only see „stripe-like“ features (cf. Figure 4). Filtering removes signal in addition to noise, which is an undesired artefact of filtering. In order to overcome this problem, efforts are made to assimilate reliable external data sources to improve the accuracy and reliability of time-variable gravity from GRACE. Such external data sources act as constraints on the GRACE dataset and provide control to the mass change estimation problem. In the current research, of the many external data sources that can be used for improving the GRACE dataset, reliable observed hydrological information and a priori stochastic information about the time-variable gravity field are used.

The external data sources are assimilated into the GRACE data via a sequential least squares estimator, which has the advantage that the complicated processing of GRACE data need not be repeated again. However, the method has a few challenges that have to be dealt with: sparsity

(20% of the continental cover which are the black patches in Figure 4) of the available observed hydrological information, a priori signal covariance of the time-variable gravity field, and the signal and noise covariances of observed hydrological information. Initial estimates of the assimilated gravity field have been computed by ignoring the sparsity of hydrological information, and deriving empirical signal covariances from the data for both the time-variable gravity field and the hydrological information. The results (Figure 3-5) show great promise for the method to retrieve the information contained in GRACE, and provides a way for quantifying the relative contribution of the assimilated data sources. However, more work needs to be done in the direction of signal and noise covariances of observed hydrology information and parameterization of the sequential estimation problem.

This work is being carried out as part of the Direct Water Balance project within the Special Priority Programme (SPP)1257 - „Mass transport and mass distribution in the system Earth".

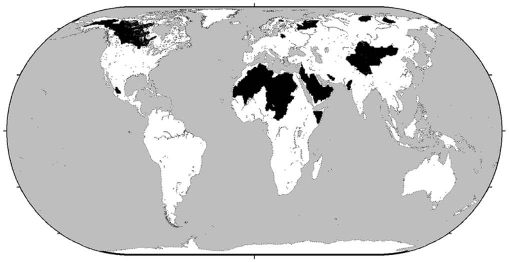

Figure 3: Catchments with reliable observed hydrology data for January 2003

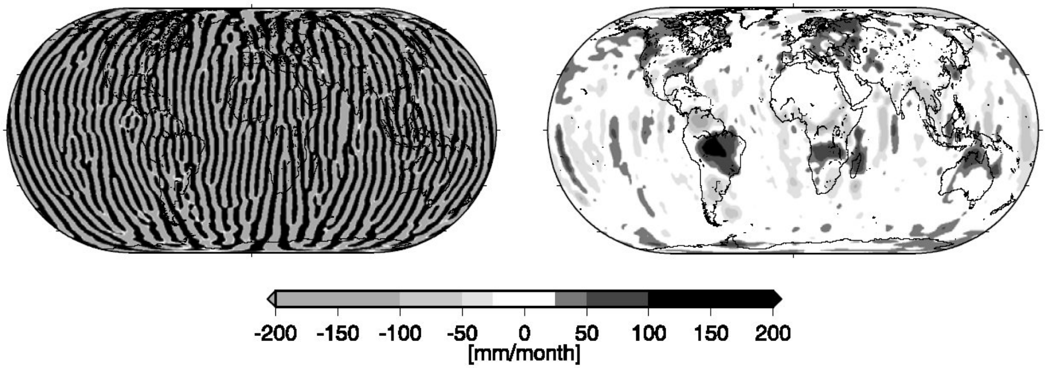

Figure 4: Mass estimates from GRACE time-variable gravity estimates

Figure 5: Mass estimates after combining hydrology and a priori knowledge about time-variable gravity field with GRACE

Space-time sampling - multi-satellite concepts for the detection of time variable gravity fields

In a joint ESA project „Mass Transport Study“ of several international research institutes (from Geodesy, Geophysics, ice sciences, Oceanography, ...) concepts for future multi-satellite missions for the detection of time variable gravity fields are investigated. Two of the main objectives are the reduction of the aliasing-problem and the separation of the mass-transport sources. At the Institute of Geodesy, multi-satellite and multi-orbit concepts for the improvement of the space-time-sampling have been studied. We focus on β/α-repeat orbits (β revolutions in α nodal days) to reduce the problem of time-variable ground tracks. The space-time sampling of a satellite-mission is mainly driven y two sampling theorems (Figure 6): (i) the „Nyquist-theorem“ $\beta \geq 2$L (or 2M), which determines the spatial resolution (maximum degree/order L/M) and (ii) the „Heisenberg-theorem“ $D_{space} \times D_{time} = 2\pi\alpha/\beta = 2\pi T_{rev}$ = const., which means that the product of spatial resolution D_{space} and the time-resolution D_{time} is constant. If the spatial resolution of a satellite mission should be improved (Figure 6), additional satellites have to be placed on interleaved ground tracks ($\Delta\lambda$-shift), the time-resolution can be improved by further satellites orbiting on the same ground track with a time shift (Δt-shift). By means of mixed cases, both the spatial and time-resolution can be improved. Another option which was considered is a $\Delta\Omega$-shift, which can mean simultaneously a Δt-shift if the satellite is on the same ground track and a $\Delta\lambda$-shift if the satellite is on an interleaved ground track. Figure 7 shows various 31/2-repeat-orbits in the different modes (Δt-shift, $\Delta\lambda$-shift, $\Delta\Omega$-shift (on same/interleaved ground track)): orbit 1 (origin), orbit 2 (Δt-shift), orbit 3 (interleaved, $\Delta\lambda$-shift), orbit 4 (interleaved, $\Delta\lambda$- and Δt-shift), orbit 5 ($\Delta\Omega$-shift), orbit 6 ($\Delta\Omega$- and Δt-shift), orbit 7 (interleaved, $\Delta\Omega$-shift), orbit 8 (interleaved, $\Delta\Omega$- and Δt-shift).

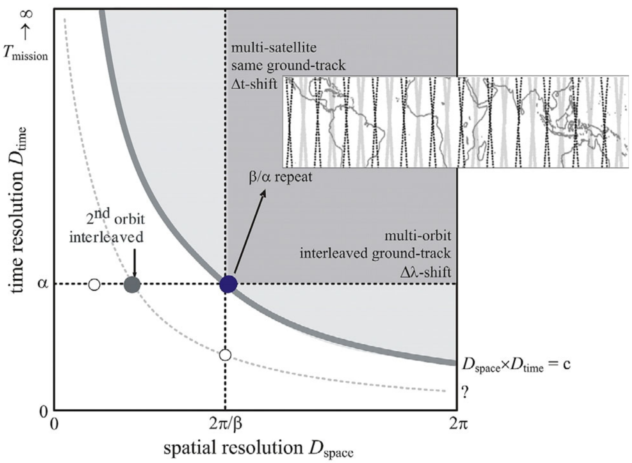

Figure 6: Multi satellite and multi-orbit concepts: relation between spatial and time resolution

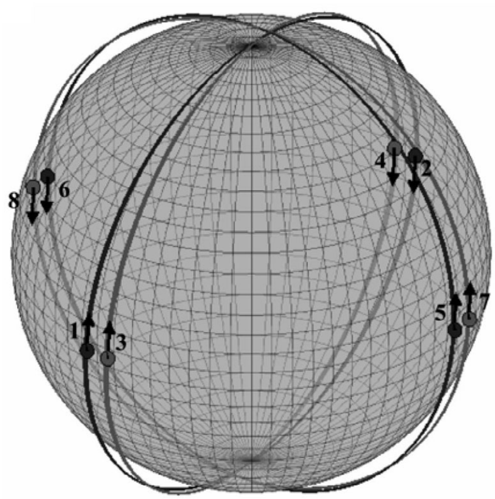

Figure 7: Different 31/2-repeat-orbits on same (black) and interleaved (grey) ground tracks

Monitoring and modelling individual sources of mass distribution and transport in the Earth system by means of satellites

With the successful GRACE mission (data collection since Spring 2002), global time-variable gravity fields can be recovered beyond the lower degrees for the first time. Although GRACE is able to detect significant features of the time-variable geopotential, e.g. the continental hydrological cycle, trends in ice-mass change in Antarctica or Greenland or sea level rise, its mission concept suffers from inherent deficiencies. The main limitations of GRACE are (i) the range-rate measurements (insufficient accuracy, anisotropy of the leader-follower-formation), (ii) aliasing due to spatial and temporal undersampling and (iii) de-aliasing products with limited accuracy. This leads to an erroneous North-South striping pattern and a limited accuracy and resolution for many scientific studies. Within the ESA project „Monitoring and Modeling Individual Sources of Mass Distribution and Transport in the Earth System by Means of Satellites" (ESA Contract 20403) potential future satellite mission concepts, which could improve time-variable geopotential recovery, have been studied.

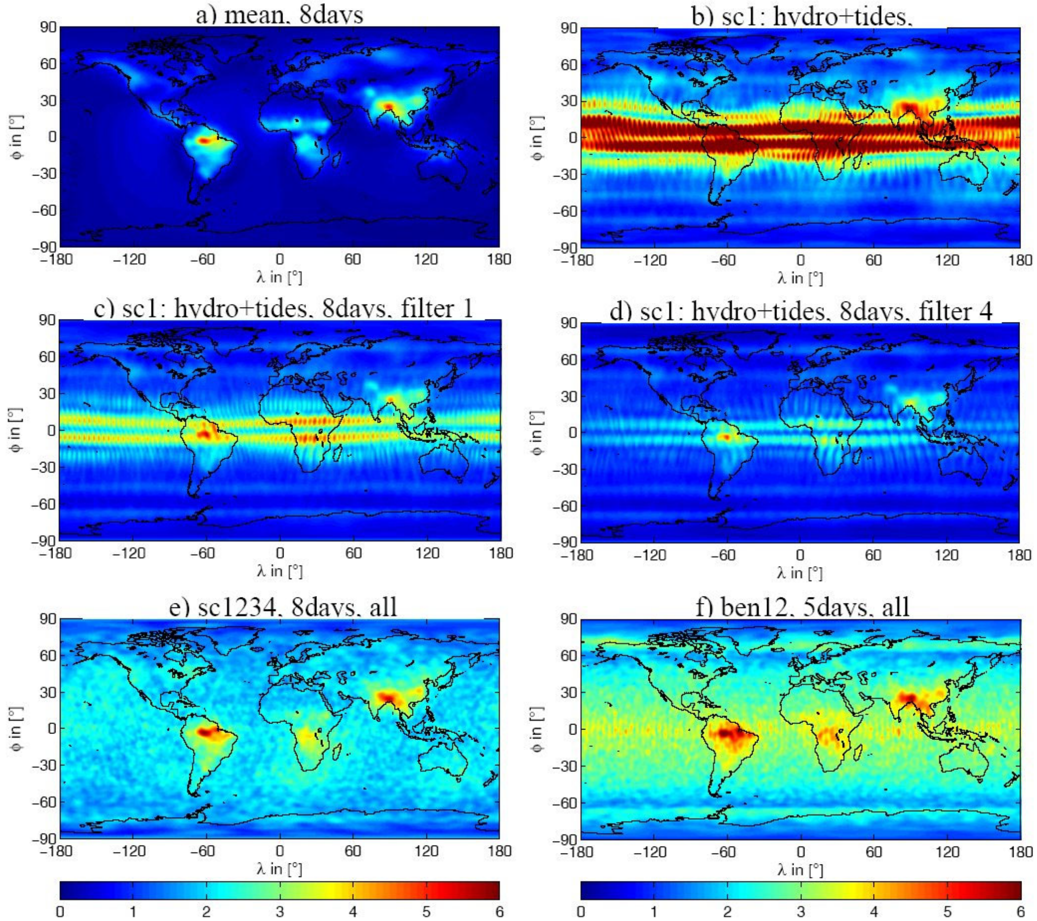

Figure 8: RMS (mm) of the geoid height for the source model (8-days mean hydrology) and different retrievals (unfiltered and filtered) for year 1996, L_{max} = 50

An improved accuracy of a future laser instrument as well as an enhanced temporal sampling have been regarded in the simulations, which were based on repeat orbits. An enhanced sampling can be achieved by means of multi-satellite missions, where the spatial and/or temporal resolutions are improved by: 1) additional satellites on interleaved ground tracks ($\Delta\lambda$-shifts) and/or 2) time shifted satellites on the same ground track (Δt-shifts). Another possibility is the so-called Pete-Bender-design, where the satellites fly on different repeat-orbits with different inclinations, which also allows for more homogeneous ground track coverage. Sophisticated satellite-formations such as cartwheels or gravity wheels have not been regarded so far due to the unsolved technical problems (e.g. control of the laser instrument) related to these designs. The primary objective of the simulation studies was the precise recovery of the input hydrological signal and the trends of the ice-melting in Antarctica and Greenland. Furthermore, the detection of the Sumatra Earthquake and the separability of hydrology, the ocean signal and ocean tides have been investigated.

Figure 8 shows some results (up to maximum degree L_{max} = 50) from the simulations investigated in the project in terms of the variability of the original (Figure 8a) and recovered (Figures 8b-f) hydrological signal (determined as RMS-values on a 1° x 1°-grid). The mission scenarios sc1 and sc1234 are based on GRACE-like satellite tandems flying on (125/8)-repeat orbits and retrieval intervals of 8 days, where sc1 is a single tandem and sc1234 consists of 4 ?t-shifted tandems. The scenario ben12 consists of 2 tandems arranged in the Pete-Bender-design (ben1-tandem: 360/23-repeat orbit, inclination I = 117.4°; ben2-tandem: 79/5-repeat orbit, I = 90°) with retrieval intervals of 5 days. While for scenarios sc1234 (Figure 8e) and ben12 (Figure 8f) all errors were taken into account, for sc1 (Figures 8b,c,d) only the errors induced by ocean tides were regarded. As it can be seen in Figure 8b the single tandem sc1 leads to large errors around the equator. By filtering out the signal on the theoretically determined tidal aliasing frequencies (Figures 8c,d), the hydrological structures become visible again. The multi-tandem missions sc1234 and ben12 are able to recover the hydrological structures without filtering, since they are able to reduce spatio-temporal aliasing. Further investigations show that the Pete-Bender design offers advantages concerning the homogeneity of the recovered signal.

Non-linear techniques for regional gravity field modelling using SST data

(1) Description of the problem

The GRACE satellite mission was launched to study the time-variability of the Earth's gravitational field. Usually, the gravity-field models derived from GRACE observations are represented in terms of spherical harmonics. If this spherical harmonics model is used to compute synthetic GRACE observations, their difference to the actual GRACE observations are not pure white noise but still contains a residual signal. This residual signal shows a correlation to geographic features of the Earth (cf. Figure 9).

The reason for this effect is that spherical harmonics, due to their global support, smooth out regional details of the gravity field. Hence, a regional improvement of the global spherical harmonics of the GRACE solution is possible by an analysis of the residual signal with respect to localizing base functions. Accompanying to this measure, also the residual observations have to be converted to so-called in-situ observations. In contrast to the original GRACE observations, which are integral means of the gravitational field along the orbital arc, in-situ observations solely depend upon the gravitational field at the location of the observation. Consequently, the analysis of the residual signal requires four steps:

- ▷ Conversion of the GRACE K-band observations into in-situ observations using the line-of-sight gradiometry technique.
- ▷ Representation of the line-of-sight gradients as linear functionals of localizing base functions.
- ▷ Computation of the partial derivatives of the functionals with respect to those parameters, which describe the location, size and shape of the localizing base functions.
- ▷ Estimation of these position-, size- and shape-parameters as the solution of a non-linear least-squares problem.

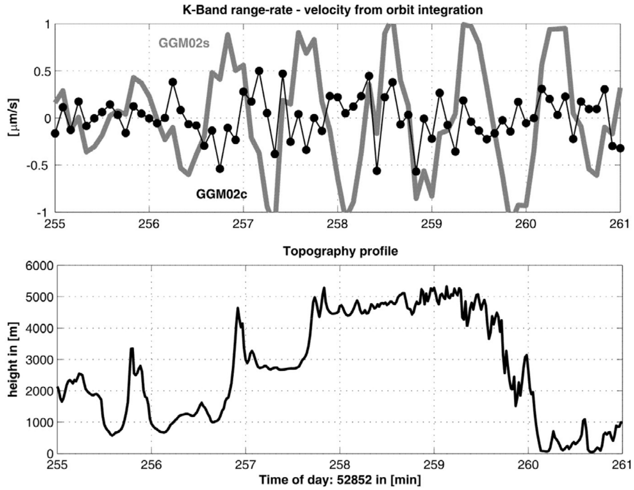

Figure 9: The residual range rate - based on the satellite only field GGM02s - shows higher amplitudes during the flyover of major masses like the Himalayan. This effect is mainly reduced by using the combined model GGM02c

(2) Line-of-sight gradiometry

If the K-band range rates are differentiated with respect to time, the result is the second order derivative of the gravitational potential of the Earth in the direction of the satellite motion, taken at the barycentre of the satellite-pair, plus some correction terms. These correction terms can be derived from a precise orbit computation. The following picture compares the original K-band observations with the line-of-sight gradient (LOS) along the same orbital arc. Obviously, the line-of-sight gradients are more sensitive to local information in the gravitational field. The LOS-gradient might contain also a lot of noise addicted to the priori model for the synthetic observations or unsolved error sources, which is overcome with a smoothing binomial filter in Figure 10.

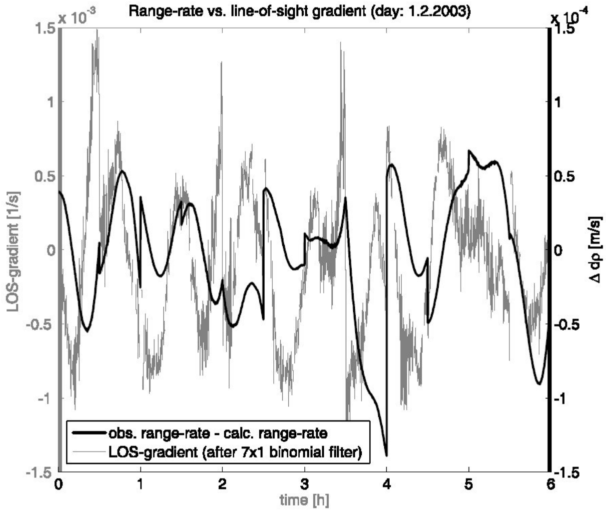

Figure 10: Smoothed line of sight gradient and the residual range rate during a six hour orbit in February 2003

(3) Representation of line-of-sight gradients as functionals of localizing base functions

The radial base functions, used here as localizing system are characterized by the properties:

- ▹ They are harmonic functions.
- ▹ They have exactly one global maximum.
- ▹ From their maximum they decay radially symmetric.

Hence, the parameters, defining the position, size and shape of a base function are:

- ▹ The location of the maximum.
- ▹ The maximal value.
- ▹ Some shape parameters controlling the speed of decay.

In our study an exponential model $\sigma_b(n) = \sigma_b^n$ is chosen to represent the decay by a single value. The parameter has an upper limit at $\sigma_b(n) = 1$, where the function becomes very localizing and the base function grows wider for smaller values (cf. Figure 11). These parameters enter non-linearly the representation of the observations as functionals of the base functions. For this reason they cannot be estimated by traditional linear adjustment techniques but by methods of non-linear optimization.

(4) Partial derivatives of the functionals with respect to the base-function parameters

Because radial base functions can be represented as a series of Legendre polynomial, their derivatives with respect to the characterizing parameters can be given in a closed form. This does not mean, that these derivations are trivial. In contrast, a very sophisticated treatment is necessary to arrive at manageable final formulae.

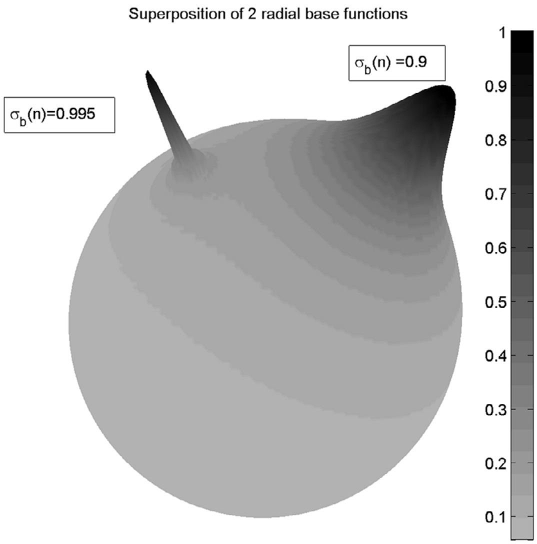

Figure 11: Superposition of two radial base functions with different shape parameters

(5) Non-linear optimisation

Since the observations depend non-linearly upon the characterizing parameters of the base-functions, they can only be estimated by the solution of a non-linear least-squares problem. The obvious idea, to apply traditional least squares adjustment iteratively fails, because it leads to too large corrections. For this reason the so called Levenberg-Marquardt algorithm was applied, which regularizes the normal equation matrix in each step (cf. Figure 12). The sequence of the regularization parameters tends to zero and provides a over-linear convergence to the local minimum.

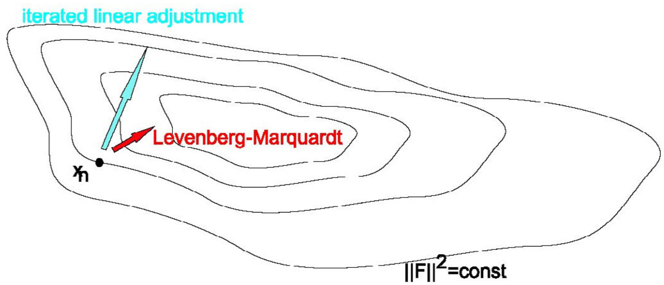

Figure 12: Solution of a two dimensional minimum problem by Levenberg-Marquard and least squares adjustment

(6) Results

Meanwhile the line of sight gradiometry approach has been implemented and shows promising results. The correlation of topography and residual range rate in the Himalaya region could be decreased to 40 percent in most arcs of the year 2003. As the error sources are not expected to be correlated with the topography, this gives a hint that some gravitational signal was found by the localizing base functions.

Further studies are necessary for other test regions or time series, as well as for other observation types like the K-band itself.

GOCE Gravity Field Recovery

Rescheduled to be launched in spring 2009, the ESA satellite mission GOCE (Gravity field and steady-state Ocean Circulation Explorer) will be the first gradiometer experiment in satellite geodesy history. To meet the scientific objectives, national programs have been designed to support the activities of the European GOCE Gravity Consortium (EGG-C). The German part is called GOCE-GRAND (GOCE GRavitationsfeldANalyse Deutschland). It is funded by the Federal Ministry of Education and Research (BMBF) and the German research foundation (Deutsche Forschungsgemeinschaft) within the GEOTECHNOLOGIEN II program „Observation of the System Earth from Space".

Due to the sun-synchronous orbit of the GOCE satellite, the data does not cover a double polar cap with a radius of more than six degrees. Numerous ways exist to approach this problem. We have successfully solved this kind of problem with the Slepian approach, characterized by a set of base functions that are defined within the area of GOCE data coverage. Numerical tests show the applicability of the Slepian approach with regard to solvability and stability in the case of polar data gaps. Furthermore, in the frame of GOCE GRAND II Work Package 150 „The Polar Gap Problem: Solution Strategies and Influence on the GOCE/GRACE Combination Solution", we have developed two other solutions with (1) incorporating additional measurements over the polar regions and (2) introduced α-Weighted BLE (Best Linear Estimation), a uniform Tykhonov-Phillips regularization together with a method to compute the optimal regularization parameter (or weight factor) α by A-optimal design.

In terms of spatial stabilization, the external observations or additional information, being supplied in order to overcome the polar gaps, may be provided in three ways: (1) augmenting data in the polar regions, such as terrestrial or airborne gravity data; (2) the high quality GRACE gravity field models and (3) the Earth Gravity Model 2008 (EGM2008) developed by the American National Geospatial-Intelligence Agency (NGA), which is a model up to degree and order 2160 combined with CHAMP / GRACE and terrestrial data. For these combinations we investigated two possible approaches, such as mixed estimator (Rao, Toutenburg, 1999) with additional information as stochastic linear restrictions, and the light constraint solutions (Reigber, 1989). Our study shows that

- ▷ for the Polar Gap Problems in GOCE data processing, the stabilization solutions with additional observations and related stochastic information as linear stochastic restrictions are efficient, but the priority and mathematical strictness of these two approaches should be carefully considered;
- ▷ the estimator of the mixed model is unbiased, and has a smaller generalized mean squared error than original LS estimator, if the variance-covariance matrix is known, see Figure 13 and 14;
- ▷ the estimator of the light constraint model is not complete, since the introducing of a priori information as zero observation is not proper, which is obviously proven by the difference between both estimators of the mixed models and light constraint models derived in this study, see Figure 15.

Both of the approaches and their difference are tested with the simulated GOCE SGG data corrupted by white random noise and EGM2008 spherical harmonic coefficients, and tested with the null hypothesis to check the compatibility of additional and sample information. These results will not only substantially improve the theoretical background of GOCE combination solutions with external observations or additional information, but also be significant to the forthcoming GOCE real data processing of the Project REAL-GOCE.

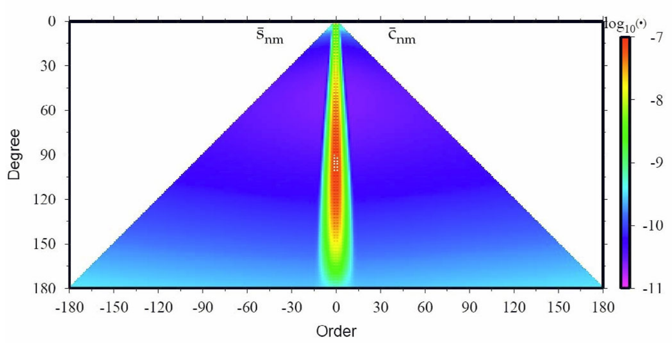

Figure 13: Errors of the harmonic coefficients in the GOCE-only solution

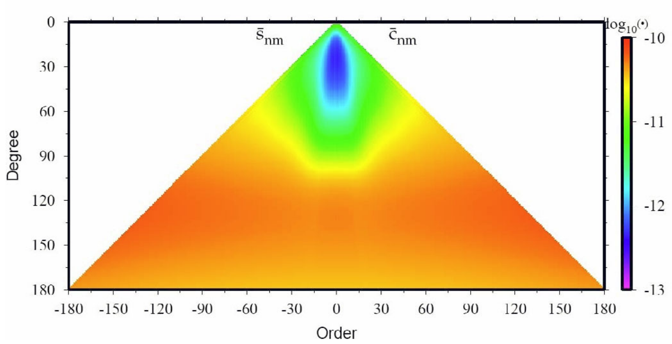

Figure 14: Errors of the harmonic coefficients in the GOCE mixed model solutions together with the additional observations and their stochastic information

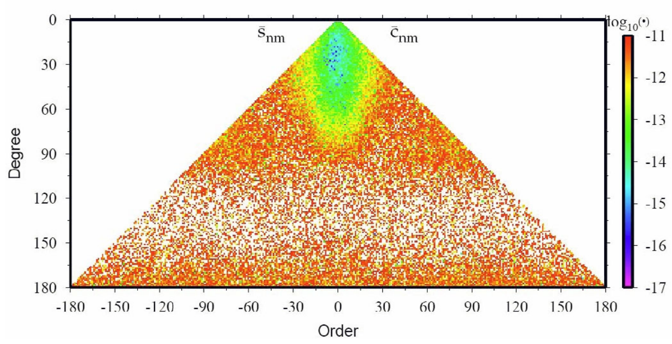

Figure 15: Difference between estimated harmonic coefficients using the mixed model and using the light constraint model

Statistical estimation and hypothesis testing for the GPS mixed integer linear models

(1) Bootstrap method and its application to the hypothesis testing in GPS mixed integer linear model

High-accuracy GPS relative positioning is usually based on double-differenced (DD) carrier phase observables. When considering short baseline (less than 20 km), the linear model for DD phase may be simplified to a mixed integer linear model, where the central problem of the determination of the integer phase ambiguities must be first solved. This topic has therefore been a rich source of GPS geodesy research over the last decades and more than 300 papers related to the method and application are published. Until now most of the existing validation and hypothesis tests (e.g. χ^2-test, F-test, t-test, and ratio test etc.) about the float solution and the fixed solution within Least Squares Ambiguity Search (LSAS) or „Integer Least Squares“ approaches are performed under the assumption that the measured phases or phase differences are approximately Gauss-Laplace normally distributed. But based on our new research results (Cai et al., 2007), the GPS carrier phase observables that are actually measured on the unit circle have been statistically validated to have a von Mises normal distribution. The existing validation and hypothesis testing procedures should therefore be improved accordingly.

Since the distributions of the statistics commonly used for inference on directional distributions are more complex than those arising in standard normal theory, bootstrap methods are particularly useful in the directional context. As one of the modern statistical techniques since 1980s the bootstrap method refers to a class of computer-intensive statistical procedures, which can often be helpful for carrying out a statistical test of a point estimate in situations where more usual statistical procedures are not valid and/or not available (e.g. the sampling distribution of a statistic is not known). In the linear model context, these bootstrap methods provide inference procedures (e.g. confidence sets) that are asymptotically more accurate than those produced by the other methods. This is just the case for the validation and hypothesis tests of the float and fixed estimates of GPS mixed models in the directional context, with the emphasis on the determination of the confidence intervals of the estimates. In this project we are studying the technological and methodological aspects of the bootstrap methods, and developing new efficient bootstrap algorithms based on two bootstrap analysis methods for linear model, bootstrapping residuals and bootstrapping pairs, to the confidence domains/hypothesis tests on the parameters of the GPS mixed integer linear models.

(2) Total optimal search criterion in solving the GNSS mixed integer linear model

Existing algorithms for GPS ambiguity determination can be classified into three categories, i.e. ambiguity resolution in the measurement domain, the coordinate domain and the ambiguity domain. There are many techniques available for searching the ambiguity domain, such as FARA (Frei and Beutler 1990), LSAST (Hatch 1990), the modified Cholesky decomposition method (Euler and Landau 1992), LAMBDA (Teunissen 1993), FASF (Chen and Lachapelle 1995) and modified LLL Algorithm (Grafarend 2000; Lou and Grafarend 2003). The widely applied LAMBDA method is based on the Least Squares Ambiguity Search (LSAS) criterion and employs an effective decorrelation technique in addition. G. Xu (2002) proposed also a new general criterion together with its equivalent objective function for ambiguity searching that can be carried out in the coordinate domain, the ambiguity domain or both. Xu's objective function differs from the LSAS function, leading to different numerical results. The cause of this difference is identified in this study and corrected. After correction, the Xu's approach and the one implied in LAMBDA are identical.

For the mixed integer linear model we have proposed a total optimal search criterion for resolving the integer ambiguity in both coordinate and ambiguity domain. We have also derived algebraically and geometrically the orthogonal decomposition of the objective function and the related minimum expressions together with the extensive derivations given in the Appendix. This criterion has been verified with real GPS carrier phase observables. The theoretical and numerical results show that

- the LSAS criterion can be derived from the total optimal search criterion with the constraint on ambiguity parameters; both criteria are leading to the same objective function and ambiguity search methods, and
- the equivalent criterion from Xu is incorrect because it does not consider the correlation of the integer and coordinate parameters correctly.

This provides an explicit answer to the ongoing debate about the priority of both criteria in the sense of optimality and unbiasedness. The effects of the total optimal criterion on GPS carrier phase data processing are discussed and its practical implementation is also proposed.

3-D Viscoelastic Lithosphere and Mantle Model

One of the activities during the first phase of the DFG Priority Program SPP 1257 was the VILMA Project addressing the development of a 3-D viscoelastic lithosphere and mantle model. Its main objective is to consider lateral variations in the earth's viscosity when modelling glacial-isostatic adjustment (GIA).

The GIA process describes the adjustment of the earth's interior to the loading resulting from the last Pleistocene ice sheets, which depressed the earth's surface by up to one kilometre. Although this glacial loading essentially terminated about 8000 years before present, the readjustment of the viscous earth is continuing. Whereas the induced vertical motion has been known since long to be largely confined to the formerly glaciated regions of North America and Fennoscandia, the pattern of the horizontal motion has been disclosed only recently. This is mainly the result of the use of the GPS technique for the accurate determination of the surface motion. A major aspect of the VILMA Project is the modelling of the global pattern of the GIA-induced horizontal motion. Here, the consideration of the low-viscosity plate boundaries and the variable lithosphere thickness have been identified as an important aspects. Two major results achieved so far are as follows:

▷ For a 3-D viscosity distribution, the horizontal motion of the plates due to GIA shows the same equipartitioning of spheroidal and toroidal displacements as the horizontal motion of the plates due to mantle convection. The toroidal component is induced by coupling to the spheroidal excitation produced by surface loading. For a 1-D earth model, no toroidal displacement is generated by such loads (Figure 16).

▷ The computation of the GIA-induced horizontal motion for 1-D and 3-D earth models shows that this 'GIA correction' for plate rotations is comparable to or larger than the accuracy of plate rotations determined by geodetic methods (Figure 17).

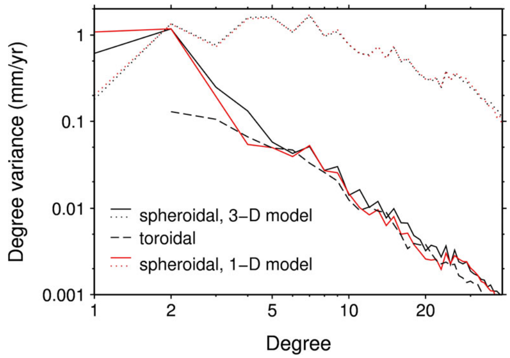

Figure 16: Degree variances of spheroidal-vertical (dotted), spheroidal-horizontal (solid) and toroidal-horizontal (dashed) displacements for 1-D (spherically symmetric) and 3-D (plate boundaries and variable lithosphere thickness) earth models.

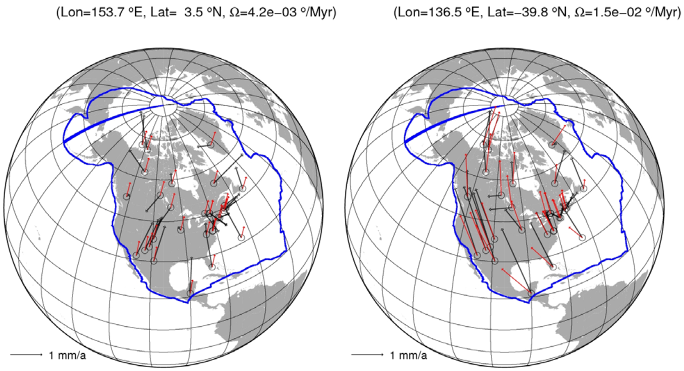

Figure 17: GIA-induced horizontal velocities (black arrows) at locations in North America considered in ITRF 2005 for 1-D (left) and 3-D (right) earth models. Red arrows indicate the horizontal velocities resulting from the corresponding rigid-plate rotation with the parameters given at the top of each panel.

Theses

Doctoral Theses

(http://www.uni-stuttgart.de/gi/research/index.en.html)

AUSTEN G: On the treatment of the geodetic boundary value problem by means of regular gravity space formulations (Zur Behandlung des geodätischen Randwertproblems mittels singularitätenfreier Schwereraumformulierungen)

HENGST R: Der Einfluss der kontinentalen Wasserspeicherung auf das Rotationsverhalten der Erde (The impact of continental water storage in terms of the Earth orientation parameters)

REUBELT T: Harmonische Schwerefeldanalyse aus GPS-vermessenen kinematischen Bahnen niedrig-fliegender Satelliten vom Typ CHAMP, GRACE und GOCE mit einem hochauflösenden Beschleunigungsansatz (Harmonic analysis of the Earth's gravitational field from kinematic orbits of a Low Earth Orbiting GPS tracked satellite of type CHAMP, GRACE and GOCE by means of an acceleration approach)

Diploma Theses

(http://www.uni-stuttgart.de/gi/education/diploma_theses.en.html)

BECK FS: Noise Minimization in Multi-Frequency GNSS Measurements (Rauschminimierung für Mehrfrequenzen GNSS Beobachtungen)

DENG Z: Preprocessing of high-rate GPS data for real-time applications (Vorprozessierung von hochfrequenten GPS-Daten für Echtzeitanwendungen)

GLÄSER PA: Implementation of an orbit-integrator and investigation of disturbing accelerations for the Mars-moon Deimos (Implementierung eines Bahnintegrators und Untersuchung von Störbeschleunigungen am Beispiel des Marsmondes Deimos)

GUO R: Variance-covariance matrix estimation with LSQR in a parallel programming environment (Varianz-Kovarianzmatrix-Schätzung mittels LSQR in einer parallelen Programmierumgebung)

LERKE O: Densification of kinematic orbits using Kalman-filtered GPS observations (Verdichtung kinematischer Orbits mittels Kalman Filterung aus GPS Beobachtungen)

RAIZNER C: A regional analysis of GNSS-levelling (Eine regionale Untersuchung des GNSS-Nivellements)

Study Theses

(http://www.uni-stuttgart.de/gi/education/study_reports.en.html)

KILIC B: Mikrogravimetrische Erfassung eines S-Bahn Tunnels (Microgravimetric survey of a railway tunnel)

RAIZNER C: GOCE Data and Gravity Field Model Filter Comparison (Vergleich zwischen along-track und isotropen Spektralfiltern im Rahmen der GOCE-Datenprozessierung)

WU X: Influence of regional gravity anomalies on GRACE K-band observations (Einfluss regionaler Schwerefeldanomalien auf GRACE K-Band Beobachtungen)

XIA J: Punktmasseschätzungen auf Grönland aus GRACE (Point mass estimation on Greenland from GRACE)

ZIMMERMANN N: Comparison of mean sea surface data for oceanography (Vergleich von Datensätzen der mittleren Meeresoberfläche für die Ozeanographie)

Publications

(http://www.uni-stuttgart.de/gi/research/index.en.html)

Refereed Journal Publications

ANTONI M, W KELLER AND M WEIGELT: Regionale Schwerefeldmodellierung durch Slepian- und radiale Basisfunktionen. Zeitschrift für Geodäsie, Geoinformation und Landmanagement 133 (2008) 120-129

AUSTEN G AND W KELLER: Singularity free formulations of the geodetic boundary value problem in gravity space. Journal of Geodesy. Online publication, 19. October 2008

BAUR O, G AUSTEN AND J KUSCHE: Efficient GOCE satellite gravity field recovery based on LSQR. Journal of Geodesy 82 (2008) 207-221, DOI:10.1007/s00190-007-0171-z

BAUR O, N SNEEUW AND EW GRAFAREND: Methodology and use of tensor invariants for satellite gravity recovery. Journal of Geodesy 82 (2008) 279-293, DOI:10.1007/s00190-007-0178-5

BAUR O: Tailored least-squares solvers implementation for high-performance gravity field research. Computers and Geosciences, Elsevier, in press, DOI:10.1016/j.cageo.2008.09.004

CAI J, J WANG, J WU, C HU, EW GRAFAREND AND J CHEN: Horizontal deformation rate analysis based on multi-epoch GPS measurements in Shanghai. Journal of Surveying Engineering 134 (2008) 132-137

IVINS ER AND D WOLF: Glacial isostatic adjustment: new developments from advanced observing systems and modelling. Journal of Geodynamics 46 (2008) 69-77, DOI:10.1016/j.jog.2008.06.002.

PALÁNCZ B, P ZALETNYIK, JL AWANGE AND EW GRAFAREND: Dixon resultant's solution of systems of geodetic polynomial equations. Journal of Geodesy 82 (2008) 505-511

VANÍCEK P, EW GRAFAREND AND M BERBER: Short Note: Strain Invariants. Journal of Geodesy 82 (2008) 263-268

XU C, M WEIGELT, MG SIDERIS AND N SNEEUW: Spaceborne gravimetry and gravity field recovery. Canadian Aeronautical Space Journal 53 (2007) 65-75

Other Refereed Contributions

BAUR O: Eismassenänderungen in den polaren Gebieten der Erde und deren Effekt auf den globalen Meeresspiegel. Kepler-Seminar für Naturwissenschaften, Universität Stuttgart (4.6.)

CAI J, EW GRAFAREND, C HU AND J WANG: The uniform Tykhonov-Phillips regularization (?-weighted S-homBLE) and its application in GPS rapid static positioning. In: Xu P, J Liu and A Dermanis (Eds., 2008): VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy, IAG Symposium 132, pp 221-229, Springer Verlag (VI Hotine-Marussi Symposium Wuhan, PR China, 29.5.-2.6.2006)

CAI J, H KOIVULA, EW GRAFAREND AND M POUTANEN: The statistical analysis of the eigenspace components of the strain rate tensor derived from FinnRef GPS measurements (1997-2004) in Fennoscandia. In: Xu P, J Liu and A Dermanis (Eds., 2008): VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy, IAG Symposium 132, pp 79-87, Springer Verlag (VI Hotine-Marussi Symposium Wuhan, PR China, 29.5.-2.6.2006)

DEVARAJU B, N SNEEUW, H KINDT AND J RIEGGER: Estimating GRACE monthly water storage change consistent with hydrology. Accepted for publication in: Proceedings of the IAG symposium on Gravity, Geoid, and Earth Observation 2008. Chania, Crete, Greece (23.-27.6.)

SNEEUW N, MA SHARIFI AND H SCHAUB: Formation Flight Stability in a Gravitational Field. Proc. 3rd International Symposium on Formation Flying, Missions and Technologies, 23.-25.4.2008, Noordwijk, The Netherlands. ESA SP-654, June 2008

SNEEUW N, MA SHARIFI AND W KELLER: Gravity Recovery from Formation Flight Missions. In: Xu P, J Liu and A Dermanis (Eds., 2008): VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy, IAG Symposium 132, pp 29-34, Springer Verlag (VI Hotine-Marussi Symposium Wuhan, PR China, 29.5.-2.6.2006)

WU J, J CAI, C HU, F XIAO AND C LIU: A quaternary prototype for spatiotemporal analysis of permanent scatter interferometry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7, pp. 157-160, Beijing, 2008

XU C, N SNEEUW AND MG SIDERIS: The Torus Approach in Spaceborne Gravimetry. In: Xu P, J Liu and A Dermanis (Eds., 2008): VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy, IAG Symposium 132, pp 23-28, Springer Verlag (VI Hotine-Marussi Symposium Wuhan, PR China, 29.5.-2.6.2006)

Non-refereed Contributions

ARDALAN AA, EW GRAFAREND, R KARIMI AND M POUTANEN: A new Geodetic Boundary Value Problem approach to high-resolution geoid computations based on relative gravity, geopotential numbers and Mean Sea Level as the boundary data. Case study: Geoid of Southwest Finland. Geophysical Research Abstracts, Vol. 10, A-11169, European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

GRAFAREND E, AA ARDALAN AND R KARIMI: Towards Mars reference equipotential surface, reference ellipsoid and ellipsoidal harmonic coefficients. Geophysical Research Abstracts, Vol. 10, A-12042, European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

GRAFAREND EW: Kinematische und dynamische Gleichungen zur Erdrotation: Messexperimente, Präzession/Nutation versus Tageslängenschwankung (LOD)/Polbewegung (PM). Sitzungsberichte der Leibniz-Sozietät 94 (2008) 67-82

VAN DAM T, P VISSER, N SNEEUW, M LOSCH, T GRUBER, J BAMBER, M BIERKENS, M KING AND M SMIT: Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the earth System by Means of Satellites, Final Report, ESA Contract 20403, November 2008.

WOLF D, WR JACOBY, O HARTMANN, V KLEMANN AND I SASGEN: Glaziale Isostasie im Südosten Islands. Festschrift zum 65. Geburtstag von Prof. Dr.-Ing. Carl-Erhard Gerstenecker, pp. 145-156. Schriftenreihe der Fachrichtung Geodäsie, Technische Universität Darmstadt, Heft 28.

Poster Presentations

AWANGE JL, MA SHARIFI, O BAUR, W KELLER, WE FEATHERSTONE AND M KUHN: GRACE hydrological monitoring of Australia: current limitations and future prospects. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

CAI J, J WU, Y LIN, J WANG AND EW GRAFAREND: Systematic analysis of the present-day crustal deformation in Shanghai based on the multi-epoch GPS measurements. International Symposium on GPS/GNSS 2008, Tokyo, Japan (11.-14.11.)

CAI J, N SNEEUW, X ZOU AND O BAUR: The study of the combination approaches in solving the polar gap problems. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

DEVARAJU B, N SNEEUW, H KINDT AND J RIEGGER: Estimating GRACE monthly water storage change consistent with hydrology. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

DEVARAJU B, N SNEEUW, H KINDT, J RIEGGER AND C LORENZ: Constraining monthly GRACE solutions with hydrological mass estimates. EGU General Assembly, Vienna, Austria (13.-18.4.)

ELHABIBY MM, C XU, M WEIGELT AND MG SIDERIS: Global Gravity Field Pattern Recognition on the Torus using First Generation Wavelets. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

SHARIFI MA, N SNEEUW, O BAUR AND T REUBELT: Repeat orbit design using genetic algorithms. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

WEIGELT M AND W KELLER: Line-of-sight Gradiometrie und ihre praktische Umsetzung im Falle von GRACE. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

WEIGELT M, N SNEEUW AND W KELLER: Evaluation of PGM2007A by comparison with globally and locally estimated gravity solutions from CHAMP. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

Conference Presentations

ANTONI M, W KELLER AND M WEIGELT: Analyse der GRACE-Beobachtungen durch optimierte radiale Basisfunktionen. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

ARDALAN AA, R KARIMI AND N SNEEUW: Application of satellite altimetry derived Mean Sea Level as a boundary data for an iterative gravimetric boundary value problem approach to the Sea Surface Topography and the marine geoid computations. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

ARDALAN AA, EW GRAFAREND, H HASHEMI, N SNEEUW AND M POUTANEN: On the latest improvements in the geoid’s potential value computations: Procedure and accuracy. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

BAUR O, M KUHN AND WE FEATHERSTONE: Ice-mass and sea-level variations from GRACE. EGU General Assembly, Vienna, Austria (13.-18.4.)

BAUR O, M KUHN AND WE FEATHERSTONE: Investigations on reliable secular ice-mass and sea-level changes from GRACE. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

CAI J, C HU AND EW GRAFAREND: Directional statistics and statistical property of the GNSS carrier phase observations. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

CAI J, C HU AND EW GRAFAREND: Statistical property of the GNSS carrier phase observations and the related hypothesis testing with the bootstrap methods. International Symposium on GPS/GNSS 2008, Tokyo, Japan (11.-14.11.)

DEVARAJU B AND N SNEEUW: Impact on filtering on the spatial covariance structure of GRACE. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

DEVARAJU B, N SNEEUW, H KINDT, J RIEGGER AND C LORENZ: Constraining monthly GRACE-solutions with hydrological mass estimates. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

GRAFAREND EW: Das Somigliana-Pizzetti Referenzfeld, die Äquipotentialfläche als Referenzfläche vom Planeten Mars und seine ellipsoidische Schwerefelddarstellung. Leibniz-Sozietät, Symposium zu Ehren von Prof. Dr. tech. Dr. h.c. mult. H. Moritz, Berlin (14.11.)

GRAFAREND EW: System dynamics of polar motion (POM) and length-of-day (LOD) variation. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

GRAFAREND EW: Towards Mars equipotential suface, its reference ellipsoid and its ellipsoidal harmonics. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

KELLER W: A Localizing Basis Function Representation for Low-Low Mode SST and Gravity Gradients Observations. In: Xu P, J Liu and A Dermanis (Eds., 2008): VI Hotine-Marussi Symposium on Theoretical and Computational Geodesy, IAG Symposium 132, pp 10-16, Springer Verlag (VI Hotine-Marussi Symposium Wuhan, PR China, 29.5.-2.6.2006)

KINDT H, J RIEGGER, A BÁRDOSSY, B DEVARAJU AND N SNEEUW: Evaluation of GRACE Measurements with Hydrologic Data. European Geophysical Union 2008, General Assembly 2008, Vienna, Austria (13.-18.4.)

REUBELT T AND N SNEEUW: Raum-Zeit-Auflösung und künftige Satellitenkonfigurationen. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

SNEEUW N, A BÁRDOSSY, J RIEGGER, H KUNSTMANN, B DEVARAJU, H KINDT AND B FERSCH: The global continental water balance using GRACE spaceborne gravimetry and high-resolution consistent geodetic-hydrometeorological data analysis. DFG-Kolloquium, München, Germany (6.-8.10.)

SNEEUW N, MA SHARIFI AND H SCHAUB: Formation Flight Stability in a Gravitational Field. International Symposium on Formation Flying, Missions and Technologies, Noordwijk, The Netherlands (23.-25.4.)

SNEEUW N, T REUBELT AND MA SHARIFI: Einsatz genetischer Algorithmen beim Entwurf von Satellitenbahnen. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

WEIGELT M, M ANTONI AND W KELLER: Regional gravity recovery from GRACE using position optimized radial base functions. IAG International Symposium on Gravity, Geoid and Earth Observations (GGEO 2008), Chania, Crete, Greece (23.-27.6.)

ZOU R, N SNEEUW, J CAI, J LIU AND C SHI: The comparison of methods and results by IGN and DGFI in the realization of ITRF2005. EGU 2008, Vienna, Austria (13.-18.4.)

ZOU X, J LI, N SNEEUW AND J CAI: Developments in satellite gravity data analysis at Wuhan University. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

ZOU X, N SNEEUW, J LI AND J CAI: Research on the Accelerometer Calibration Model. Geodätische Woche, Bremen, Germany (30.9.-2.10.)

Guest Lectures and Lectures on special occasions

LI J (Head of School of Geodesy and Geomatics, Wuhan University): Progress of high-accuracy local geoid determination in China (5.8.)

PEDZICH P, Dr. (Department of Cartography, Warsaw University of Technology): Application of elliptic integrals to construction of the Soldner projection of an entire ellipsoid (21.2.)

REUBELT T: Harmonische Gravitationsfeldanalyse aus GPS-vermessenen kinematischen Bahnen niedrig fliegender Satelliten vom Typ CHAMP, GRACE, GOCE mit einem hoch auflösenden Beschleunigungsansatz. Doctoral Presentation, Universität Stuttgart (11.4.)

WANG Z (School of Geodesy and Geomatics, Wuhan University): Mean Ocean Dynamic Topography derived from T/P Jason-1 Altimeter Data and GRACE Gravity Field Model WHU-GM-05 (18.9.)

WIESE DN (Department of Aerospace Engineering Sciences, University of Colorado at Boulder): Alternative Mission Architectures for a Gravity Recovery Satellite Mission (20.11.)

ZHANG X (School of Geodesy and Geomatics, Wuhan University): GNSS Precise Point Positioning - a powerful tool in geodetic and geodynamic applications (18.9.)

Lectures at other universities

CAI J

New Investigation of the statistical property of the GNSS carrier phase observations. Wuhan University (6.5.)

Systematical analysis of 2-D and 3-D Coordinate Transformations with different estimation methods. Wuhan University (23.12.)

Systematical analysis of 2-D and 3-D Coordinate Transformations with Total Least-Squares Methods. Wuhan University (23.12.)

The developments of the GNSS data analysis methods. Wuhan University (20.5.)

GRAFAREND EW

Mars reference equipotential surface and the Somigliana-Pizzetti reference gravity field. Workshop „Geomatics“ in honour of Willi Freeden’s 60th birthday, Technische Universität Kaiserslautern (2.-4.7.)

The equipotential reference surface of Mars, its gravity field and ellipsoidal harmonics. Geodeetinen Laitos, The Finnish Geodetic Institute, Masala/Helsinki, Finland (11.9.)

KELLER W

Graduate course „Wavelets in Geodesy and Geodynamics“, University of Calgary, Canada (17.7.-4.9.)

SNEEUW N

Satellitengestützte Gravimetrie. Geodätisches Kolloquium, Technische Universität Dresden (5.11.)

Research Stays

CAI J
School of Geodesy and Geomatics, Wuhan University (5.-18.5.)
Finnish Geodetic Institute, Masala, Finland (14.-24.8.)

GRAFAREND E
Finnish Geodetic Institute, Masala, Finnland (9.8.-14.9.)
Geodetic and Geophysical Research Institute, Seismological Observatory, Budapest, Ungarn (9.-14.3.)

KELLER W
Curtin University Perth, Australia (15.2.-16.4.)

SNEEUW N
School of Geodesy and Geomatics, University of Wuhan, China (10.-15.5.)
Tongji University, Shanghai, China (16.-17.5.)
Geodetic and Geophysical Research Institute, Seismological Observatory, Budapest, Ungarn (18.-29.8.)

Lecture Notes

(http://www.uni-stuttgart.de/gi/education/lecturenotes.en.html)

GRAFAREND E AND F KRUMM
Kartenprojektionen (Map Projections), 300 pages

HAUG G
Grundstücksbewertung I (Real Estate/Property Valuation I), 28 pages
Grundstücksbewertung II (Real Estate/Property Valuation II), 11 pages

KELLER W
Dynamic Satellite Geodesy, 90 pages
Foundations of Satellite Geodesy, 51 pages
Observation Techniques in Satellite Geodesy, 50 pages

KRUMM F AND SNEEUW N
Adjustment Theory, 102 pages

SCHÖNHERR H
Amtliches Vermessungswesen und Liegenschaftskataster (Official Surveying and Real Estate Regulation), 58 pages

SNEEUW N
Analytic Orbit Computation of Artificial Satellites, 90 pages
Geodesy and Geodynamics, 68 pages
Physical Geodesy (Measurement Techniques of Physical Geodesy, Modeling and Data Analysis in the Field of Physical Geodesy), 137 pages

WOLF D

Continuum Mechanics in Geophysics and Geodesy: Fundamental Principles, 100 pages

Participation in Conferences, Meetings and Workshops

ANTONI M

DFG SPP1257 Workshop „Mass transport and mass distribution in system Earth“ Workshop (Glaciology, Mantle, and Crust), Herrsching, Germany (31.3.-2.4.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)
GGEO 2008 Symposium, Chania, Greece (23.-27.6.)
Kick off meeting of the PPP project „GPS-levelling in Poland“, Agricultural University Wroclaw, Poland (13.-16.5)

BAUR O

Erdrotation und globale dynamische Prozesse. Statusseminar der DFG-Forschergruppe FOR584, Hotel Miethaner, Höllenstein (12.-14.3)
European Geosciences Union (EGU) General Assembly, Vienna, Austria (13.-18.4.)
IAG Symposium, Chania/Kreta, Greece (23.-27.6.)

CAI J

GGEO 2008 Symposium, Chania, Greece (23.-27.6.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)
International Symposium on GPS/GNSS 2008, Tokyo (11.-14.11.)

DEVARAJU B

DFG SPP1257 Workshop „Mass transport and mass distribution in system Earth“ Workshop (Glaciology, Mantle, and Crust), Herrsching, Germany (31.3.-2.4.)
European Geosciences Union (EGU) General Assembly, Vienna, Austria (13.-18.4.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)
GGEO 2008 Symposium, Chania, Greece (23.-27.6.)

GRAFAREND E

European Geosciences Union (EGU) General Assembly, Vienna, Austria (13.-18.4.)
Workshop zum 60. Geburtstag von Prof. W. Freeden, Technische Universität Kaiserslautern, Kaiserslautern (2.-4.7.)
Symposium „Helmut Moritz, 75 Jahre“, Leibniz-Sozietät, Berlin (13.-15.11.)

KELLER W

Collaboration within the framework of the ARC research Project „Global warming induced sea-level rise“, Curtin University Perth, Australia (15.2.-16.4.)
GGEO 2008 Symposium, Chania, Greece (23.-27.6.)
Kick off meeting of the PPP project „GPS-levelling in Poland“, Agricultural University Wroclaw, Poland (13.-16.5)

REUBELT T

Final Meeting of the project “Mass Transport Study“, ESA Contract 20403, ESA, Noordwijk, The Netherlands (4.11.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)
Progress Meeting 3 of the project „Mass Transport Study“, ESA Contract 20403, Technical University Munich, Munich, Germany (31.3.)
Progress Meeting 4+5 of the project „Mass Transport Study“, ESA Contract 20403, University of Luxemburg, Luxemburg (27.8.)
Working Meeting of the project „Mass Transport Study“, ESA Contract 20403, Institute of Geodesy, Universität Stuttgart (6.6.)

SNEEUW N

DFG SPP1257 Workshop „Mass transport and mass distribution in system Earth“ Workshop (Glaciology, Mantle, and Crust), Herrsching, Germany (31.3.-2.4.)
DFG-SPP1257 Colloquium „Mass transport and mass distribution in system Earth“, München (6.-8.10.)
DGK Jahressitzung, München (26.-28.11.)
DVW-Fachtagung, Müllheim (30.04.)
ESA, 3rd International Symposium on Formation Flying, Missions and Technologies, Noordwijk, The Netherlands (23.-25.4.)
European Geosciences Union (EGU) General Assembly, Vienna, Austria (13.-18.4.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)
GGEO 2008 Symposium, Chania, Greece (23.-27.6.)

WEIGELT M

DFG-SPP1257 Colloquium „Mass transport and mass distribution in system Earth“, München (6.-8.10.)
GGEO 2008 Symposium, Chania, Greece (23.-27.6.)
Geodätische Woche, Bremen, Germany (30.9.-2.10.)

University Service

BAUR O

Chairman of the PR-Commission of the study course Geodesy & Geoinformatics

GRAFAREND E

Member Faculty of Aerospace Engineering and Geodesy
Member Faculty of Civil- and Environmental Engineering
Member Faculty of Mathematics and Physics

KELLER W

Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart

KRUMM F

Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart

SNEEUW N

Associate Dean (Academic) Geodäsie & Geoinformatik and GeoEngine
Member Examining Board of the Faculty of Aerospace Engineering and Geodesy
Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart
Member Search Committee Quest, Hannover
Member Search Committee Raumtransporttechnologie, Stuttgart

Professional Service (National)

GRAFAREND E

Emeritus Member German Geodetic Commission (DGK)

SNEEUW N

Chair AK7 (working group 7), „Experimentelle, Angewandte und Theoretische Geodäsie", within DVW (Gesellschaft für Geodäsie, GeoInformation und LandManagement)
Full Member of the Deutsche Geodätische Kommission (DGK)
Member of DGK-working group „Neue Satellitenmissionen"

Professional Service (International)

CAI J

Luojia Professor at School of Geodesy and Geomatics, Wuhan University, China
Member of the Institute of Navigation (ION, USA)
Member of European Geosciences Union (EGU)

GRAFAREND E

Member Royal Astronomical Society, Great Britain
Corresponding Member Österreichische Geodätische Kommission (ÖGK)
Member Flat Earth Society
Elected Member Leibniz-Sozietät, Berlin
Fellow International Association of Geodesy (IAG)

SNEEUW N

Präsident of IAG InterCommission Committee on Theory (ICCT)
Member Editorial board of Studia Geophysica et Geodaetica
Member Editorial board of Journal of Geodesy
Fellow of the International Association of Geodesy (IAG)

WEIGELT M

Member Inter-Commission Working Group (IC-WG2): „Evaluation of Global Earth Gravity Models" (IAG)

Courses - Lecture/Lab/Seminar

Geometric Data Processing (Keller)	1/1/0
Adjustment I, II (Krumm, Baur)	4/2/0
Coordinates and Reference Systems (Krumm, Reubelt)	1/1/0
Geodesy and Geodynamics (Sneeuw, Finn, Reubelt)	2/1/0
Measurement Techniques of Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Modeling and Data Analysis in the Field of Physical Geodesy (Baur, Engels, Reubelt)	2/1/0
Foundations of Satellite Geodesy (Keller)	1/1/0
Observation Techniques and Evaluation Procedures of Satellite Geodesy (Keller)	1/1/0
Satellite Geodesy Observation Techniques (Weigelt)	2/1/0
Dynamic Satellite Geodesy (Keller)	1/1/0
Map Projections (Krumm)	1/1/0
Mathematical Geodesy (Krumm)	2/1/0
Official Surveying and Real Estate Regulation (Schönherr)	2/0/0
Real-Estate/Property Valuation I, II (Haug)	2/1/0
Geodetic Seminar I, II (Keller, Krumm, Sneeuw)	0/0/4
Integrated Field Work Geodesy and Geoinformatics (Keller, Sneeuw)	10 days
Gravity Field Modeling (Keller, Baur)	2/1/0
Analytic Orbit Computation of Artificial Satellites (Baur, Sneeuw)	2/1/0
Orbit Determination and Analysis of Artificial Satellites (Sneeuw, Reubelt)	2/1/0
Geodetic Reference Systems (ICRS-ITRS) for Satellite Geodesy and Aerospace (Weigelt, Reubelt)	2/1/0
Advanced Mathematics (Keller, Weigelt)	3/2/0
Statistical Inference (Krumm, Baur)	2/1/0
Satellite Geodesy (Keller)	2/1/0
Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Map Projections and Geodetic Coordinate Systems (Krumm, Baur)	2/1/0

Institute of Navigation

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e-mail: ins@nav.uni-stuttgart.de
homepage: http://www.nav.uni-stuttgart.de

Head of Institute

Prof. Dr.-Ing. A. Kleusberg

Deputy:	Dipl.-Ing. Alexandra Seifert (since February 2008)
Secretary:	Helga Mehrbrodt
Emeritus:	Prof. em. Dr.-Ing. Ph. Hartl

Staff

Dipl.-Ing. Jürgen Ming, Akad. Rat	Administration (until January 2008)
Dipl.-Ing. Doris Becker	Navigation Systems
M.Sc. Shan Chen	Navigation Systems
Dipl.-Ing. Roland Pfisterer	Laser Systems
Dipl.-Phys. Manfred Reich	Interferometry
Dipl.-Ing. Wolfgang Schöller	Education/Navigation Systems
Dipl.-Ing. Alexandra Seifert	Navigation Systems
M. Sc. Hendy Suhandri	Navigation Systems
Dipl.-Ing. (FH) Martin Thomas	Laser Systems
Dr.-Ing. Aloysius Wehr	Laser Systems
Dr. Ing. Franziska Wild-Pfeiffer	Navigation Systems

EDP and Networking

Regine Schlothan

Laboratory and Technical Shop (ZLW)

Dr.-Ing. Aloysius Wehr (Head of ZLW)
Technician Peter Selig-Eder
Mech. Master Michael Pfeiffer

Guest Research Staff

M.Sc. Godfrey O g o n d a   Navigation Systems

External teaching staff

Dr.-Ing. Gerhard S m i a t e k - Fraunhofer Institute for Atmosheric Environment al Research
Dr.-Ing. Volker L i e b i g - Programme Directorate DLR-GE
Dr.-Ing. B r a u n - RST Raumfahrt Systemtechnik AG, St.Gallen

Research Projects

Improving the performance of GNSS Tracking-Loops by using MEMS-acceleration measurements

This topic is part of the BMBF supported Research and Development Task within the Support Program of Industrial Activities and Technology Transfer in Applied Satellite Navigation for Aero Space IV (UniTAS IV). The carried out research and development work is made by a consortium of industry and academia. In the course of this project the Institute of Navigation has to develop algorithms and to build-up a GNSS software receiver, which tightly coupled acceleration measurements obtained by MEMS sensors. An experimental cube was set-up containing MEMS acceleration sensors mounted orthogonally to each other, so that the accelerations could be measured in three dimensions (s. Figure 1). These measurements can be used to support the tracking loops of GNSS receivers. However, supporting the tracking loop with external sensor data means that the sensor data must be related to the actual frequency of the GNSS receiving signal. In case of this project this means that actual Doppler frequencies to the GNSS satellites within the receiver’s field of view have to be determined on the basis of the MEMS acceleration measurements. Therefore, in a second step algorithms were development for transforming the accelerations into Doppler frequencies. These algorithms were implemented into the GNSS software receiver. This software realized in MATLAB code is based on the Baseline Receiver Toolbox of the company Data Fusion Cooperation. The total receiver comprises a rf-front-end, a fast analogue to digital conversion interface, data storage devices and a PC. The front-end converts down the rf-GNSS-signal to an intermediate frequency of 2 MHz. This signal is analogue to digital converted with a resolution of 8 bits using a sampling rate of 20 MHz. The data is stored on a hard disk and can be processed offline by the software receiver. To verify the performance of the extended GNSS tracking loops a mobile data recording system was built-up in the year 2008. Figure 2 shows the block chart of the setup and Figure 3 the implementation in a van. A first test was carried out and showed that MEMS and GNSS data were gathered correctly and synchronously. In the following year the MEMS data will be tightly coupled into the GNSS tracking loop and the system will be tested on the road.

Figure 1: Cube with MEMS-Sensors

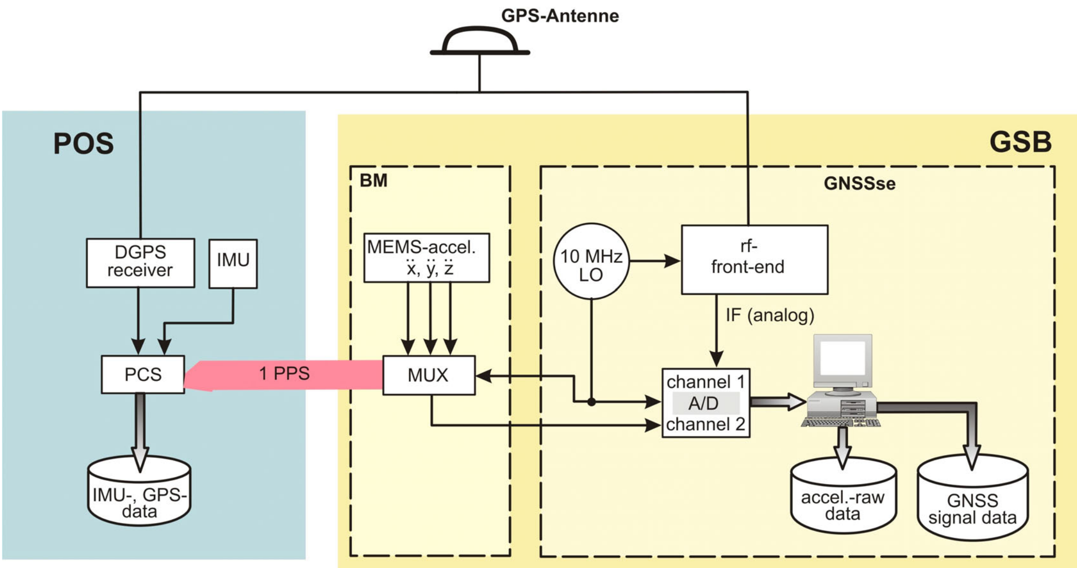

Figure 2: Mobile data recording system

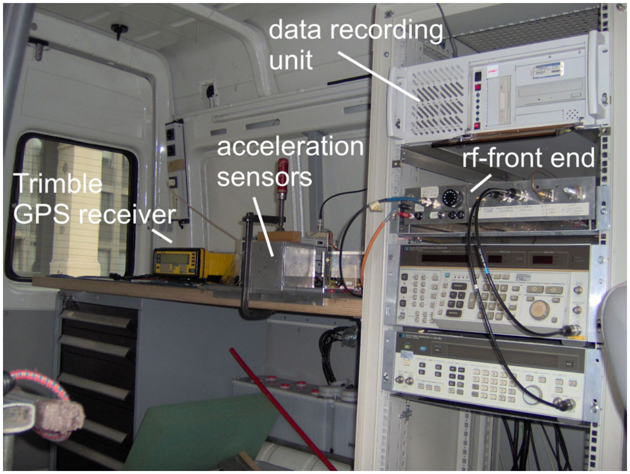

Figure 3: Mobile data recording system in van

Evaluation of a High-Sensitivity GPS Receiver for Kinematics Application in Regions with High Shading

GPS positioning has been very much improved with high-sensitivity GPS (HSGPS) receivers. This kind of receiver can track the signal until 20-25dB below the level of conventional receivers. Obviously, no problem occurs when GPS technology is used for air and ocean vehicles navigation; sufficient and/or redundant signals can be easily acquired due to good hemispherical signal reception. A problem arises whenever signals cannot be traced anymore, if not enough satellites are available or if there is very weak signal reception in forest areas or between buildings. Those situations cannot be avoided or eliminated in land vehicle navigation. The HSGPS technology tries to solve those problems by tracking signals below the normal signal threshold of non-HSGPS receivers.

Discussing the two factors of availability and accuracy in the context of navigation with HSGPS receivers in order to investigate these issues some scenarios of receivers-placing are examined which represent various receiver environments: good hemispherical signal reception, strong signal shading environment and indoor environment. The signal availability and accuracy are investigated during observation sessions of several hours by comparing the measurements of the HSGPS receiver with the measurements of a conventional, non-HSGPS receiver.

As expected, the non-HSGPS receiver yields the same level of availability as the HSGPS receiver in an environment with good hemispherical signal reception. When both receivers are located in an environment with significant signal shading, the percentage of availability will significantly decay for the non-HSGPS receiver whereas the availability of the HSGPS receiver is much less reduced. However the results from the HSGPS receiver in this case are at a significantly reduced accuracy level. The accuracy level is assessed by using three parameters: i) the difference between the C/A code and the carrier phase in order to investigate how big the multipath and other disturbance effects are, ii) investigation of the carrier phase accuracy by using triple-difference, iii) comparison of the signal-to-noise ratio with satellite elevation.

After analyzing the availability and accuracy for both receivers, data processing has been done by using static and kinematic methods. Both are based on post processing methods calculating the baselines from double-difference carrier phase and code measurements.

Table: Degraded GPS signals characteristic [source: Gao, 2007 with simplification]

	Multipath Signal	**Platform Dynamics**
Urban Canyon Auto navigation	Strong, high frequency	Moderate
Indoor personal positioning	Strong, low frequency	Low

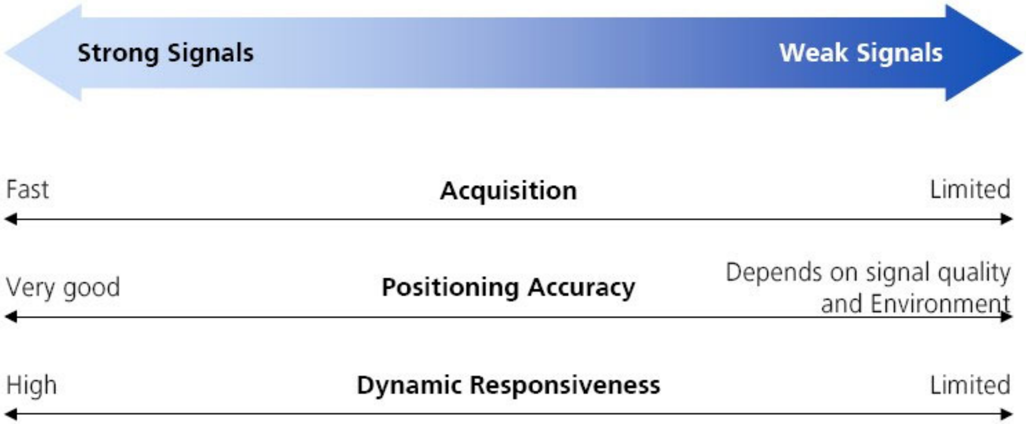

Figure 4: Trade-off in Weak Signal GPS [source: Antaris Manual, 2007]

Figure 4 shows the signal strength is one of parameters in order to achieve optimal quality of measurement. The accuracy achievement for signals in HSGPS is not absolutely parameterized by the signal strengths. With its ability to track weak signals by increasing coherent/non-coherent integration time, HSGPS provide wider applicability and higher availability compared to the standard/conventional GPS. However, this ability is also associated with higher noise level, thus the system cannot fulfil all requirements in weak signal conditions. In other words, the ability of HSGPS to 'see' the satellites which may not be tracked by conventional receiver allows this system to be applied in environments like urban canyon, forest, or even inside buildings. Such conditions where it is difficult for conventional receivers to get signals are called 'indoor environment'.

The ability is not only to see the attenuated signal but also delayed signal. They arrive at the antenna indirectly, i.e. reflection and/or diffraction, rather than along line-of-sight. However this technology has disadvantages of higher measurement noise, echo-only signals, multipath, and in many cases poor geometry as well.

The experiment was performed on the fifth floor of the Navigation Institute with five GPS receivers and three antennas. The instruments consist of one geodetic receiver and its antenna as fixed station located on the roof; one shared navigation antenna containing two receivers (HSGPS and non-HSGPS) located also on the roof; and another shared navigation antenna with two receivers (HSGPS and non-HSGPS) as rover.

Figure 5 below depicts the conditions of the observation site on the fifth floor at Institute of Navigation, University of Stuttgart. At the time we mounted the antennas directly on the pole without a plate under the antennas, the other antenna was placed at the high disturbing area, with air conditioner, wall and some metal materials. This situation caused our antennas to receive more indirect signals.

Figure 5: Situation of Observation Site with GPS antennas for trimble and U-blox receivers

The geodetic receiver is a Trimble GPS series 4700, the HSGPS receivers are U-blox series AEK-4T, and non-HSGPS receivers are U-blox series SBR-TIM-LH. For further description we can see figures 6, 7, 8, 9 below which depict the instruments.

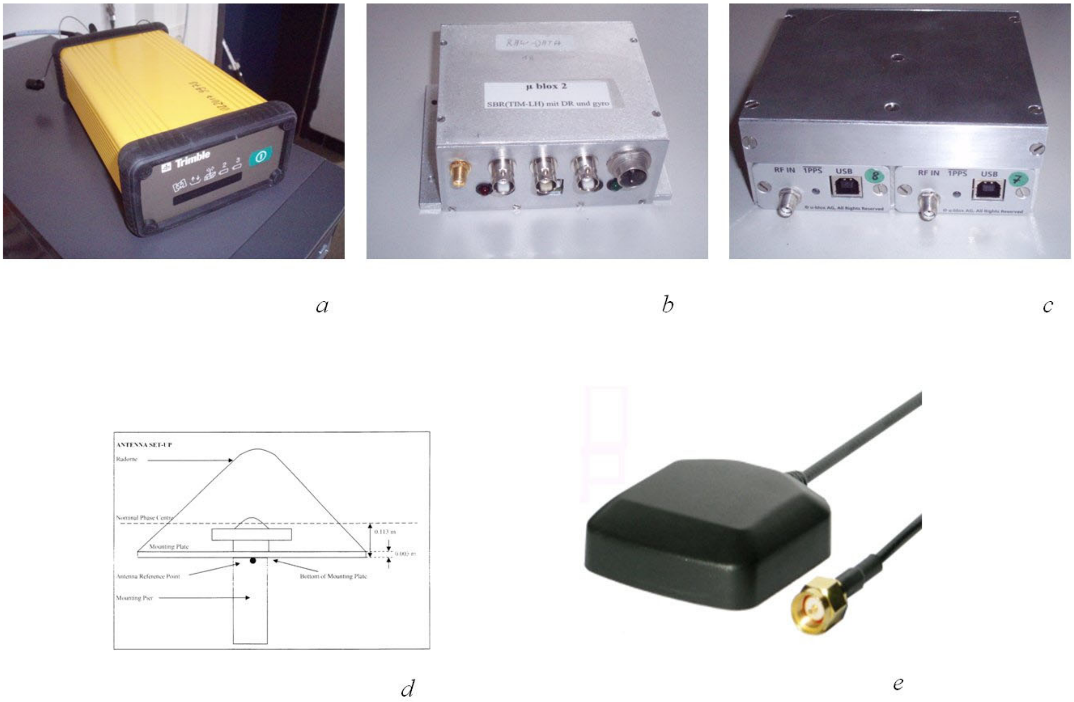

Figure 6, 7, 8, 9, 10: a) Trimble receiver series 4700, b) non-HSGPS series SBR-TM-LH, c) HS-GPS series AEK-4T, d) structural figure of Trimble antenna series TRM 29659.00 RPTR, e) Antaris antenna series ANN-MS-005

Assessment, Prognosis, and Review of Deposition Loads and Effects in Germany

The joint research project „Assessment, Prognosis, and Review of Deposition Loads and Effects in Germany“ (BMU/UBA FE-No 3707 64 200), is carried out on behalf of the German Federal Environment Agency (UBA) and on the account of Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Within the project national maps of air concentration levels and deposition loads are generated using measurement network data, additional model estimates and high resolution land use maps.

From modelled data sets high resolution maps of deposition loads and air concentration levels are calculated using GIS technique. The dose, in terms of deposition loads of air pollutants causing acidification and eutrophication in different forest and non-forest ecosystems in Germany, are compared to ecosystem sensitivity given as critical levels and modelled critical loads in order to provide an impact assessment in the form of exceedance maps for ecosystems. The trend of air pollutant input over time into the respective receptors on the national, regional, and local scale can be identified.

The joint project is elaborated in close co-operation between the Netherlands Organization for Applied Scientific Research (TNO, Dept. Air Quality and Climate), Utrecht, The Netherlands, the working group on Tropospheric Research of the Institute for Meteoroliogy of Freie Universität Berlin (FU Berlin, IfM, AG TrUmF), the Corporation for Ecosystem Analysis and Environmental Data Analysis (ÖKO-DATA, Strausberg), and the Institute of Navigation, Universität Stuttgart (INS). The results of the project are support for the German Federal Environment Agency (UBA, Dessau) in calculation and verification of national data which are implemented in European scale Critical Loads and Levels maps. The project results are national contribution for the protocols within the framework of UN/ECE Convention on Long-range Transboundary air pollution (UN/ECE LRTAP). Moreover the data are supporting EU and national regulations on air pollution control and emission abatement (EU NEC directive, BImSchG, TA-Luft).

Further information:
on the project: MAPESI (Modelling of Air Pollutants and EcoSystem Impact) *www.mapesi.de*
on the methods applied: *http://www.icpmapping.org/htm/manual/manual.htm*
on previous projects: *http://www.nav.uni-stuttgart.de/navigation/forschung/critical_loads*

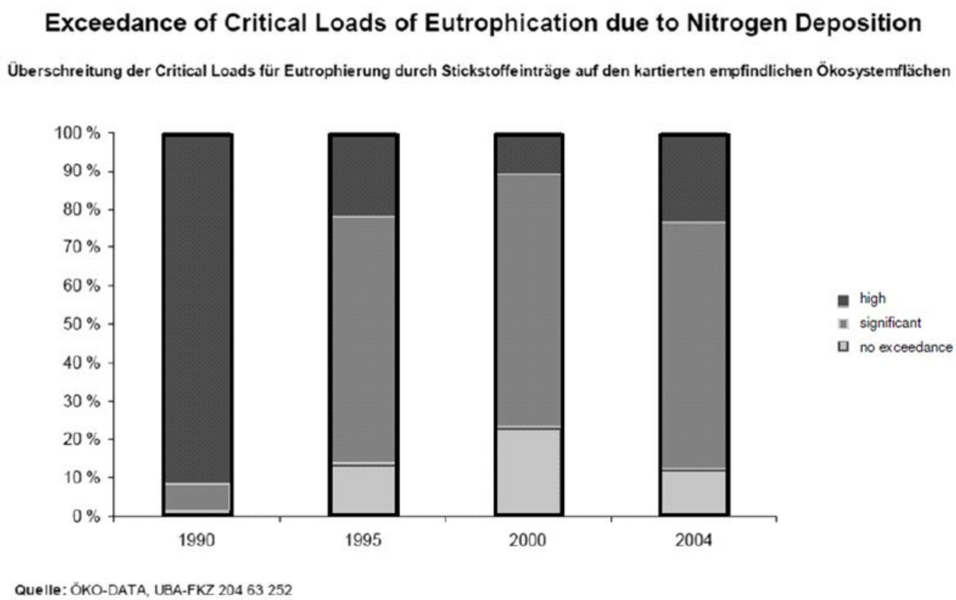

Fig. 11: Exceedance of Critical Loads over time caused by nitrogen deposition in Germany

Assessment of a Nationwide Digital Terrain Model for E-Plus

The E-Plus Mobilfunk GmbH acquired a digital terrain model (DTM) for the whole countryside of Germany from Intermap Technologies, called „NEXTMap Europe - Deutschland“. The resolution amounts to 25m. Since 2007 the INS has provided advice and has made the quality investigations for E-Plus.

In 2007 investigations had been performed for two test-areas „Erfurt“ and „Stuttgart“. Based on these results E-Plus decided to buy the DTM. In 2008 there were 6 test areas altogether to be able to form an opinion about the quality of the DTM at the end of the project: Clausthal-Zellerfeld, Erlangen, Garmisch-Partenkirchen, Heidelberg, Westerhever and Wuppertal. Investigations have been made to verify the product specifications given by Intermap: 1m vertical accuracy, 2m horizontal accuracy and removal of vegetation and man-made structures.

The basis for the tests were 10km x 10km sections of the DTM for each test area with a resolution of 5m. Besides the DTM-data additional DSM (Digital Surface Model) -data with a resolution of 5m and also ORI (Orthorectified Radar Image)-date with 1.25m raster has been provided by Intermap Technologies. Reference datasets have been provided by E-Plus: DTMs ordered from the geodetic authorities with a resolution of 1 to 12,5m depending on the test area, digital orthophotos (DOP) in 0,4m raster, a landuseraster dataset for Germany in 25m raster and footprints of buildings for 3 test areas.

During 2008 a new version of the DTM was delivered by Intermap Technologies making a comparison of both the new and the old version necessary. It could be shown that the vertical height of the new version was better in detail. Mainly hilly areas were affected by this improvement.

As in 2007 the difference between the Intermap DTM and the reference DTM for all test areas has been calculated and statistical evaluated.

In Fig. 12 you can see a shaded relief of one test area and a difference image between the NEXTMap DTM and the reference DTM. Wide variances - positive or negative - occur on the slopes. However, in flat areas the difference is almost zero.

Due to the unexpected premature death of our colleague in September of 2008 the project was suspended for the rest of the year and hasn’t been finished yet.

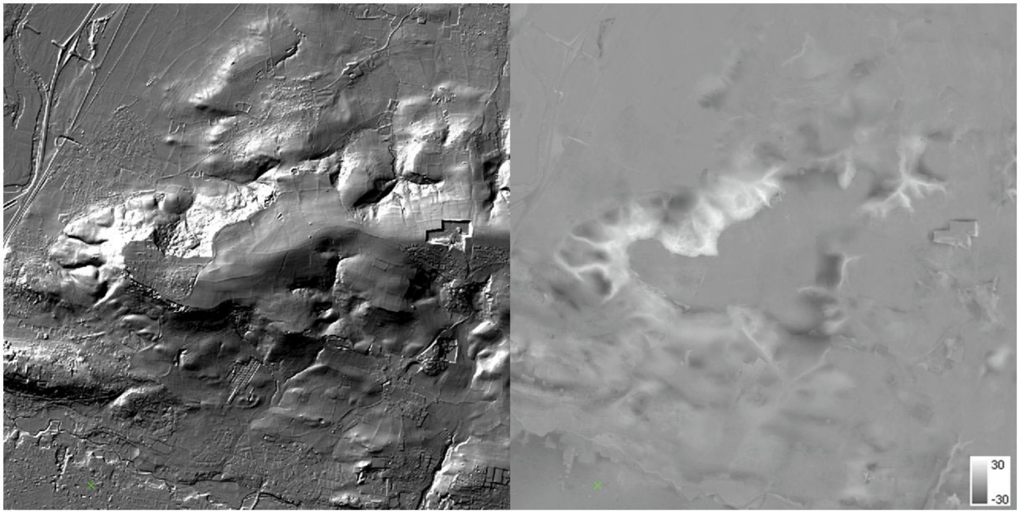

Fig. 12: Shaded relief of one test area (illumination angle: 315°, inclination angle: 35°) (left) and difference NEXTMap-reference DTM (right)

Publications and Presentations

Elsewhere, J., Wild-Pfeiffer, F.: „Comparison of various topographic-isostatic effects in terms of smoothing gradiometric observations“, IAG International Symposium on Gravity, Geoid and Earth Observation (GGEO), 23.-27.06.2008, Chania.

Wild, F., Heck, B.: „Topographic and isostatic reductions for use in satellite gravity gradiometry“, Xu, P., Liu, J., Dermanis, A. (eds.): VI Hotine-Marussi Symposium of Theoretical and Computational Geodesy: Challenge and Role of Modern Geodesy Wuhan, May 29 - June 2, 2006, Vol. 132 (2008), Springer-Verlag, S. 49-55.

Wild-Pfeiffer, F.: „A comparison of different mass elements for use in gravity gradiometry“, J Geod 82 (10, 2008): 637 - 653 DOI: 10.1007/s00190-008-0219-8.

Wild-Pfeiffer, F., Janák, J.: „Smoothing gradiometric observations using different topographic-isostatic reductions“, Geodetic Week 2008, 30.09.-02.10.2008, Bremen.

Participation in Conferences, Meetings and Workshops

Gyro Symposium, Karlsruhe, 16.-17.09.2008
Geodetic Week, Bremen, 30.09.-02.10.2008

Activities in National and International Organizations

Alfred Kleusberg
- Fellow of the International Association of the Geodesy
- Member of the Institute of Navigation (U.S.)
- Member of the Royal Institute of Navigation
- Member of the German Institute of Navigation

Franziska Wild-Pfeiffer
- Meeting „Frauen im DVW“, Intergeo Bremen, 01.10.2008

Education (Lecture / Practice / Training / Seminar)

Navigation and Remote Sensing (Wild-Pfeiffer)	2/1/0/0
Electronics and Electrical Engineering (Wehr)	2/1/0/0
Satellite Measurement Engineering (Kleusberg)	2/1/0/0
Aircraft Navigation (Schöller, Wehr)	2/0/0/0
Parameter Estimation Technics in Dynamic Systems (Kleusberg)	2/1/0/0
Navigation I (Kleusberg)	2/2/0/0
Inertial Navigation (Kleusberg)	2/2/0/0
Remote Sensing I (Wild-Pfeiffer)	2/2/0/0
Remote Sensing II (Smiatek)	1/1/0/0
Satellite Programs in Remote Sensing, Communication and Navigation I (Liebig)	2/0/0/0
Satellite Programs in Remote Sensing, Communication and Navigation II (Liebig)	2/0/0/0
Radar Measurement Methods I (Braun)	2/0/0/0
Radar Measurement Methods II (Braun)	2/1/0/0
Navigation II (Kleusberg)	2/2/0/0
Integrated Positioning and Navigation (Kleusberg)	2/1/0/0
Interplanetary Trajectories (Kleusberg)	1/1/0/0
Practical Course in Navigation (Schöller)	0/0/2/0
Geodetic Seminar I, II (Fritsch, Sneeuw, Keller, Kleusberg, Möhlenbrink)	0/0/0/4

Institute for Photogrammetry

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Head of Institute

Director: Prof. Dr.-Ing. Dieter Fritsch
Deputy: PD. Dr.-Ing. habil. Norbert Haala
Secretary: Martina Kroma
Emeritus: Prof. i.R. Dr. mult. Fritz Ackermann

Research Groups at the ifp:

Geoinformatics

Head: Dr.-Ing. Volker Walter	GIS and Remote Sensing
Dipl.-Ing. Hainan Chen	Data Integration
Dipl.-Ing. Yevgenia Filippovska	Data Quality
Dr.-Ing. Martin Kada	3D-Visualisation
M.Sc.Eng. Daud Nawir	GIS Update
Dipl.-Ing. Michael Peter	Generalisation

Photogrammetry and Remote Sensing

Head: Dr.-Ing. Michael Cramer	Digital Airborne Sensors
Dipl.-Ing. Susanne Becker	Resolution Enhancement
Dipl.-Ing.(FH) Markus Englich	Sensor Laboratory
M.Sc.Eng. Mohammed Othman	Image Orientation
Dipl.-Ing.(FH) Werner Schneider	Digital Photogrammetry Laboratory

Terrestrial Positioning Systems and Computer Vision

Head: Dr.-Ing. Jan Böhm	Spatial Segmentation and Object Recognition
M.Sc.Eng. Angela Budroni	Indoor Model Reconstruction
Dipl.-Ing. Alessandro Cefalu	Photogrammetric Calibration and Object Recognition
Dipl.-Ing. Alexander Fietz	Indoor Mapping
Dipl.-Ing. Carina Raizner	Objective Stray Light Measurement

External Teaching Staff

Prof. Volker Schäfer, Ltd. Verm. Dir., Wirtschaftsministerium Baden-Württemberg
Dipl.-Ing. Sabine Urbanke, Landesvermessungsamt Baden-Württemberg

Research Projects

Geoinformatics

Generalization of 3D Building Models

In recent years, the diversity of applications for 3D city models has widened from traditional analysis and simulation applications more towards the presentation of urban scenes. Most popular are real-time and web-based visualization systems like digital city or earth viewers that offer graphics of near photorealistic quality. Such accurate illustrations, that are true to detail, are not always the most adequate tool to communicate spatial information. Therefore, expressive rendering techniques have been explored that imitate sketchy drawing styles so that spatial situations are easier to perceive and comprehend. Similar intentions are pursued in the creation of thematic and map-like presentations where specific requirements about the minimum object and feature size must be met. Particularly affected by this principle are location based services and context-aware applications. They usually run on mobile devices, like personal digital assistants or mobile phones, which are equipped with displays of limited size and resolution.

These and numerous other applications for 3D city models rely on models at different levels of detail. Real-time visualization systems realize rendering performance and exactness by composing 3D scenes with models of varying complexity. The selection of the appropriate level of detail for an object may even be guided by its distance to the viewer. For applications that are not time critical or aim on photorealism, one level of detail is usually sufficient. However, the level of detail must fulfill the requirements of the application. For example, building models can be of considerable lower detail when seen from the air in comparison to a pedestrian’s viewpoint. Cartographic visualizations place the emphasis on the global shape of objects rather than on unimportant details. The same is true for expressive rendering techniques that highlight the characteristic edges of a model.

Because it is not reasonable to collect and store data for all required levels of detail, an automatic process is necessary that transforms 3D building models towards a more simplified shape. During this transformation, building-specific properties must be preserved. These are (amongst others) the parallel and right-angled arrangement of façade walls and the symmetries of roof structures. Furthermore, object specific features are especially important for landmarks. For example, a simplified model of a church or cathedral, must not miss its towers after simplification as otherwise the object is hardly recognizable anymore. A simplification of solitary objects under these spatial constraints is one of the elemental operators of cartographic generalization. In cartography, both the object's shape and their arrangement are altered with the goal to create maps or map-like presentations to better communicate spatial situations.

The geometry of 3D building models can be simplified by the following generalization approach. Its main idea can be best described by using the analogy of sculpturing. The 3D object in question is reproduced from a large solid block by a sculptor. However, the sculptor is only allowed to make planar cuts through the whole block. Afterwards, the sculptor peels away the pieces that do not belong to the resulting sculpture and glues the remaining solids together to form the final shape. In order to create a simplified counterpart of a given 3D building model, the number of executed cuts must be as few as possible. However, the number must still be high enough to reproduce the characteristic shape of the original object.

This technique is digitally emulated by first finding a minimal set of planes that approximate the facade and roof polygons of the input model. Then, a cell decomposition is generated from a solid that generously fits the dimension of the original model by subdividing it along the direction of the planes. The first three steps of the generalization algorithm generate a 2D decomposition of space that approximates the ground plan polygon by a disjoint set of quadrilateral primitives. We accomplish this by deriving plane equations from the major facade walls, subdividing the infinite space along these planes and identifying the resulting cells that feature a high percentage of overlap with the original ground plan polygon. The fourth step reconstructs the simplified geometry of the roof. Here, the first three steps are repeated for plane equations derived from the major roof polygons. A union operation of the resulting primitives composes the final 3D building model and concludes the generalization.

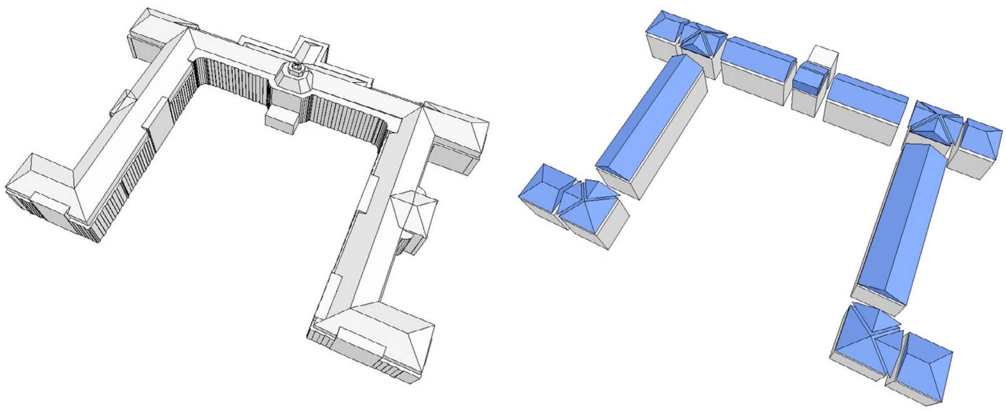

Figure 1: 3D model of the New Palace of Stuttgart (left) and its cell decomposition from major planes (right).

Inconsistencies in multiple represented 3D building models

The geometric simplification of complex structures like 3D building models leads inevitably to differences between original and generalized representation. While the major part of these differences is intended in favour of the model's simplification, unintended differences may result in conflicts between neighbouring objects and visually inconsistent transitions between different LoDs. In order to find these unwanted inconsistencies and to visualize them, an adjustment of the generalized to the original model becomes necessary.

The main idea of the ground plan adjustment approach is the description of the generalized model with movable wall planes. The model's 3D structure is represented by a decomposition into distance ratios with respect to the movable planes and fixed z-values. Using least squares adjustment, the movable wall planes are then adjusted to the major planes of the original model by shifting them in their normal direction. This causes changes to the faces, as for example changed roof slopes. This approach can also be used to adjust less detailed models to ground plans that provide higher accuracy.

Furthermore, when merging city models stemming from different sources, the inconsistencies between these models have to be analyzed in order to avoid double representations and visual inconsistencies. This analysis is done by comparing faces in both models that are spatially close and similar in direction. Relevant faces in the input model are then projected into the coordinate system of the reference model's face, followed by a comparison between the projected area and the reference face's area. This area difference together with the mean angle and mean distance between the reference face and the set of relevant faces are mapped on an interval [0:1] and used to color the input face.

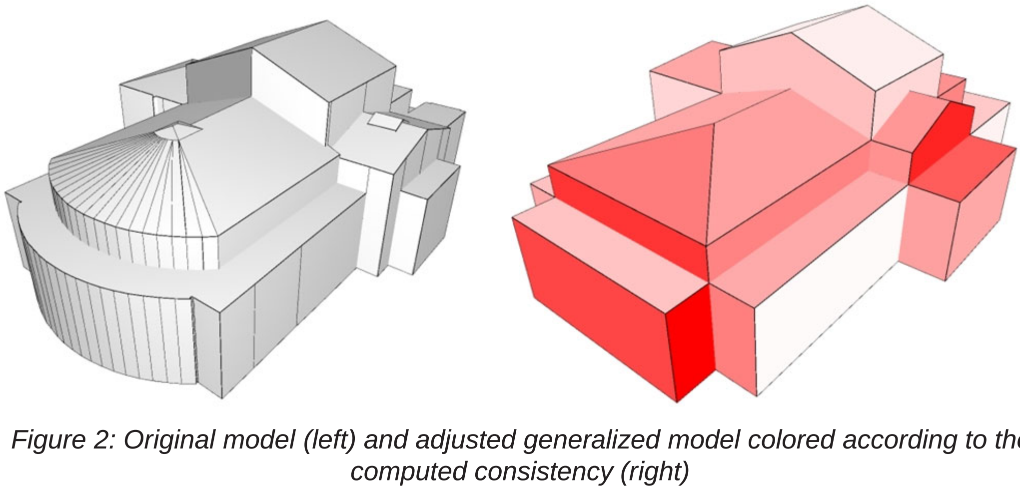

Figure 2: Original model (left) and adjusted generalized model colored according to the computed consistency (right)

Quality evaluation of ground plan generalization

Unlike model-oriented generalization, which reduces the amount of information within a data base, cartographic generalization concerns the optimization of spatial data towards a certain scale with regard to visualization. This means that the shape of spatial objects can be changed by the generalization process. The degree of object change can be seen as a quality measure of the generalization. This work is particularly interested in the quality evaluation of generalized ground plans.

The generalization changes not only the coordinates of an object, but it is also possible that existing vertices are deleted or new vertices are added. Although these new vertices are inserted into the ground plan in order to not disturb the orientation or the extension of the ground plan, they have no reference to reality. They do not exist in the real world, which means the quality of the generalization cannot be measured only by the accuracy of the coordinates. Instead of that, the difference between the original and the generalized ground plan must be quantified with other measures.

Since many different generalization algorithms have been published in the literature, it is important to compare them in order to find the most suitable approach. In many cases, it is almost impossible to identify a single solution which will be definitely the best one. The problem is that different properties of an object can be prioritized by the generalization process. For example, some approaches aim to preserve the outline of a ground plan, others aim to preserve the area. These are not the only parameters which can be used to characterize the similarity of ground plans before and after generalization. Quality parameters can be classified into four classes in compliance to the properties of map representations. These classes are “trueness of contour“, “trueness of location“, “trueness of extension“ and “trueness of shape“.

In order to compare an original and generalized ground plan, the ground plans are considered as closed, bounded subsets of points in Euclidean space. This assumption allows the use of operators from set theory. The “trueness of contour“ can be characterized by two boundary based measures: (1) the “Hausdorff distance“ and (2) the “outline intersection“. The “Hausdorff distance“ is the largest distance between two polygons and must not exceed the minimal generalization distance (see Figure 3). Therefore, it can be used as an indicator of the correctness of a generalization. The “outline intersection“ represents the percentage of the original outline remained after simplification (Figure 4).

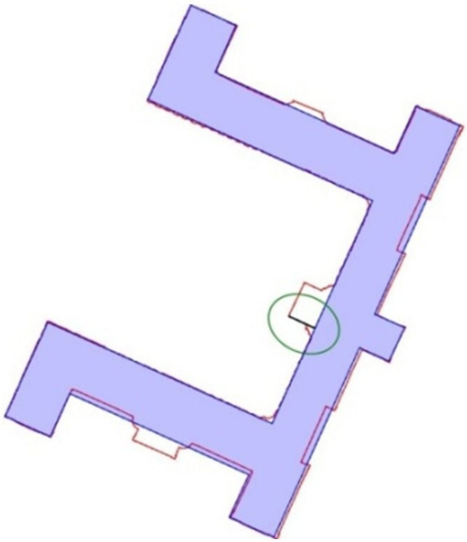

Figure 3: Hausdorff distance between original (red) and generalized (blue) ground plan

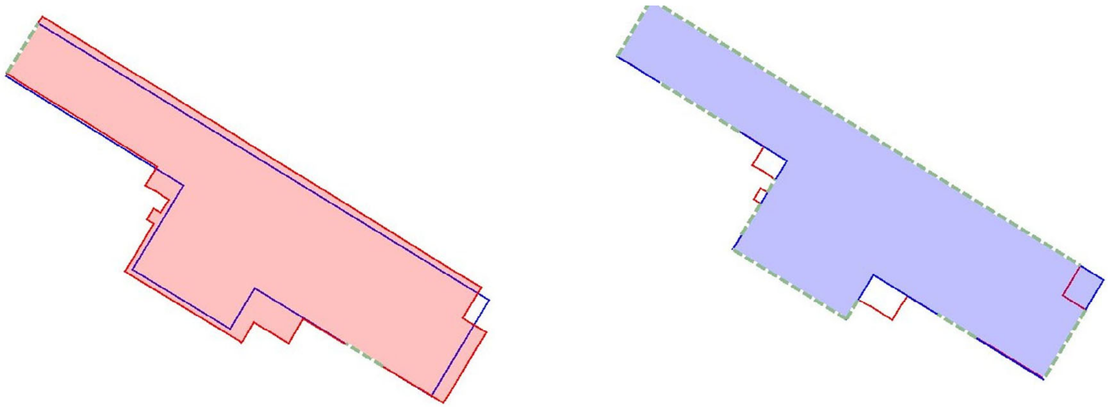

Figure 4: Original outline remained after simplification (dashed line)

The “trueness of extension“ is measured with a region-based approach. The degree of intrusions and the degree of extrusions represent the amount of missing and added parts when comparing the generalized with the original ground plan. From these, the Area Difference (AD) and the Symmetric Difference (SD) can be calculated. To aggregate all quality parameters to a final quality evaluation result, the Euclidean distance can be used, which ensures a better differentiation of the results than just a sum. After normalization, the quality of a generalized building ground plan ranges from 0 (worst) to 100 (best), which makes it easy to compare and understand different quality results.

Quality inspection and quality improvement of road network data

Spatial data are collected by different institutions for different purposes which lead to multiple representations of the same objects of the world. Multiple representations mean that redundant information is available which can be used for the inspection and improvement of the data quality.

In our study we use the following data sets: GDF (NavTeq), GDF (TeleAtlas) and OpenStreetMap. All three datasets are representing the road network and are available for very large areas. The GDF data from TeleAtlas and NavTeq are represented in the same data model whereas the data model of OpenStreetMap is different. However, the modelling of the street network is similar in all data sets. Figure 5 shows an example of the different acquisition of an area with NavTeq and TeleAtlas data.

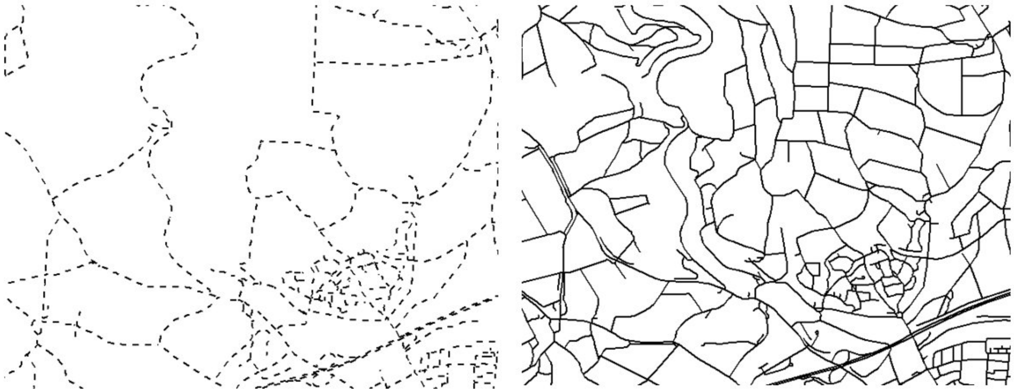

Figure 5: Different acquisition of an area with NavTeq (left) and TeleAtlas (right) data.

The first step is the matching of the objects of two or more different datasets. We developed a matching model that allows the matching of data with very different geometries. The next step is to evaluate the similarity of the matched data. A quality measure can be calculated based on the geometrical, topological and thematic similarity. The geometrical similarity is measured with a distance function, the topological and thematic similarity with statistical analyses. High similarity is an indicator for the relative quality. The last step is the fusion of the data sets. First, the unmatched objects of one dataset are allocated in clusters and transferred into the other dataset using a geometrical transformation. Afterwards, the attributes and semantic relationships of the matched objects are transferred with a rule-based approach from one data set into the other data set.

GPS Odyssey - a location based interactive city game

The interactive city game GPS Odyssey has been developed as a contribution to a special performance of the theatre of Stuttgart, which focused on the subject of „Ulysses“. The project introduced mobile PDAs with GPS receivers in a scientific and artistic context where real-time visualization of multiple GPS tracks was required.

If the King of Ithaca, Odysseus, had been equipped with a satellite navigation system, one of the most influential works of occidental literature would have been sacrificed to the demands of efficiency. The interpretation of the „Odyssey“, with the challenge of solving a variety of tasks at different stages of a journey, served as an inspiration for a thrilling city game to which the audience is invited to contribute. According to the motto „The journey is the reward“, several teams of audience members are each guiding a mobile player equipped with a GPS receiver (further on called „Mobinaut“) to special places within the city. As soon as the Mobinauts reach one of these places and the team members identify the place correctly, points can be scored by answering questions related to this place. In addition to scoring points, the personal goal for each member of the audience is also to score the consciousness about his or her own mental map of the city, and to gain knowledge of the city in a playful and interactive way. The Project was developed by the Universitaet Stuttgart, Institute of Urban Planning and Design and Institute for Photogrammetry.

One PC server connected to a beamer or a graphic wall is needed to run the game and to visualize the movements of the Mobinauts to the audience. Each Mobinaut has to have a GPS receiver and a mobile phone for the communication with the team and for transferring the actual position to the server via an internet connection. Modern mobile phones have all these features already integrated. The costs for the data transfer can be disregarded because only a small amount of data has to be transferred during one game. The costs for the communication with the team are depending on the mobile phone contract, but will also be not significant. The installation of the software can be done automatically from an internet server. Only the content of the game has to be changed, dependent on the place where the game is played. The time which is needed to create a new content depends on the complexity of the game.

Figure 6 shows the used system architecture with four Mobinauts. Altogether thirteen wireless connections are used (4 GSM connections for the communication of the teams with the Mobinauts, 4 Bluetooth (BT) connections for the communication of the GPS receivers with the PDAs, 4 GPRS connections for transferring the GPS coordinates to a server, 1 UMTS connection for the communication of the mobile PC - which is connected to a beamer - with the server.

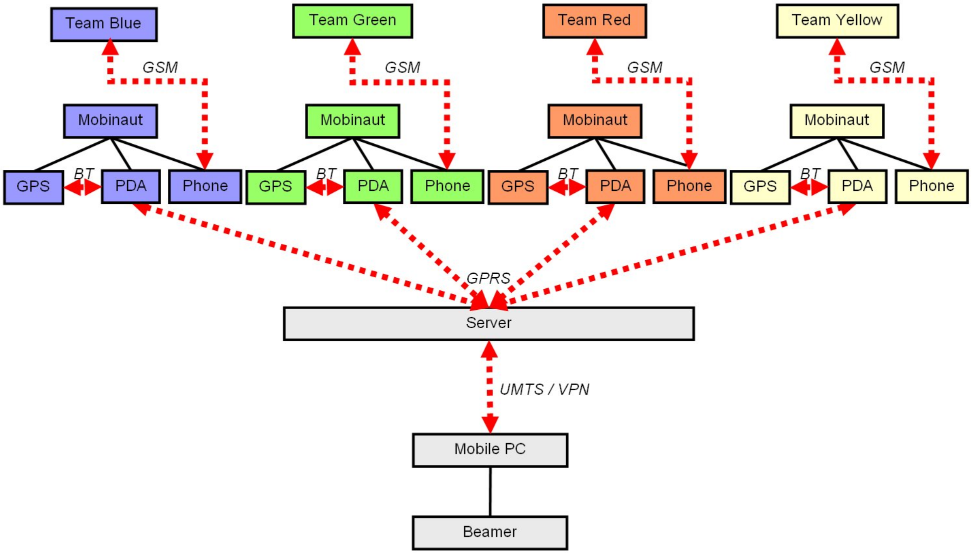

Figure 6: System architecture

The game asks for concentration, reactivity, strategic planning and team spirit of the players. In addition to that, knowledge of facts concerning the local historical and cultural background of a city must be activated to answer the questions. The game was performed four times and was received each time very enthusiastically by the audience and we got a lot of feedback and questions about the realization of the game. Therefore, location based games are not only a good entertainment but also an interesting way to make people understand modern geoinformation technology in a pleasant way. Figure 7 shows some impressions of the game. For more information (including a video) of the project please see: www.labor8.de/GPS-ODYSSEY.

Figure 7: Impressions of the game

Photogrammetry and Remote Sensing

Digital Photogrammetric Camera Evaluation in Vaihingen/Enz test site - The Initiative of the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF)

The testing and independent evaluation of the new digital airborne photogrammetric camera systems is an ongoing issue since the last few years. Driven by individual institutions or even national or international organizations such tests primarily are done to gain experience in digital camera performance and to finally support decisions when changing from analogue to digital sensor flights. Meanwhile some national mapping agencies have already decided to completely switch to digital image recording, selling their old analogue cameras and film development equipment. Still, comprehensive testing of digital sensor systems including quality analysis of sensor products (i.e. covering the whole process line) is typically not yet considered so far. In addition, sensor validation from independent test sites seems to become one standard process for future system certification. Thus, the optimal design of test procedures and test site layouts is another topic of concern. Empirical performance tests will also support the development and optimization of such processes and test sites.

Based on this and additional requests from camera and data users in photogrammetric working environments the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF) started to set-up a comprehensive test to analyse the performance of new photogrammetric digital airborne camera systems already end of 2007. The Institute for Photogrammetry (ifp) was defined as pilot centre and also delivers considerable scientific contributions. Based on empirically test flight data flown in the ifp Vaihingen/Enz test site the project is focusing not only on the analysis of geometric accuracy and sensor calibration. Additionally the radiometric performance including on-site radiometric calibration and multi-spectral land classifications is of concern. Furthermore the performance of photogrammetric DSM generation is considered, which is delivering one of the classical photogrammetric products. In addition, the potential of manual stereo plotting from digital images is evaluated and compared to results from analogue images.

Figure 8: Ground teams performing reference measurements in radiometric test field

In order to allow for such comprehensive analysis, several different flight campaigns were done in the Vaihingen/Enz photogrammetric test site. Table 1 lists the different flight campaigns from summer 2008. The imaging data was flown at 6 different flight days during a 10 weeks time window starting at the beginning of July till mid of September 2008. All sensors were flown in two different flying heights, resulting in two blocks with different ground sampling distances (GSD), namely GSD 20cm and GSD 8cm. The GSD 20cm blocks were flown with 60%/60% overlap conditions, whereas for the GSD 8cm block a higher forward overlap of 80% was aspired. Unfortunately not all cameras finally fulfilled these overlap requirements. The block geometry also slightly differs due to the fixed test site extensions and different sensor formats; all this slightly influences the later comparison of sensor performances. The variations in weather conditions also have to be considered especially when looking for the radiometric test performance. Thus, the main focus of this project is to derive the sensor specific strengths and maybe weaknesses, which are of relevance when later choosing a sensor for specific applications.

Additional flights were done with LiDAR and hyperspectral scanners. This data is used later as a reference for the photogrammetrically derived surface models and multi-spectral land cover classifications. Parallel spectrometer measurements were done on the ground, at same time the area was flown by the airborne sensors. By this, ground references for the later atmospheric corrections and sensor calibrations were delivered. Spectrometer measurements were done for artificial and natural targets. Bidirectional reflectance values were acquired with a special measurement set-up. All this was done in cooperation with the Institute of Space Systems (IRS) at Universitaet Stuttgart. Figure 8 shows a part of the radiometric test range and ground team members during reference measurements. To complete the reference data for comprehensive radiometric performance analysis, extensive field-walkings have been done for documentation of different land use.

First results from geometric performance of the Intergraph/ZI DMC digital camera are listed in Table 2. For comparison, the accuracies obtained from classical RMK-Top15 images, are also depicted. Since both cameras were installed in the same double-hole aircraft flight, their images were almost simultaneously recorded, resulting in identical atmospheric conditions for both data sets. Overlapping conditions are also quite similar. It has to be mentioned that the given results are based on a very high control point distribution. The image coordinates have already been corrected by additional parameter sets. Since high control point distribution and corrected image coordinates typically are not available for standard production blocks the given accuracy gives an estimation of highest achievable accuracy potential which can be expected under most optimal conditions. As one can see, the quality from RMS of check point differences is almost similar. The DMC vertical accuracy seems to be slightly worse compared to RMK which might be due to the less good base to height ratio. If one looks for the theoretical object point accuracy obtained from error distribution, the quality of the DMC points is better. This reflects the better image quality and thus better quality in image matching when comparing digital images to scanned analogue images.

In addition to this geometric performance, the quality of automatic DSM generation is also investigated for DMC and RMK and exemplarily shown in Figure 9. In this case the result from automatic point matching for analogue scanned RMK-Top images is compared to the results from DMC image data, both with GSD 8cm resolution. A flat grassy sports field was selected as test object. A LiDAR point cloud is available as reference. LiDAR data was captured with more than 5 pts/m^2. Colour coding reflects the terrain height. The much higher density of matched points from DMC images (close to 18 pts/mm^2) compared to classical RMK images (less than 1 pt/mm^2) is clearly shown. The 3D point cloud generated from DMC images is even denser than the reference LiDAR data. The higher radiometric quality of digital images obviously allows for much denser point matching. The matched points from RMK-Top image data are not sufficient to derive high accurate surface models. The vertical accuracy of points can be seen from the standard deviations obtained from individual height differences relative to the flat sports field surface. For the LiDAR data the std.dev. is about 2cm, almost without any gross errors. For DMC data this value is about 10cm, which is in the range of 1 pix GSD. Nevertheless, as you can see from the original DMC image used for matching, the point cloud is affected by erroneous matched points due to moving shadows. The effects from tree and floodlight pole shadows are clearly seen in the point cloud. Note that for point cloud visualization an orthophoto obtained from another sensor flight was used. Thus the shadows cannot be seen in the lower two sub-figures. The shadow effect is well known in automatic surface model generation. Nevertheless, such gross errors might be eliminated by later filter processes. If std.dev. of height differences is re-calculated after 1.2% of

3D points (gross errors) have been eliminated from the DMC point cloud, the accuracy increases up to 6cm (std.dev.). This filter process is supported by the high point density for this configuration.

Results from this comprehensive test data material clearly prove the very high potential of nowadays digital airborne camera systems and their accompanying processing software. The potential of photogrammetric DSM generation based on digital cameras, will definitely re-open new application areas, which only were fulfilled by LiDAR so far. Similar trends are expected for those applications, which rely on high quality multi-spectral data, like remote sensing tasks.

Table 1: Participating sensor systems and flight companies

System	Manufacturer	Flight company	Day(s) of flight
DMC	Intergraph/ZI	RWE Power	24.07.08 + 06.08.08
ADS 40, 2nd	Leica Geosystems	Leica Geosystems	06.08.08
JAS-150	Jenaoptronik	RWE Power	09.09.08
Ultracam-X	Vexcel Imaging Graz	bsf Swissphoto	11.09.08
RMK-Top15	Intergraph/ZI	RWE Power	24.07.08 + 06.08.08
DigiCAM quattro	IGI	Geoplana	06.08.08
AIC-x1	Trimble/Rolleimetric	Alpha Luftbild	11.09.08
AIC-x4	Trimble/Rolleimetric	Vulcan Air	19.09.08
DLR 3K-camera	DLR Munich	DLR Munich	15.07.08
AISA+ hyperspectr.	specim-FH Anhalt	RWE Power	02.07.08
ROSIS hyperspectr.	DLR Munich	DLR Munich	15.07.08
ALS 50 LiDAR	Leica Geosystems	Leica Geosystems	21.08.08

Table 2: Absolute geometric accuracy from DMC and RMK image blocks (very dense control point distribution, already corrected image observations)

Image block	Number of GCP / ChP	RMS from ChP diff. [m]			Std.Dev. from adjustm. [m]		
		ΔX	ΔY	ΔZ	σX	σY	σZ
DMC, GSD 20cm 60 photos	70 / 114	0,03	0,04	0,08	0,02	0,02	0,06
DMC, GSD 8cm 136 photos	60 / 47	0,02	0,02	0,04	0,01	0,01	0,02
RMK, GSD 20cm 47 photos	70 / 116	0,03	0,04	0,05	0,03	0,04	0,08
RMK, GSD 8cm 74 photos	60 / 48	0,02	0,02	0,03	0,01	0,02	0,03

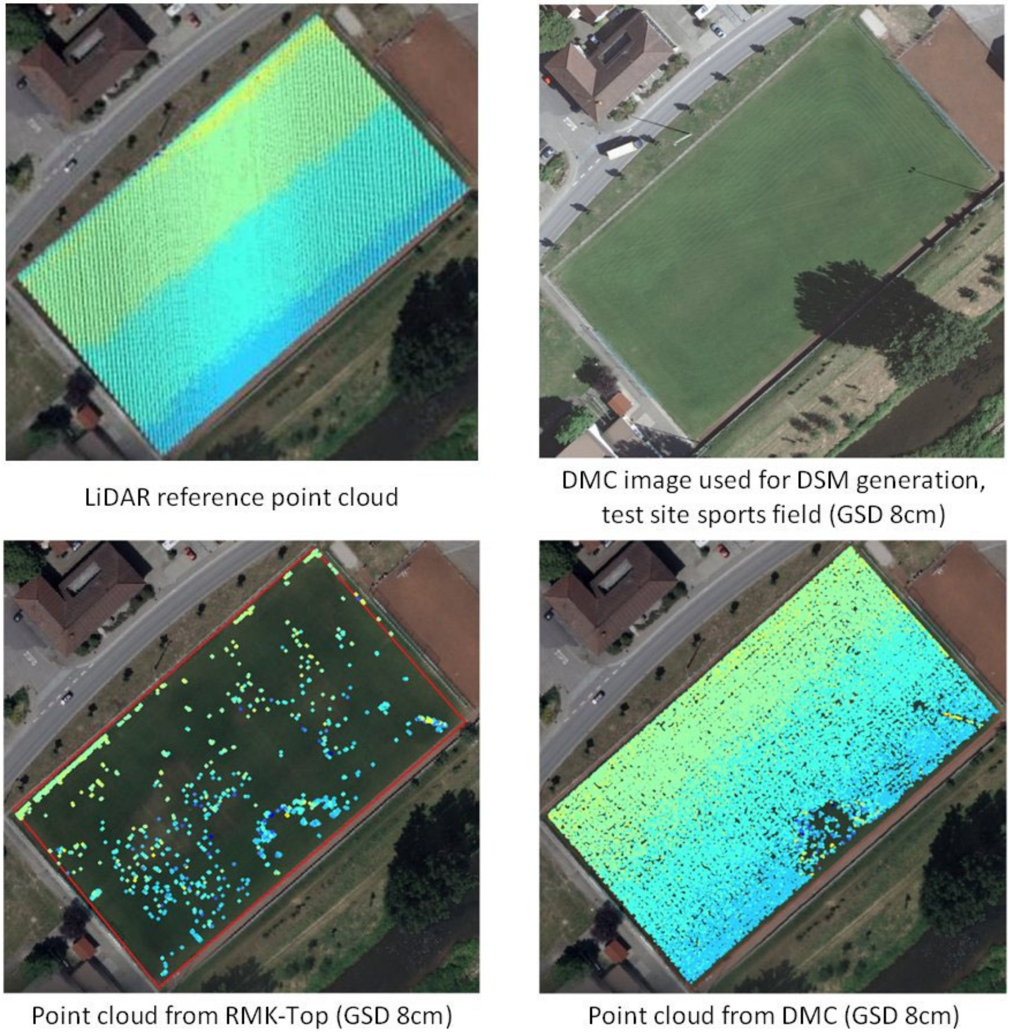

Figure 9: Performance of photogrammetric surface model generaration

Scene analysis positioning using 3D LiDAR information and image data

With the availability of high speed wireless data connections, the use of mobile applications is increasing dramatically. Optimized mobile phones with more processing power and larger displays and integrated internet search engines are part of latest generation devices and offer services optimized for mobile use. This mobile information needs in many cases to be linked to the position of the user in reality. Research is done by many scientists to solve this positioning task, most approaches are focusing on using a small digital camera (which are part of today's mobile phones normally), typically supported by other information sources like GPS positions or already available 3D city models.

Within this project a scene-analysis technology for positioning is developed to deliver improved position and orientation of mobile phone users in almost real time. Images are collected by a small digital camera integrated part of the cell phone. Additional information is obtained from point based environment model (PEM) databases using photogrammetric orientation methods. PEM is a dense point wise sampling of the surface of the objects in a scene and it can easily be acquired by long range 3D sensors, such as terrestrial LiDAR. Besides 3D point information additional laser reflectance (LR) images are typically available. Both data sources will be used for this scene-analysis. Motivation for this approach is the expectation, that dense point clouds of large building complexes, industrial facilities and urban areas will become widely available during the next few years. The main enabling factor is the recent wide spread availability of reliable sensor systems and service companies. The main drive behind the acquisition of such data is from the computer-aided facility management (CAFM) industry, preservation authorities and safety agencies.

One of the main steps in this application is to detect the 3D structure around the mobile phone user in the cell phone camera image. In order to do this, the computer needs to understand which objects or points in the cell phone query image correspond to the same object in LR image.

The LR-images are generated from the backscattered laser light which is a signal of high dynamic range. The strength of the return varies over a large range, from almost no return due to low reflective, far away surfaces, to direct reflection from retro reflective material. Therefore, we have to firstly apply image pre-processing to make this image appear more like a typical intensity image. Histogram equalization and normalization are usual tools for increasing the contrast of images, especially when the usable data of the image is represented by close contrast values.

Every matching point pair detected in the query-image (image point's data) and the now normalized LiDAR reflectance (NLR) image (object point's 3D data) can later be a constraint on the unknown camera point distances. The problem is therefore to find out which points in one image matches with the other image. In our case this task is solved by feature based techniques using the SIFT operator. The features extracted by this algorithm are robust to changes in rotation and scaling, which makes the SIFT features efficient for many applications. The matching quality is improved by applying a double direction matching (DDM). Exemplarily results are shown in Figure 10, where results from matching direction from query image to NLR image, inverse direction matching and double direction matching can be compared.

Due to invalid points, holes, dark or reflective spots on the object's surface and symmetry and self-similarity of the facade structures in the scans, the pairs of matched points contain a lot of false matches. As shown in the figure repetitive elements such as windows and beams, which are especially dominant in the example scene, cause false matches when the geometry of the scene is ignored. The wrong matches are removed by RANSAC based computation of closed form resection. For this purpose, the SIFT point correspondences can be used as control point information since each pixel with a valid laser reflectance value refers to the 3D coordinates of the related sample point. The number in inliers matches are represented with lines in Figure 11.

a: from query to NLR image b: from NLR to query image c: double direction

Figure 10: SIFT matching points for normalized laser reflectance (NLR) image and query image

a: from query to NLR image b: from NLR to query image c: double direction

Figure 11: Best matches found through RANSAC

Grammar supported facade reconstruction using mobile LiDAR mapping

Terrestrial laser scanning (TLS) is frequently used for the collection of high quality 3D urban data. However, the collection of dense point clouds can become very labor expensive, especially if larger areas have to be captured from multiple viewpoints. Such scenarios opt for vehicle based mobile mapping systems which allow for so-called kinematic terrestrial laser scanning. The 3D data collection is realized by a combination of laser scanners, which are mounted on a vehicle, while a high performance GNSS/inertial navigation system provides the required georeferencing information. Within our investigations the accuracy of the measured 3D point cloud from the commercial „StreetMapper“ system was determined based on reference values from an existing 3D city model. An example for these data sets is given in Figure 12. Originally, this first commercially available fully integrated vehicle based laser scanning system was developed for measurement and recording of highway assets. As it could be demonstrated, the achievable accuracy level also in dense urban areas is better than 30mm in good GPS conditions and thus makes the system practical for many applications in urban mapping. Thus, the system provides a good and accurate coverage of 3D points in urban areas. As an example, the data can very well be used for the extraction of geometric features like windows or doors for the captured building facades.

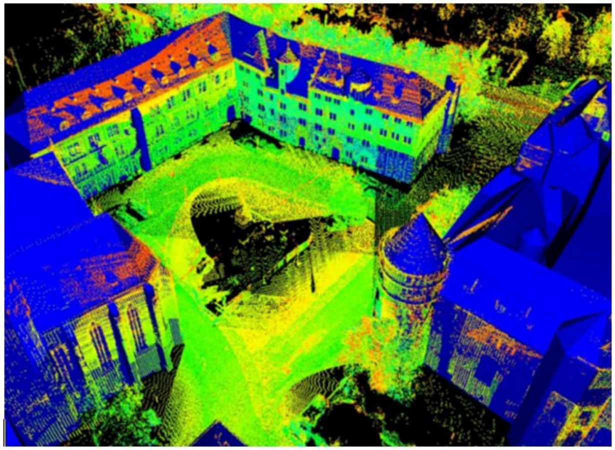

Figure 12: Point cloud from mobile LiDAR mapping aligned with existing 3D city model

Frequently, such algorithms for 3D facade reconstruction extract high resolution building geometries like windows, doors and protrusions from terrestrial LiDAR and image data. However, such a bottom-up modelling of facade structures is only feasible if the observed data meets considerable requirements on data quality. Errors in measurement, varying point densities, reduced accuracies, as well as incomplete coverage affect the achievable correctness and reliability of the reconstruction result. For this reason, we enhance the explicit reconstruction of facades by the integration of rules. The rules are derived automatically from already reconstructed facades, which serve as a knowledge base for further processing. They are used for the verification of the facade model produced during the data driven reconstruction process and the generation of synthetic facades for which only partially or no sensor data is available.

In principle, object reconstruction is feasible either knowledge-based in a top-down fashion or in a bottom-up manner, which is more data driven. Knowledge-based techniques usually apply formal grammars that ensure the plausibility and the topological correctness of the reconstructed object elements. A famous example for formal grammars is given by Lindenmayer-systems (L-systems), which can be used to model the growth processes of plants. Since L-systems allow for the procedural modelling of complex objects, they serve as a basis for the development of further grammars appropriate for the modelling of architecture, for instance shape grammars or split grammars. Generally, model based reconstruction techniques provide a means for procedurally creating architecture in a predefined style. However, this style first has to be constituted and translated into some kind of model or grammar description, manually. Another problem is that the variety of facade structures to be generated is restricted to the knowledge base inherent in the grammar rules or model libraries. The appearance of facade elements is limited to prespecified types, even when leaving some freedom in the values of their parameters. In this respect, data driven approaches are more flexible. The facade structure is not subject to predefined rules since geometrical features are directly extracted and modelled from the measured data. As a consequence, such approaches are relatively sensitive to erroneous or incomplete data.

To overcome these difficulties, we pursue an approach for the geometric refinement of planar building facades which runs fully automatically and includes both bottom-up and top-down propagation of knowledge. The goal is to extract rules from observed facade geometries, which are - due to limitations during data acquisition - mostly available only for parts of a building. These rules then can be applied to generate facade structures for the remaining parts of the building. Our algorithm starts with the extraction and modelling of facade geometries using terrestrial LiDAR and image data in a bottom-up fashion as it was suggested in our previous work. After this interpretation step, the resulting reconstructed facade serves as knowledge base for further processing. Dominant or repetitive features and regularities as well as their hierarchical relationship are detected from the modelled facade elements. At the same time, production rules are automatically inferred. The rules together with the 3D representations of the modelled facade elements constitute a formal grammar which we call facade grammar. It contains all the information that is necessary to reconstruct facades in the architectural style of the respective building. This knowledge is applied in three ways. First, the facade model generated during the data driven reconstruction process can be verified and made more robust against inaccuracies and false reconstructions due to imperfect data. Second, facades which are only partially covered by dense sensor data are completed. Third, totally unobserved facades are synthesized. As an example, Figure 13 shows the 3D facade model of Stuttgart's Lindenmuseum from two different views. The building part that has been modelled during the bottom-up reconstruction is shaded in blue. All remaining facade areas are synthesized based on the grammars inferred from the marked region.

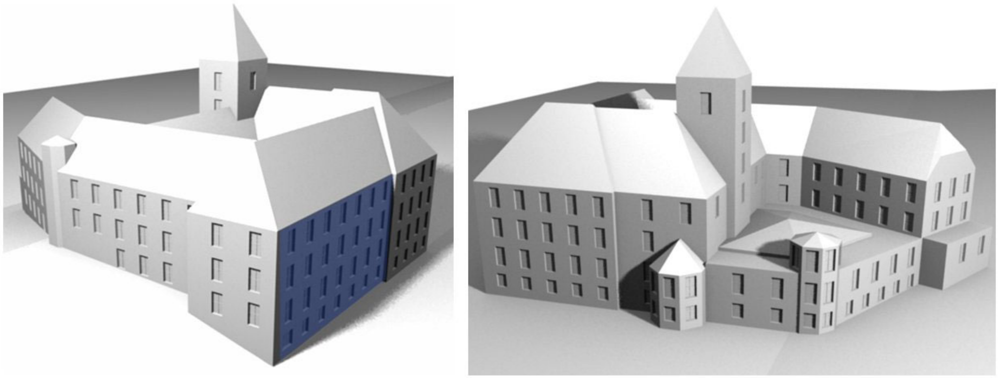

Figure 13: Stuttgart's Lindenmuseum as 3D facade model from rule and data based reconstruction

Terrestrial Positioning Systems and Computer Vision

RoboMAP - Robot-guided inline multi-sensor measurement system

Due to strong national and international pressure of competition in industrial production, manufacturers are increasingly forced to customize their products to individual customer requests. This leads to either a broad palette of products or a large number of variants based on some basic products. To exploit production facilities efficiently, it is often necessary to handle different constructional elements in one production line. On the other hand, especially German and European manufacturers can only set themselves apart from their international competitors by maintaining the high quality of their products. Thus, strict quality inspections have to be established. In an ideal case, 100% of all products and features are checked. The sooner defects in the production line are detected, the lower are losses, caused by unnecessary exhaustion of resources in the following processing steps.

This situation results in a direct need for industrial inspection systems which

- are fast, so that as many features as possible can be checked without interrupting the production flow
- are flexible to inspect different variants of a product
- work directly in the production line, so that defects are detected early
- are precise to guarantee high standards of quality

Flexible application of optical sensors offers the ideal solution for these requirements. Nowadays numerous methods of optical measurement and inspection are already well established in industrial environment. The broad variety of methods yields a similar variety of suppliers and systems.

Representatively two complementary techniques are mentioned: first the method of triangulation and second the method of interferometry. Fringe projection is an important representative of triangulating measurement methods and has proven itself in various industrial applications. Such systems also have been integrated directly into production lines, where they can verify their high precision and working speed. As all triangulating methods, fringe projection especially suits well for measuring outer geometry, i.e. preferably convex structures. In contrary interferometry can be used to establish systems particularly capable of measuring inner geometry, such as boreholes.

In industrial practice, such systems most commonly are used statically. This means the sensors are aligned in a fixed way according to a certain object feature. If multiple features or different variants of one product are to be inspected, the sensors have to be repositioned. This again requires a reconfiguration of the system and causes additional expenses and/or downtime. Therefore, automation of this reconfiguration is worthwhile. Early approaches aimed at the development of special inspection centers equipped with several sensors and thus able to inspect an object completely. However, such centers lack a lot of flexibility. Newer developments aim for the use of industry robots as systems for handling the sensors. Such systems are already in use for industrial mid-accuracy applications. For high-accuracy applications such a combination of multisensory and industry robot marks a great challenge and an up-to-date research task. The Bildungsministerium für Bildung und Forschung therefore funds a consortium, named RoboMAP, consisting of members from industry and public academies to develop a system as mentioned above (Figure 14).

In particular the Institute for Photogrammetry is responsible for an initial determination of the object's pose using a monoscopic camera system and the object's CAD model as pre-information (Figure 15). It also covers most terms of calibration and fusion of data.

Figure 14: Simulation of the robot's working area (by FH-Augsburg)

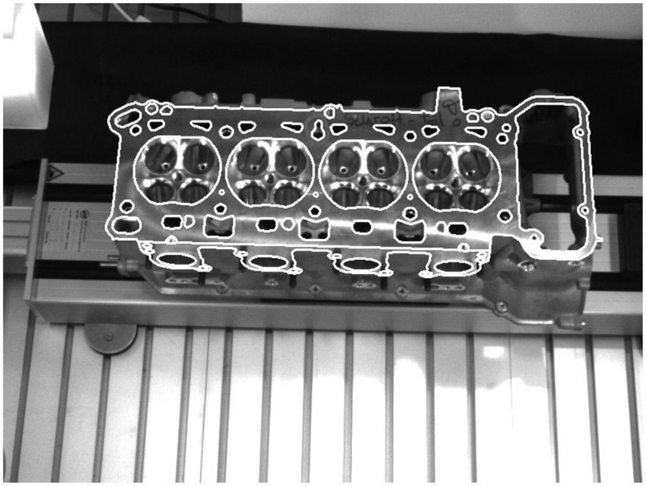

Figure 15: Detection of a cylinder head with following projection of the object's CAD model

Automatic reconstruction of indoor scenes from laser data

So far, realistic models of interiors have always been designed manually with the help of dedicated software packages. However, the demand for indoor models for different purposes has recently increased, thus a higher degree of automation could better satisfy different applications and speed up the processes. We developed a technique for the fully automated modelling of indoor environments from a three-dimensional point cloud. The results we achieve are very promising and the method suggested may provide completion to the actual standard for 3D city modelling.

Geometry and appearances of the urban reality can be currently represented in the international format CityGML, defined by the Open Geospatial Consortium (OGC). The model proposed by OGC supports five different levels of detail (LoDs) that provide a hierarchical description of building entities. A higher classification level corresponds to a more detailed representation of building features. The most elaborate representation is done at LoD4, which ensures the largest number of details for architectural models from the interior. Our research focuses on the implementation of an algorithm able to reconstruct an indoor room automatically according to the degree of resolution pointed to in LoD4. The motivation of this work lies in the convenience of achieving a 3D model, which incorporates internal architectural details. That means, structures and objects that are only detectable from inside, such as internal walls, doors or furniture may be automatically modelled.

For a long time within the geodetic community, automatic building model reconstruction has been restricted to the simple reconstruction of the outer shape of a building. However, it is obvious that for a full reconstruction, the interior of the building has to be considered as well. The availability of methods for automatic reconstruction of interiors could be useful in several applications, which may fit for different industries. Simple visualization purposes could be met, for example for virtual tours into indoor contexts like museums or expositions. Computer Aided Facility Management (CAFM) would also benefit from the automation of indoor reconstruction.

Our approach is based on a plane sweep algorithm for the segmentation of a point cloud in order to recognize the planar structures of a room. The specific procedure chosen to process the data in order to extract the 3D model is strictly connected to the laser measurements available, which provide a point cloud as an input for our algorithm. Such a point cloud is a collection of three dimensional points whose position in space is defined by Cartesian coordinates. The entire data set is the result of the registration of several scans along a hallway. The goal is to detect the positions of the walls, floor and ceiling. First, the horizontal surfaces are segmented from the point cloud by computing a vertical plane sweep along the z-direction and fixing a threshold for the point distances. On the other side, the vertical surfaces are localized by means of a rotational plane sweep, followed by a horizontal sweep. The goal of the rotational sweep is to compute the wall directions with respect to the x- and y-axis. Finally, the ground plan of the room is computed and the 3D model is built. The ground plan extraction is fundamental to design the correct model. The floor plan is calculated by intersecting the directions of the main walls and finding the vertices of the polygons, which constitute the ground shape. Techniques based on half space modeling and cell decomposition are used. Namely, the space bounded by the walls is divided in cells, which may be either accepted as floor cells or rejected. The knowledge of the floor plan is important to establish the exact extent of the room, which is limited by the contours corresponding to the walls. In our implementation, both the segmentation and the modelling algorithm are completely independent from the coordinate system.

The method to 3D modeling is robust and completely automatic since our program takes a binary point cloud as an input and writes the actual model on a CAD file. A priori information about the topology of the targeted room shape is not required. Only basic assumptions on the vertical axis and the position of the instrument are made. In the future, we expect to increase the functionalities of our algorithm by providing new capabilities for the automatic recognition of pieces of furniture and other critical objects, such as windows or doors.

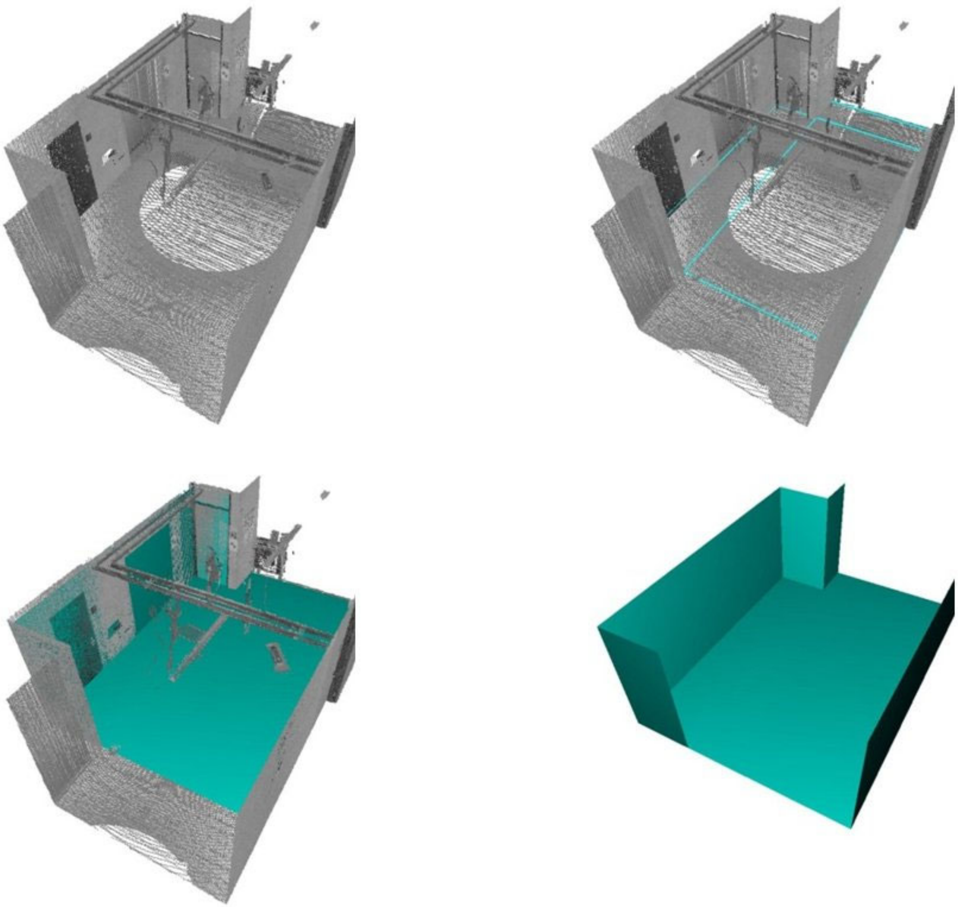

Figure 16: The algorithm starts from a point cloud and computes a three-dimensional model of the indoor scene

Facade detail from incomplete range data

In recent years, the demand for highly detailed building models has clearly risen. Most of the details, which characterize a building, come from its facade. It is obvious that such facade detail is ideally acquired from ground-based sensors. For any street-level data acquisition system, a common problem arises: that of occlusions and hence incomplete data. In the past, we have shown how multi-image coverage can overcome occlusions in image based facade recording.

In this work, we demonstrate new approaches on facade detail from range data in the case of incomplete data. The approach builds on our development of LASERMAPs, a simple and efficient way to use street-level LiDAR data to enhance existing prismatic building models.

In ground-based facade scanning, as in any ground-based data acquisition, incomplete data acquisition is a major problem and a primary reason for insufficient data quality. Incomplete data acquisition can occur for multiple reasons. One cause is the partial occlusion of the facade by other objects, such as cars, trees, pedestrians, street signs and so on. Figure 17 shows an extreme case for an occlusion by a tree and the incomplete data it causes. Another cause is the self-occlusion of the facade due to an oblique viewing angle. Protruded balconies or indented windows will cast shadows along the direction of measurement and cause incomplete data acquisitions. While such effect can be minimized by proper station planning, we have to keep in mind, that optimal stationing of the sensor is not always possible, especially in inner city areas, where traffic, property boundaries and other circumstances limit the choice for sensor stationing.

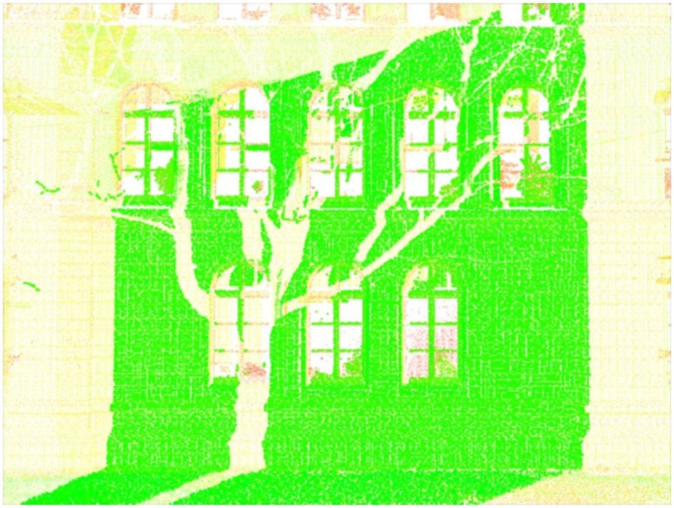

Figure 17: Incomplete ground-based LiDAR data due to an occlusion by a tree

Since facade architecture does not consist of purely random geometry, but is composed of repetitive elements, we can simply replace defective areas with a copy of an intact element. Since the representation of the LASERMAP is essentially the same as an image, image-processing operations can be employed to automate this task. In Figure 18 we show an example of a semi-automated repair process. The right one of the two windows clearly has a defect, due to the window being half-opened at the time of scanning. The repair process starts by interactively marking the defective area in the LASERMAP, shown as a white box in the image. Then we automatically search for a similar area in the LASERMAP. This is implemented using simple template matching. We perform a global template matching across the full LASERMAP and the best match (depicted by a black box) is copied over the defect area. The result of the repair operation is shown in the bottom rows of Figure 18.

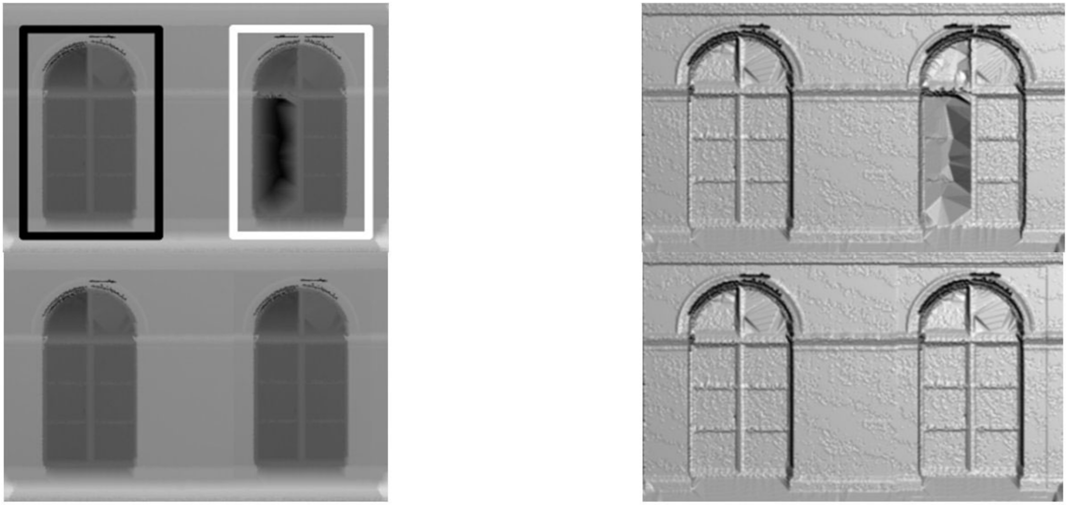

Figure 18: Semi-automatic repair of a defect shown in the top row. The bottom row shows the result of the substitution.

The above approach uses global template matching, a computationally expensive task. Thus, we rather restrict the matching to key points. We use the non-maximum suppression on the difference-of-Gaussian to detect robust key points. This is in effect the same operation used to localize SIFT key points. However, we do not compute SIFT features. To detect corresponding key points within the same dataset, we compute the normalized correlation coefficient of the patches surrounding the key points. Matching key points are assigned to the same equivalence class. In Figure 19 the image on top shows the key points detected in a LASERMAP.

We use a graph to store the relations among the key points. A Graph G consists of a set of vertices V and a set of edges E. The edges connect the vertices and thus are represented by pairs. If two key points $k1$ and $k2$ have matching patches, we add the two vertices $v1$ and $v2$ to the graph and add an undirected edge $e(v1, v2)$. The Euclidian distance of $k1$ and $k2$ is set as the weight of the edge e. An example for such a graph is shown in Figure 19. The resulting graph (after some transformation) can be used in different ways to aid in the retrieval of replacement patches. For one it can be used to determine standard values for floor height and horizontal separation of facade elements. It can be further used to reduce the template search for substituting defect areas. Instead of a global search, we only have to search at the vertices of the sub-graph, which has a vertex closest to the defect area.

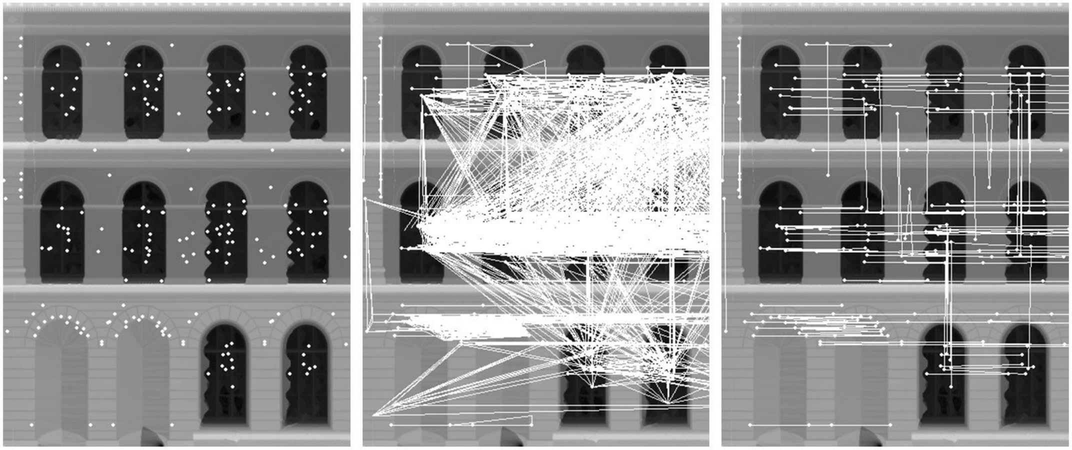

Figure 19: (Left) The key points detected from the LASERMAP. (Middle) The fully connected sub-graphs of matching key points. (Right) The minimum spanning tree(s).

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Gao, Y.: Automatic Photogrammetric DSM Generation and Accuracy Analysis (Geoengine Master Thesis). Supervisor: Cramer, M.

Ju, H.: Optimization and Evaluation of the Microsoft Automatic Aerial Triangulation Software Package. Supervisor: Haala, N., Gruber, M. (Vexcel Imaging GmbH) & Reitinger, B. (Vexcel Imaging GmbH).

Kling, S.: Kalibrierung eines Stereokamerasystems über projizierte Punktmuster. Supervisor: Haala, N. & Gebhard, M. (Robert Bosch GmbH).

Qiong, M.: Entwicklung eines mobilen Forstinformationssystems auf Basis von ArcGIS Server und Mobile ADF, Helm, M. (Intend Geoinformatik GmbH). Supervisor: Haala, N.

Seiß, T.: Bildverarbeitungstechniken als Entscheidungsinstanz in automatisierten Tests von Kfz-Infotainmentsystemen. Supervisor: Böhm, J.

Zheng, J.: Verfahren zur GPS-Bahnbestimmung für die Luftbildphotogrammetrie. Supervisor: Cramer, M.

Xu, F.: Konzeption und Realisierung einer automatisierten Validierung der geometrischen Verteilung von Points of Interest (POIs) in digitalen Straßenkarten. Supervisor: Walter, V. & Reichle, F. (P3-Systems GmbH).

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Beck, F.: Näherungsweise Bestimmung der inneren Orientierung von Consumer-Digitalkameras. Supervisor: Böhm, J.

Cefalu, A.: Volumetrische Oberflächenrekonstruktion terrestrischer LiDAR Daten. Supervisor: Böhm, J.

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Zheng, B.: Qualitätsvergleich von 3D Oberflächenbeschreibungen aus ARC 3D-Webservice und terrestrischen Laserscanning. Supervisor: Haala, N.

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Co-Chair ISPRS Working Group I/5 - Integrated Systems for Sensor Georeferencing and Navigation

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Chairman Scientific Advisory Board ‘Baden-Württemberg International’
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Aerotriangulation and Stereoplotting (Cramer)	2/1/0/0
Close Range Photogrammetry (Böhm)	2/1/0/0
Databases and Geoinformation Systems (Walter)	2/1/0/0
Digital Terrain Models (Haala)	1/1/0/0
Digital Image Processing (Haala)	2/1/0/0
Digital Signal Processing (Fritsch, Böhm)	2/1/0/0
Geodetic Seminar I, II (Fritsch, Sneeuw, Keller, Kleusberg)	0/0/0/4
Geoinformatics I (Fritsch, Walter)	2/1/0/0
Geoinformatics II (Walter)	2/1/0/0
Integrated Fieldworks (Fritsch, Sneeuw, Keller, Kleusberg)	0/0/4/0
Introductory Readings to Photogrammetry (Cramer)	2/0/0/0
Image Acquisition and Monoplotting (Cramer)	2/1/0/0
Urban Planning (Schäfer)	1/0/0/0
Pattern Recognition and Image Based Geodata Collection (Haala)	2/1/0/0
Photogrammetry and GIS (Cramer)	2/1/0/0
Animation and Visualisation of Geodata (Haala, Kada)	1/1/0/0
Cartography (Urbanke)	1/0/0/0

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Geoinformatics (Fritsch, Walter)	2/1/0/0
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Topology and Optimisation (Fritsch, Becker)	2/1/0/0

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