# The Department of Geodesy and Geoinformatics

Stuttgart University

**2007**

**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 2007 activities and academic highlights of the Department of Geodesy and 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).

**Prof. Möhlenbrink in memoriam**

The year 2007 was overshadowed by the decease of Prof. Wolfgang Möhlenbrink, head of IAGB since 1996. He sadly passed away on October 6th at the age of 60. The Department loses in Prof. Möhlenbrink a respected and dear colleague.

**Research**

This annual report documents our research contributions in many diverse fields of Geodesy and 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 can be found in the following individual institutes' sections.

**Teaching**

With our German Geodesy and Geoinformatics curriculum we have a vigorous programme with a total enrolment of about 140 students. Diversity is one of the programme's strengths: the female student population is about 35%, whereas foreign students account for nearly 50%. We are host to exchange students from, e.g., Canada and Poland.

Our international Master Programme Geomatics Engineering (GEOENGINE[2]) went into its second year of existence. We attract the GEOENGINE student population from such diverse countries as China, Indonesia, India, Nepal and Germany.

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

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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. Wolfgang Möhlenbrink (deceased 06.10.2007)
Prof. Dr.-Ing. Ulrich Rott, (provisional director)
Dr.-Ing. Martin Metzner, Akad. Rat

## Secretary

Christel Schüler

## Emeritus

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

## Scientific Staff

| | |
|---|---|
| Dr.-Ing. Renate Czommer | Map matching |
| Dipl.-Ing. Alexander Beetz | Sensor integration |
| Dipl.-Geogr. Wolfgang Fürst (till 31.03.2007) | Networks for Mobility |
| Dipl.-Geogr. Thilo Kaufmann (till 31.07.2007) | Geodata and GIS applications |
| Dipl.-Ing. Ralf Laufer | Information quality |
| Dipl.-Ing. Katrin Ramm (till 30.04.2007) | Kinematic positioning |
| Dipl.-Ing. Ralf Schollmeyer | Vehicle positioning |
| PD Dr.-Ing. Volker Schwieger | Engineering geodesy |
| Dipl.-Ing. Christian Waese (since 01.05.2007) | Geodata and GIS applications |
| Dipl.-Ing. Matthias Wengert | Geodata and GIS applications |
| Dr.-Ing. Thomas Wiltschko | Traffic information techniques |

## Technical Staff

Niklaus Enz
Ruping Hua
Martin Knihs
Lars Plate
Doris Reichert

## External teaching staff

Dr.-Ing. Max Mayer - Landesamt für Flurneuordnung

## General View

On $6^{th}$ October this year the head of the institute, Prof. Möhlenbrink sadly passed away after a long and painful illness. Nevertheless the research and education activities are going on. Now Prof. Rott provisionally leads the institute on behalf of Prof. Möhlenbrink.

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, traf-fic 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 cur-ricula for „Geodesy and Geoinformatics" as well as for „Geomatics Engineering", the master course in English language established in 2006. 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.

This report shows several research activities refering to projects supported by public and industrial funds. Therefore, the section „Short description of the projects" is included into this report characterizing these projects and their environment by short descriptions.

# Research and development

## Engineering geodesy and positioning technique

### Modelling and model evaluation for moving objects

For the modelling of moving objects the dynamic of the movements as well as the influencing quantities like different acting forces have to be considered. Therefore correct functional and stochastic models for the measurement quantities, e.g. GPS coordinates, have to be available. Concerning kinematic GPS measurements individual outliers and systematic falsified measurement phases have to be modelled stochastically in a correct way. Additionally the existing time-related correlations of GPS measurements have to be considered. At the IAGB these aims are reached by extending a Kalman filter including the drive dynamics by a shape filter as well as to an adapted shape filter augmentation. Figure 1 presents a successful implementation of these augmentations.

The evaluation of the non-additive approach is realised using methods of variance-based sensitivity analysis, since this method is appropriate to deliver qualitatively correct statements for non-additive equations. These statements concern the effect of the input quantities on the output quantities. Here, beside further measurements of a multi-sensor-system, the GPS measurements are the input quantities. The output quantities are the state quantities of the dynamical system „vehicle“: the position, the azimuth and the velocity. The investigations carried through within the framework of a doctoral thesis show that through shape filter augmentation a more realistic estimation of the state is realised, but the use of a correct stochastic model for individual outliers is of decisive importance.

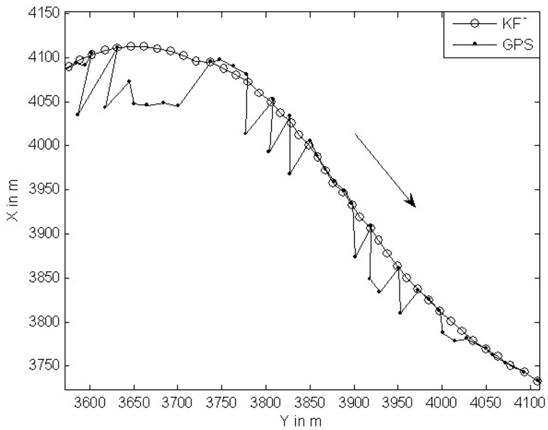


*Fig. 1: Improved filtering through correct stochastic models (KF = Kalman filter)*

**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. Positions are generated for each participant in the GSM network. By now the algorithm to match a signal strength received at a mobile phone onto a signal strength map available for every GSM antenna, is improved. Positions can be estimated with higher accuracy if differences between the signal strengths of different cells are used. This applies both to signal strength received at the mobile phone and to signal strength maps deduced from simulations. These calculated differences of measured signal strength are compared with those deduced from the signal strength maps of all antennas and the minimum of the least squares sum of these deviations indicates the searched position.

To reduce calculating time and to avoid multiple occurrences of minima a search area is cut out of the signal strength map (compare figure 2) shaped as a sector of a circle determined by the antenna's direction of radiation, their angular aperture, and the measured TA value (distance from mobile phone to antenna).

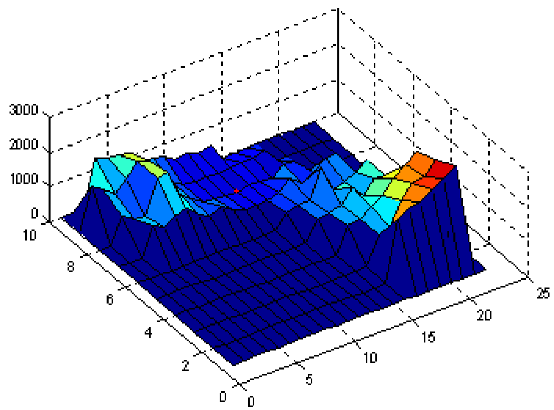


*Fig. 2: Sector for RX Matching*

Positions of one participant generated this way can be further improved by smoothing. The following mentioned figure (figure 3) shows the RX-Matching results, the smoothing the Kalman filter results, and the reference solution (GPS trajectory). The positions are generating some kinds of corridor based on the uncertainties of the position estimation. Within this corridor, data of the road network extracted from the digital map (GDF). Most probable trajectories are derived on the basis of shortest path algorithm. Figure 4 presents the results of the signal strength matching (RX-Matching) with following smoothing and the matching to the road network afterwards. Additionally, the measured GPS trajectory is shown in the figure.

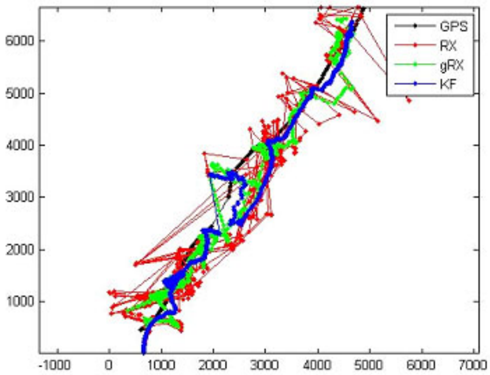


*Fig. 3: Estimated trajectory: RX-Matching, smoothing (gRX), Kalman filter (KF)*

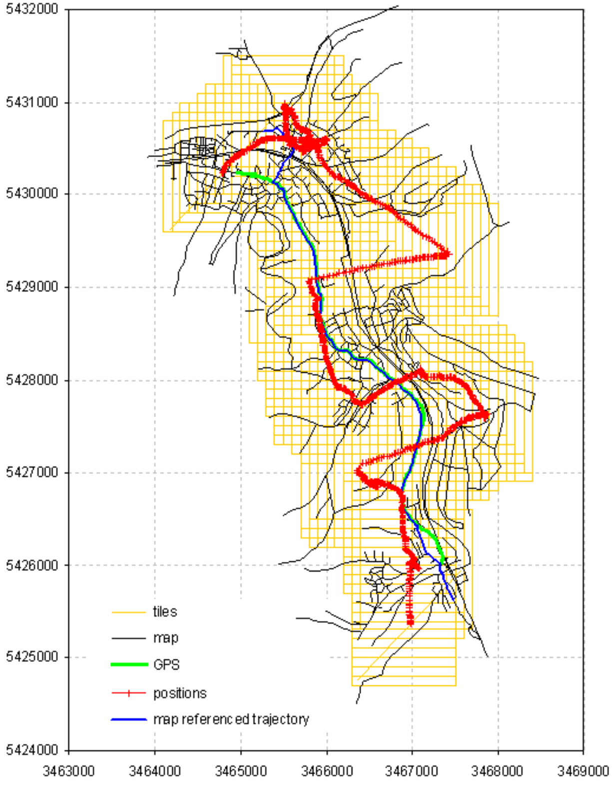


*Fig. 4: Map-referenced trajectory*

### Modular System for Construction Machine Guidance

The modular system for construction machine guidance (PoGuide), developed at the institute, is continuously enhanced. 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 5).

Beside 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 in an optimal way. The controllers are 3-point-controller, P-, PI-, PD- and PID-controller. One aim in future is the optimization of these controllers in conjunction with the Kalman filter. A further aim is the enhancement of the Kalman filter with the dynamic properties of the vehicle.

*Fig. 5: PoGuide - simulator*

### Precise positioning using High-Sensitivity GPS receivers

The investigations regarding static positioning of geodetic accuracy level using GPS navigation receivers are extended to high-sensitivity GPS receivers. Beside their price clearly below 100 Euro, high-sensitivity GPS receivers are characterised by an increased sensitivity of better than -150 dBm with respect to reflected and attenuated GPS signals. This characteristic predestinates them for use in shadowed areas and urban canyons. The instruments generally use phase-smoothed code measurements for positioning.

The receiver available at IAGB is the u-blox LEA-4T (figure 6). It shows the additional possibility to externally store the code and phase data and to post-process the data. The investigations to use this receiver type for positioning of geodetic accuracy level (mm to a few cm) have been started. First measurements were realised with different baseline lengths as well as within continuously operating reference station (CORS) networks. The preliminary results show deviations from the given coordinates within a few cms. Further evaluation steps like e.g. the important antenna calibration for the low-cost receiver have to be realised.


*Fig. 6: High-Sensitivity GPS receiver u-blox-4T and accessories*

**Kinematic GPS for evaluation of TanDEM-X data**

The TanDEM-X mission will deliver a global digital height model using synthetic aperature radar. Therefore two satellites will fly in a tandem formation. The measurements are carried through on the x-band on 9.65 GHz. The mission shall start in 2009 and run about 5 years. The generated height model will show a grid width of 12 m and a relative vertical accuracy of 2 m.

To evaluate the mentioned accuracy of the height model, GPS trajectories of some 100 km length shall be acquired in different regions of the world. The kinematic procedure allows the fast acquisition of large volumes of reference GPS positions to determine reference standard deviations. Since the required height accuracy of 2 m should be clearly exceeded by the GPS reference solution, a kinematic phase solution is required. Therefore, a report about the different possibilities of data acquisition and evaluation was made up. Besides elimination and reduction of important error sources like ionosphere, multipath effects, and antenna phase centre variations, the evaluation methods are discussed within the report. Due to the required worldwide uniformity of the evaluation PDGPS with individual reference station and precise point positioning are the two methods recommended.

**Research Area „Traffic Information Technology“**

With its activities the IAGB is contributing to the interdisciplinary research and development field of transport telematics with two core competences of geodesy and geoinformatics: positioning of dynamic objects and provision of high-quality (geo-) data and information. A variety of activities is focussed on the development of future mobility services and map-based driver assistance systems. Verification and validation of innovative telematic services and systems are performed by means of prototypical realisations and using of suitable test sites and simulation environments.

Main topics, besides others, are determination of vehicle position by using available on-board location and movement data, and correlation of the vehicle position to the digital transport network by appropriate map-matching-technologies. The necessary application-specific geo database and transport information are specified and modelled. Capturing, maintenance, and provision of data and information are designed and exemplarily implemented. To realize a quality assured-data capturing and provision of spatial data and traffic information the analysis of the entire information chain from source data to end user is necessary. In the next step an adjusted quality concept is developed and implemented. All these cases aim to provide data and information in an application-specific quality and safety level.

## Analysis of Low-Cost GPS sensors for Telematics Applications

Within the scope of a joint project with an industry partner several low-cost GPS sensors were analysed with respect to their usability for positioning of public transport vehicles. The required positioning accuracy was 5 meters or better. Besides only sensors allowing the output of the computed position using the NMEA protocol were analysed. Another requirement was the possibility of installing the sensor as simple as possible into IAGB's test car MOPSY.

GPS sensors of various suppliers were analysed (Table 1). One of the three sensors allows connecting the odometer signal of the vehicle as well as a gyro to it. Hence, this GPS sensor was combined with the odometer signal of the test vehicle and a gyro of a third party forming a multi-sensor system - in contrast to the other GPS sensors relying purely on GPS.

*Table 1: Overview of the analysed low-cost GPS sensors*

| | **iTrax 130** | **iTrax 300** | **SBR-LS** |
|---|---|---|---|
| **Vendor** | Fastrax | Fastrax | ublox |
| **Chipset** | Sony CXD2951 | SiRF StarIII | ATR0600 (Antaris) |
| **Type** | GPS-Chip | GPS-Chip | Multi-sensor system |
| **Accuracy (GPS only)** | 2 m (CEP50) | 1,5 m (CEP50) | 2,5 m (CEP50) |
| **Tracking** | L1, CA-Code | L1, CA-Code | L1, CA-Code |

During the test drive the position was acquired and saved with a data rate of 1 Hz. After the test drive the positioning results of the different GPS sensors were compared among each other. In case of good conditions, meaning good availability of GPS signals, all three sensors provide good positioning results meeting the requirement of 5 meters positioning accuracy. However, the results differ significantly where urban canyons and tunnels are along the way. In these cases the reception of GPS signals is limited or may be temporarily blocked completely, e.g. in a tunnel. When the vehicle has left the tunnel the sensors need some time to provide a new position having an accuracy of 5 meters or better. Immediately after leaving the tunnel the first GPS positions show accuracies of 10 to 40 meters (figure 7). Only the multi-sensor system is able to compensate the temporary loss of GPS signals using a dead-reckoning solution based on odometer and gyro. As a result, the position accuracy when leaving the tunnel is 10 meters or better. This proves the great potential of multi-sensor systems for vehicle positioning when driving under difficult conditions with respect to GPS signal availability.

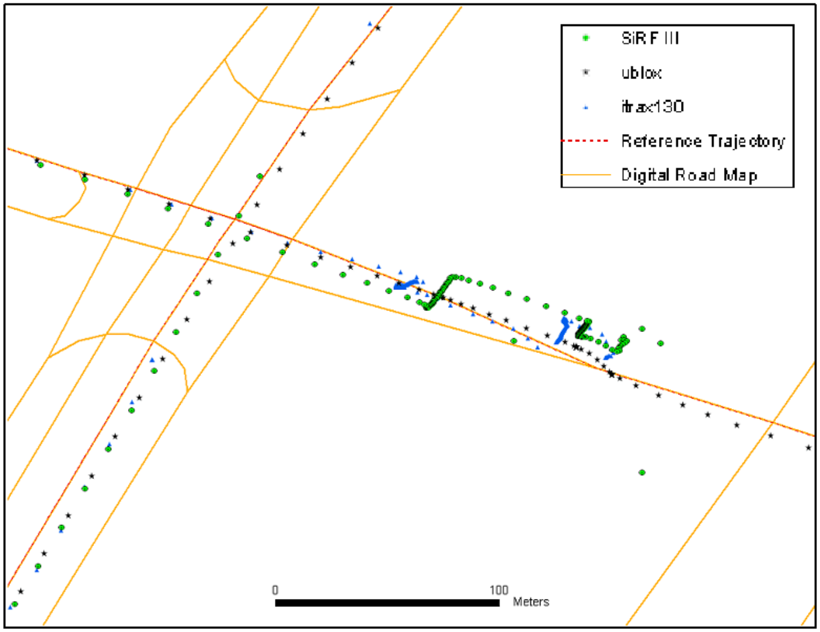


*Fig. 7: Comparison of the positions provided by several low-cost GPS sensors in case of an underpass (North-South trajectory) and a tunnel (East-West trajectory)*

**Identification of mobile subscribers**

Acquisition of traffic states using mobile phone data of infrastructure data acquisition has less accuracy than Floating Car Data supported by GPS. Furthermore it is not possible to distinguish between individual traffics and public transports or stationary mobile stations. Figure 8 shows a typical scenario. To improve coordinate accuracy a specific clustering method reduces the mobile phone coordinates in space and time to get relevant points. So moving and still standing subscribers can be differed. The following analyses classify the subscribers into classes of traffic modes. Therefore, subscribers in public transport, pedestrians, etc., as well as standing subscribers can be excluded from traffic state acquisition.

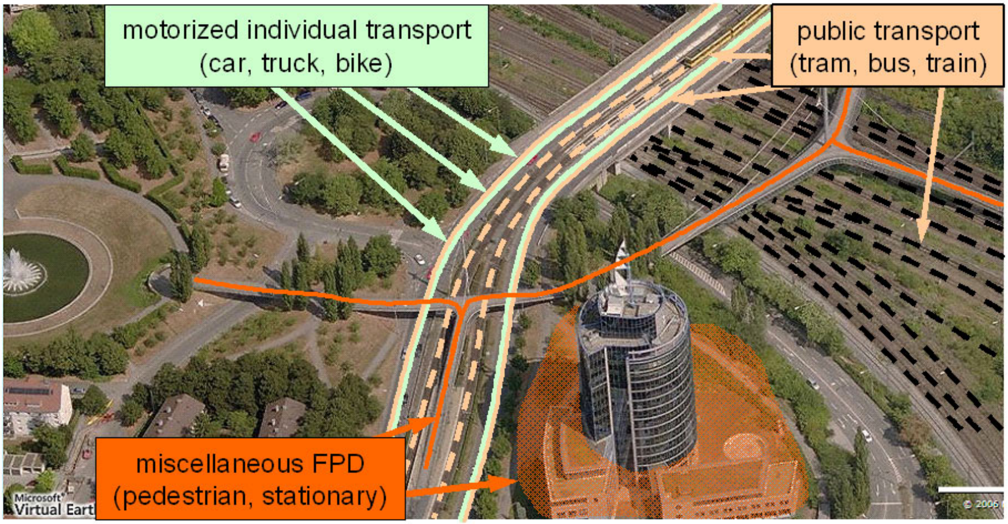


*Fig. 8: Identification of mobile subscribers for acquisition of individual traffic states*

That strategy is also used in algorithms developed by IAGB. With position data for mobile stations probabilities are computed for the use of line busses, trams, and regional and long distance trains. Also the positions are checked whether they are on road network or off-road (e.g. stadium, theme park, parking-lot, shopping centre). In some cases classification is still going ambiguously. In such cases a plausibility check is performed by testing the trafficability of the assumed road or railway networks. For this purpose an adapted fuzzy routing method is used. This method trys to find out a route in space and time based on the relevant points including the region of probability surroundings. Especially mobile stations moving on ways parallelly to railways or roads seen in figure 8, can be classified by that method. For each subscriber a value of membership is calculated for every class.

**Quality concept for geo-data**

Quality analysis of mobile phone data and its influence on positioning

Mobile radio positioning methods are used in several fields of application. In order to reveal positioning quality, the knowledge of mobile radio data quality is essential. This applies especially if only the regular data are used accrueing in the mobile network infrastructure during normal operation without special preparations. The quality model developed at the IAGB is used for an objective evaluation of data quality and enables an adequate description of the parameter for mobile data used for positioning. Table 2 shows the data model adapted to mobile data. By reason of the current project Do-iT at the IAGB, we concentrated on GSM-data and the positioning method (signal-matching et al.) developed and implemented at the Institut.

*Table 2: Quality model for mobile phone data for positioning*

| | quality characteristic | quality parameter | [unit] |
|---|---|---|---|
| dependability | availability | • temporal availability per antenna<br>• temporal availability per area<br>• spatiotemporal availability per area | [%]<br>[%]<br>[%] |
| | actuality | • mean communication delay<br>• age of data (calculated with date of record and current time) | [s]<br>[s] |
| integrity | completeness | • coverage of trajectory<br>• completeness of network data<br>• coverage rate | [%]<br>[%]<br>[%] |
| | consistency | • consistency rate | [%] |
| | correctness | • correctness of signal strength chart<br>• correctness of signal strength measuring | [%]<br>[%] |
| accuracy | | • accuracy of signal strength chart<br>• accuracy of signal strength measuring<br>• accuracy of TA-value<br>• accuracy of the time stamp<br>• accuracy of the position of antenna | [dBm]<br>[dBm]<br>[m]<br>[s]<br>[m] |

Test runs performed within the project enable the empirical determination of quality parameter. GPS measurements were taken as reference to examine the influence of mobile data quality.

First results confirm a significant impact of mobile phone data quality on positioning. The quality model seems to suit for an unbiased estimation of the influence. By using a subset of quality parameters within the processing, a selection of appropriate mobile phone data can be effected in particular.

Development and application of methods for analysing stationary traffic data acquisition systems

To warrant the quality of traffic data, in particular traffic volume and velocity collected by stationary systems, is a major effort for the operator. The recent boost of traffic control systems and driver assistance systems with their need of almost realtime usage and processing of traffic data requires a constant and high quality level of the collected data. In the recent past, a directive was worked out by the Forschungsgesellschaft für Straßen- und Verkehrswesen including proposals for quality assurance of suchlike systems (FGSV2006). However these are fairly general and restricted to accuracy and completeness of data for control of traffic control systems.

For a comprehensive analysis of quality in terms of the quality model developed at the IAGB, standard methods for system analysis and analysis of industrial processes were adapted and amplified. Deficits in quality characteristics were defined as unintended effects in the Cause-Effect Diagram (CED) used as basis for discussion. Thereby the examination of sources of defects could be directed towards the examination of data and system quality. As an example, figure 9 shows the effect „measurement incorrect“ as a lack of correctness.

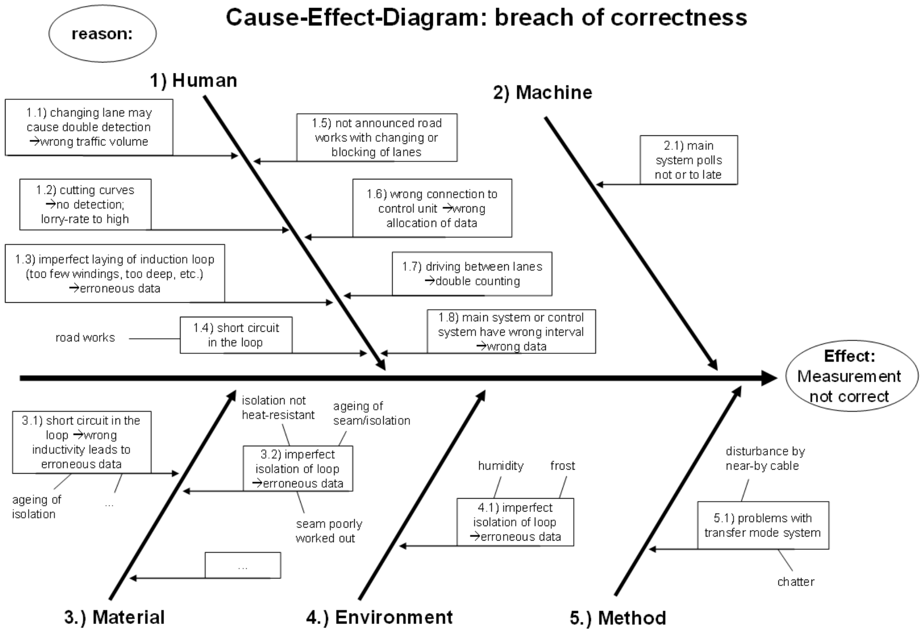


*Fig. 9: Example - CED for examination of an induction loop for correctness*

The method „Failure Mode and Effect Analysis“ (FMEA) was adapted for detailed examination and ranking of causes for deficiencies in the quality characteristics. Therefore the appraisal criterions for defining the Risk-Priority-Number had to be reworded.

By means of the activities in the Do-iT project it was possible to apply and verify the adapted methods within 3 examples of stationary traffic data acquisition systems run by project partners. On the basis of these results, provisions for individual quality assurance will be worked out and implemented, thus proofing the general benefit of the method.

## Analysis von accident hotspots

By using the developed method of the traffic situational analysis of the events of accidents the IAGB carried out an in-depth analysis of 31 accident hotspots in the region of Stuttgart, Esslingen, and Böblingen. As data basis all captured accidents from the police within the time periode

2003 to 2005 are used. So 610 accidents are available with 384 light casualties and 46 seriously injured persons. For each accident hotspot all relevant data, such as number of accidents, number injured persons, amount of physical damage, and personal injuries per year and on average, were collected.

Classical accident diagrams are prepared as well as additional diagrams, for instance, the distribution of accidents and cost within the different driving manoeuvres at the intersection to identify dangerous manoeuvres. Diagrams showing the risk of accidents take into account the accident severity and the traffic volume within the different manoeuvres (s. Fig. 10).

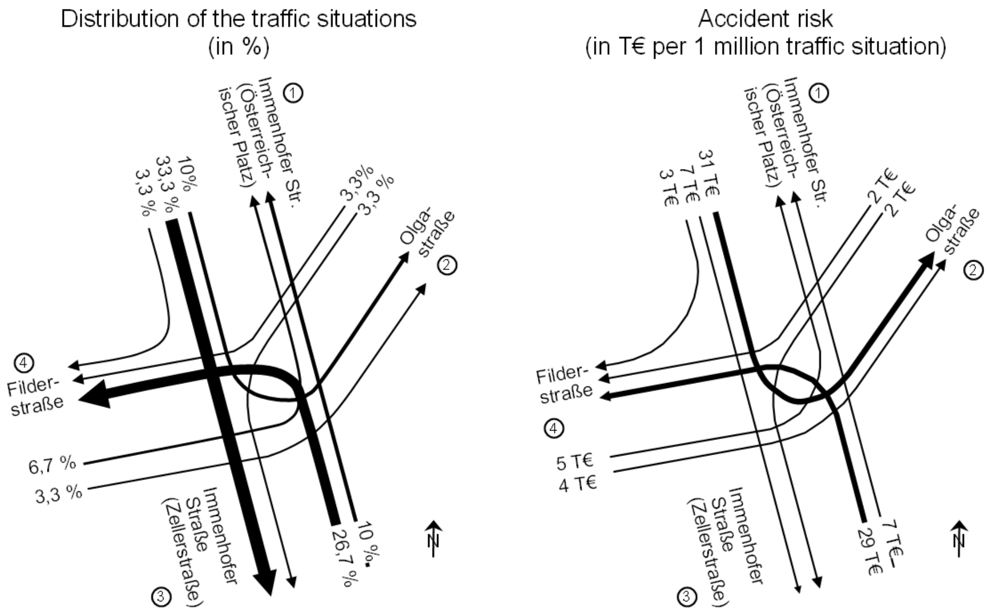


*Fig. 10: Accident diagramm of distribution of accidents and accident risk for intersection Immenhofer Str. / Olgastr. / Filderstr. in Stuttgart*

For a subset of the accident hotspots a detailed description of the topography and topology were prepared. In a specific data model all necessary data were captured and analysed by a GIS, and different thematic maps were produced (figure 11 and figure 12). As data sources the available data from public authorities were used if possible.

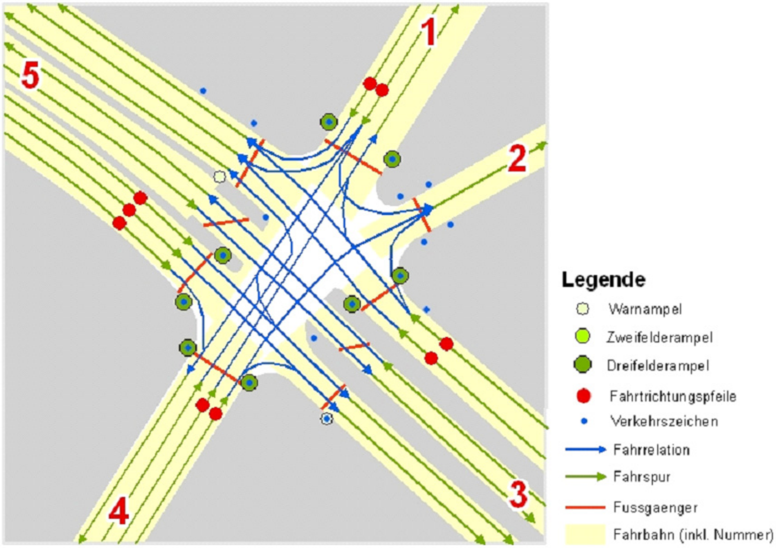


*Fig. 11: Outline map*

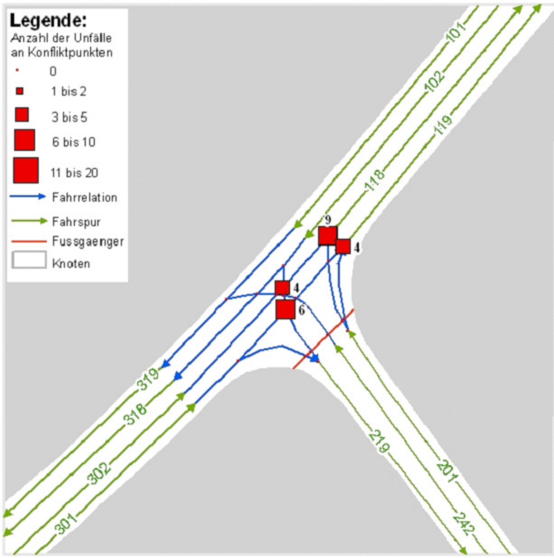


*Fig. 12: Distribution of accidents at points with crossing manoeuvres*

## Short descriptions of the projects

### Do-iT (Data optimisation for integrated Telematics)

Do-iT deals with the acquisition of traffic data using mobile phone data. The application of the so-called floating phone data (FPD) for traffic planning and traffic control is investigated. The project is funded by the German Federal Ministry of Economics and Technology (BMWi) within the research initiative „Verkehrsmanagement 2010"

Main activities of the IAGB are as follows:

- ▷ Capturing of anonymous raw data from the cellular phone network by so-called network probes installed within the network infrastructure of the provider.
- ▷ Using cellular radio positioning methods to determine the position of the mobile phones.
- ▷ Identification of active road users by means of cluster analysis, correlation methods and Fuzzy techniques.
- ▷ Generation of trajectories of the road users by map-aiding-methods.
- ▷ Provision of Floating Phone Data of the active road users as trajectories with a description of the path and the time.
- ▷ Integration of quality assurance measures and evaluation procedures within the data processes to deliver Floating Phone Data with an assured quality and a feasible quality description.

Project-website: www.vm2010.de/web/projekte/do-it.html

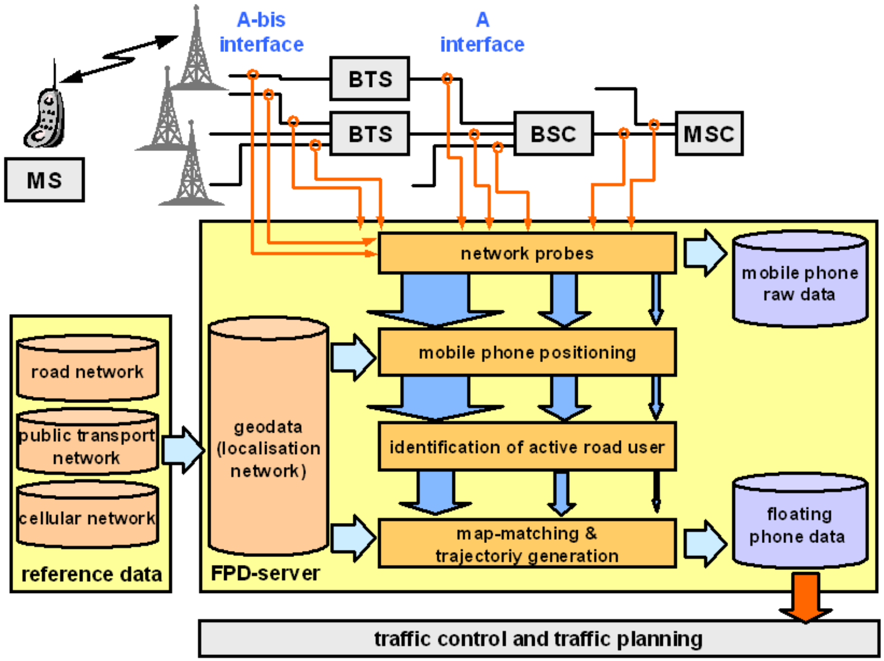


*Fig. 13: System architecture and information flow for generation of Floating Phone Data within the project Do-iT*

**GeoITCS**

The IAGB and the Institute for Railway and Transportation Engineering of University of Stuttgart work in co-operation with an industrial enterprise on the implementation of the results from the research project RUDY. Within the project the achieved findings from integration of geo-information into intermodal transport control systems (ITCS) shall be transferred into a saleable product. Following topics are of peculiar interest:

- ▷ A board-autonomous map-based location including control of all operational events such as passenger information, communication of deviations from timetable, priorisation at traffic lights.
- ▷ A central disposition of standard operation, in case of incidents, and public transport on demand.
- ▷ A tool for capturing and managing the necessary geo database.
- ▷ A planning tool for provision of geo-coded timetable and operation data.

### Analysis of the events of traffic and accident

Within different assignments by the automotive and supplying industry the institute setup a comprehensive accident data base in the region of Stuttgart East. By means of a developed microscopical accident analysis critical situations within the urban road traffic can be detected and the potential to reduce accidents by advanced driver assistance systems can be estimated. Following issues are focused:

- ▹ Description of the events of accidents by standardised traffic situations based on available accident data of the police.
- ▹ Investigation of risk indicators of standardised traffic situations.
- ▹ Analysing of characteristics possibly accountable for accidents by reasons of the topographical and topological formation of intersections.

## Activities of Prof. Dr.-Ing.Dr.sc.techn.h.c.Dr.h.c. Klaus W. Linkwitz in 2007

### 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 2007. The additional appertaining practical computer exercises were performed on windows-NT-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

Möhlenbrink, W., Schwieger, V.: Zur Prozessintegration der geodätischen Messtechnik. Allgemeine Vermessungsnachrichten, 2007.

Ramm, K., Schwieger, V.: Mobile Positioning for Traffic State Acquisition. Proceedings on 5th International Symposium on Mobile Mapping Technology, Padua, Italien, 28.-31.05.2007.

Schollmeyer, R. und Wiltschko, T.: Classification of public transport vehicles using cellular mobile radio data. Proceedings on 6th European Congress and Exhibition on Intelligent Transport Systems and Services. Aalborg, Denmark, 18-20 June 2007.

Schwieger, V.: Sensitivity Analysis as a General Tool for Model Optimisation - Examples for Trajectory Estimation. Journal of Applied Geodesy, Walter de Gruyter, Berlin - New York, Volume 1, Heft 1, 2007.

Schwieger, V.: Determination of Synthetic Covariance Matrices - an Application to GPS Monitoring Measurements. Proceedings on 15th European Signal Processing Conference, Poznan, Polen, 03.-07.09.2007.

Schwieger, V.: Positioning within the GSM Network. Proceedings on 6th FIG Regional Conference, San Jose, Costa Rica, 12.-15.11.2007.

Schwieger, V.: High-Sensitivity GNSS - the Low-Cost Future of GPS ? Proceedings on FIG Working Week 2007, Hongkong SAR, 13.-17.05. 2007.

Schwieger, V., Beetz, A.: Optimierung von Regelalgorithmen zur Baumaschinensteuerung am Beispiel eines Simulators. Beiträge zum 15. Internationalen Ingenieurvermessungskurs, Graz, Herbert Wichmann Verlag, Heidelberg, 17.20.04.2007.

Schwieger, V. Ramm, K., Czommer, R., Möhlenbrink, W.: Mobile Phone Positioning for Traffic State Acquisition. Journal of Applied Geodesy, Walter de Gruyter, Berlin - New York, 2007.

Tritschler, S. und Wiltschko, T.: Ein Ansatz zum bedarfsorientierten ÖPNV-Betrieb unter Verwendung kartenbasierter Ortungs- und Dispositionsverfahren. Beiträge zum DGON-Symposium POSNAV 2007. 6.-7. November 2007 in Madgeburg.

Wiltschko T., Schwieger, V., Möhlenbrink, W.: Zum Einsatz von Mobilfunkortungsverfahren zur Erfassung von Verkehrsdaten aktiver Verkehrsteilnehmer. Beiträge zum DGON-Symposium POSNAV 2007. 6.-7. November 2007 in Madgeburg.

Wiltschko. T., Schwieger, V., Möhlenbrink, W.: Acquisition of traffic state information by mobile phone positioning. Proceedings on 6th European Congress on Intelligent Transport Systems, Aalborg, Dänemark, 18.-20.06.2007.

Wiltschko, T. und Schollmeyer, R.: New approach of route-flexible and requested-oriented supplies in public transport. Proceedings on 6th European Congress and Exhibition on Intelligent Transport Systems and Services. Aalborg, Denmark, 18-20 June 2007.

Wiltschko, T., Schollmeyer, R., Tritschler, S. und Dobeschinsky, H.: Nutzung von Telematiklösungen für einen nachhaltigen Personennahverkehr in der Region. Tagungsband zu den 21. Verkehrswissenschaftlichen Tagen in Dresden, 24. und 25. September 2007.

## Doctorates

Gläser, A.: Modulares System zur Automatisierung hochgenauer geometrischer Positionierung und Bahnführung im Bauwesen.

## Diploma Theses

Mao, Feng: Evaluierung eines Low-Cost Multisenorsystems mittels Inertialmesstechnik und präzisem GPS

Baum, Marina: Optimierung von Messkonzepten für Tunnelmessungen unter Wirtschaftlichkeitsaspekten.

## Study works

Buhai, Adrian: Konvertierung und Erweiterung der Vermessungssoftware TOPBAU auf eine PDA-lauffähige Softwareumgebung.

Cao, Zhijie: Erstellung einer Karte zu einem historischen Campusführer.

Luo, Dan: Erfassung und Analyse von Fahrplanabweichungen ausgewählter ÖPNV-Angebote.

Mao, Junyu: Qualitätsanalyse aktuelle High-Sensitivity GPS-Empfänger.

Seiß, Thomas: Entwicklung und Erprobung eines echtzeitfähigen Verfahrens zur Krümmungsberechnung im Fahrzeug.

Vangerow, Philipp: Entwicklung eines Flottenmonitormoduls auf Basis des Open Source GIS-Frameworks OpenJUMP.

## Education

| | |
|---|---|
| Surveying I, II for Civil Engineers (Wiltscko, Laufer) | 3/1/2/0 |
| Surveying for Architects (Metzner) | 2/0/0/0 |
| Acquisition and Management of Planning Data (Metzner, Waese) | 2/1/1/0 |
| Geodetic Measurement Techniques I, II (Metzner, Wengert) | 4/2/0/0 |
| Statistics and Error Theory I, II (Schwieger, Metzner, Schollmeyer) | 2/2/0/0 |
| Basic Geodetic Field Work (Beetz, Wengert) | 5 days |
| Integrated Field Work (Schwieger, Laufer) | 10 days |
| Surveying (Metzner, Wengert) | 2/1/0/0 |

| | |
|---|---|
| Surveying Engineering IV (Schwieger, Czommer) | 2/1/0/0 |
| Surveying Engineering I, II, III (Schwieger, Beetz) | 6/3/0/0 |
| Multisensor Systems for Terrestrial Data Acquisition (Schwieger, Waese) | 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) (Wiltschko, Waese) | 1/1/0/0 |
| Thematic Cartography (Wiltschko, Waese) | 1/1/0/0 |
| Transport Telematics (Wiltschko, Czommer, Metzner) | 2/1/0/0 |
| Transport Telematics (in German) (Wiltschko, Czommer, Metzner) | 2/1/0/0 |
| Reorganisation of Rural Regions (Mayer) | 1/0/0/0 |
| Terrestrial Multisensor Data Acquisition (Schwieger, Waese) | 2/1/0/0 |
| Kinematic Measurements and Positioning (Schwieger, Beetz) | 2/1/0/0 |
| Data Management and Analysis (Wiltschko, Wengert) | $\frac{1}{2}$/$\frac{1}{2}$/0/0 |
| GIS Based Data Acquisition (Schwieger, Metzner) | 1/1/0/0 |

# Institute of Geodesy

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MUKHERJEE ARKA, Dr.-Ing. (until 30.9.)
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## Administrative/Technical Staff

HÖCK Margarete, Phys. T.A.
SCHLESINGER Ron, Dipl.-Ing. (FH)
VOLLMER Anita, Secretary

## Guests

VARGA P, Prof. Dr., Budapest/Hungary (20.1.-20.2.)
ZALETNYIK P, Budapest/Hungary (1.1.-28.2.)
KAKKURI J, Prof. Dr., Helsinki/Finland (15.3.-20.3.)
WANG J, Prof. Dr., Shanghai/China (1.8.-31.8.)
WU J, Prof. Dr., Shanghai/China (1.8.-31.8.)
ZOU R, Wuhan/China (since 4.9.)
ARDALAN A, Prof. Dr., Tehran/Iran (since 18.9.)
HASHEMI-FARAHANI H, Tehran/Iran (since 18.9.)
ABBAS YA, Prof. Dr., Assiut/Egypt (16.7.-15.10.)
ISSAWY E, Prof. Dr., Cairo/Egypt (23.7.-19.10.)
KARIMI R, Tehran/Iran (since 20.10.)
JIANG W, Prof. Dr., Wuhan/China (1.3.-20.12.)
HU C, Prof. Dr., Shanghai/China (1.3.-26.12.)
ABDEL-MONEM M, Dr., Cairo/Egypt (3.12.-31.12.)

## Additional Lecturers

ENGELS J, PD Dr.-Ing. habil., Stuttgart
HAUG G, Dr.-Ing., Stadtplanungs- und Stadtmessungsamt, Esslingen/Neckar
SCHÖNHERR H, Präsident Dipl.-Ing., Landesvermessungsamt Baden-Württemberg, Stuttgart

## Honorary Professors

HINTZSCHE M, Prof. Dipl.-Ing., Fellbach

# Research

## GRACE-derived ice-mass variations

Since 2002, the GRACE (Gravity Recovery and Climate Experiment) twin-satellite mission has been providing time-variable gravity field information from space. The data enable spatiotemporal mass changes to be monitored, providing important input to various (geo)sciences, most notably in the context of global climate and sea-level change. The five years of GRACE data now available provide the opportunity to determine reliable secular trends of mass changes. Neglecting the strong global isostatic adjustment (GIA) signals over the Canadian shield and Fennoscandia, the major secular changes observed by GRACE are located in the polar regions, more precisely over Greenland, Alaska and Antarctica.

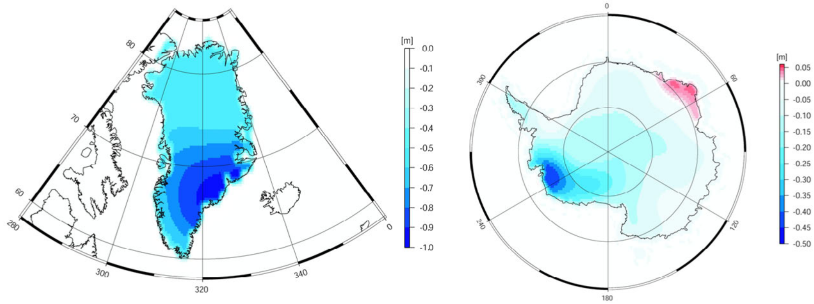

*Figure 1: Total equivalent water thickness variations from April 2002 to March 2007 over Greenland (left) and Antarctica (right)*

Analyzing five whole years of time-variable gravity field observations (April 2002 to March 2007) reveals ice-mass loss estimates in the ice-covered areas of the Earth to be considerably larger than given by previous studies. This is mainly due to properly taking leakage effects into account. Basically, spectral leakage appears 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 the effect is referred to as spatial leakage, i.e., the observed gravitational-change signal is not necessarily concentrated directly over the area of mass variation, but also leaks to the surrounding region. In terms of GRACE-derived (surface) mass-changes, spectral leakage occurs due to both the restricted spectral resolution of gravitational field estimates and spatial averaging.

Taking the effect of spectral leakage in the GRACE data into account, the total cryospheric volume change becomes $-749$km$^3$yr$^{-1}$ with the separation among Greenland, Alaska and Antarctica being $-308$km$^3$yr$^{-1}$, $-127$km$^3$yr$^{-1}$ and $314$km$^3$yr$^{-1}$ respectively. However, the value for Antarctica is highly subject to GIA modeling errors. Figure 1 highlights the magnitudes and geometries of secular ice-mass changes over Greenland and Antarctica from April 2002 to March 2007, expressed in equivalent water thickness variations.

## GRACE-derived global sea-level change

Ice-melting in the cryosphere, such as currently observed by GRACE (Gravity Recovery and Climate Experiment), directly impacts global sea-level change assuming that the melt water mostly drains into the world's oceans. Instead of resulting in an often-assumed globally uniform sea-level change, the distribution of melt water is spatially variable, which is due to the gravitational and elastic feedback effects caused by the changing surface mass geometries and loads.

The total global ice-volume decline over the five-year period from April 2002 to March 2007 is estimated to be -3745km (cf. the section on „GRACE-derived ice-mass variations"), which equates to a global average (or uniform) sea-level rise of 1.90mm/yr with individual contributions of 0.78mm/yr (41%) for Greenland, 0.80mm/yr (42%) for Antarctica, and 0.32mm/yr (17%) for Alaska. However, deglaciation-induced secular sea-level changes strongly differ from place to place, ranging from -1.8mm/yr to +2.2mm/yr, cf. Figure 2.

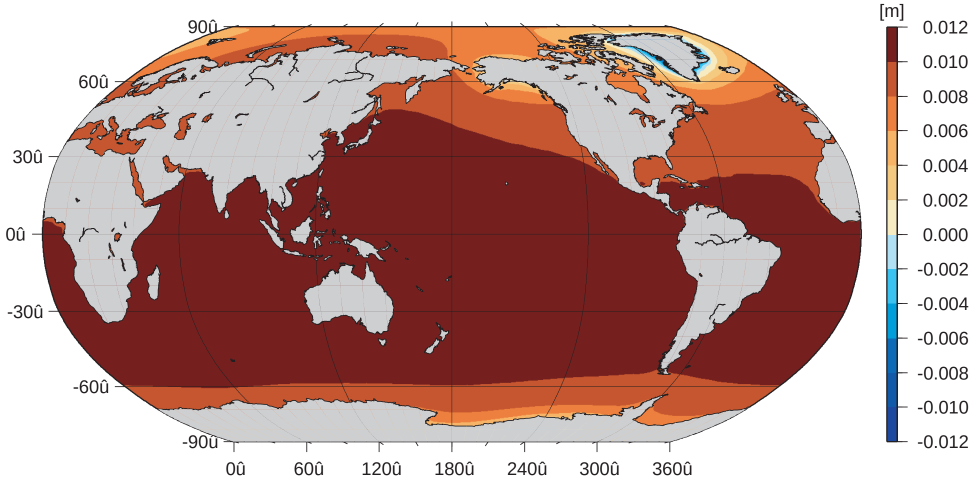


*Figure 2: Global patterns in sea-level change from combined Greenland, Alaska and Antarctica ice-change geometry from April 2002 to March 2007*

In offshore regions near land ice-mass loss, sea-level fall can even be observed. With increasing distance from the deglaciating area, sea-level rises. Hence, regions farthest from the deglaciation area are affected more by sea-level rise. Vice versa, ice accumulation causes nearby sea level rise, but sea-level fall in distant areas. Since Greenland ice melting mainly causes sea-level rise in the Southern Hemisphere and Antarctic ice-mass change dominates sea-level rise in the Northern Hemisphere, their combined sea-level change pattern (Figure 2) is close to the uniform value for vast areas of the world's oceans. However, most regions above a Northern latitude of 30° and below a Southern latitude of 60° are affected less than the uniform change. Therefore, the maximum contemporary sea-level rise is present mostly along a belt covering the tropics and subtropics.

## 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 $\beta/\alpha$-repeat orbits ($\beta$ revolutions in $\alpha$ nodal days) to reduce the problem of time-variable ground tracks. The space-time sampling of a satellite-mission is mainly driven by two sampling theorems (Figure 3): (i) the „Nyquist-theorem“ $\beta \leq 2$L (or 2M), which determines the spatial resolution (maximum degree/order L/M) and (ii) the „Heisenberg-theorem“ $D_{Space}$ x $D_{Time}$ = $2\pi\alpha/\beta = 2\pi T_{rev}$ = 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 3), 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 ($\Delta$t-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 $\Delta$t-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 4 shows various 31/2-repeat-orbits in the different modes ($\Delta$t-shift, $\Delta\lambda$-shift, $\Delta\Omega$-shift (on same/interleaved ground track)): orbit 1 (origin), orbit 2 ($\Delta$t-shift), orbit 3 (interleaved, $\Delta\lambda$-shift), orbit 4 (interleaved, $\Delta\lambda$- and $\Delta$t-shift), orbit 5 ($\Delta\Omega$-shift), orbit 6 ($\Delta\Omega$- and $\Delta$t-shift), orbit 7 (interleaved, $\Delta\Omega$-shift), orbit 8 (interleaved, $\Delta\Omega$- and $\Delta$t-shift).

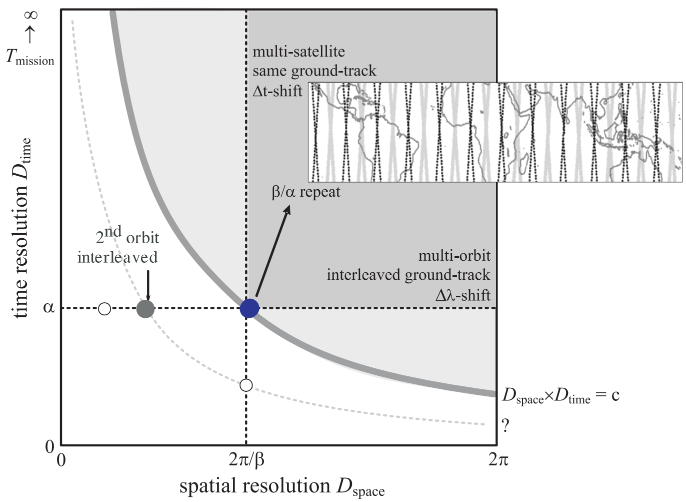


*Figure 3: Multi satellite and multi-orbit concepts: relation between spatial and time resolution*

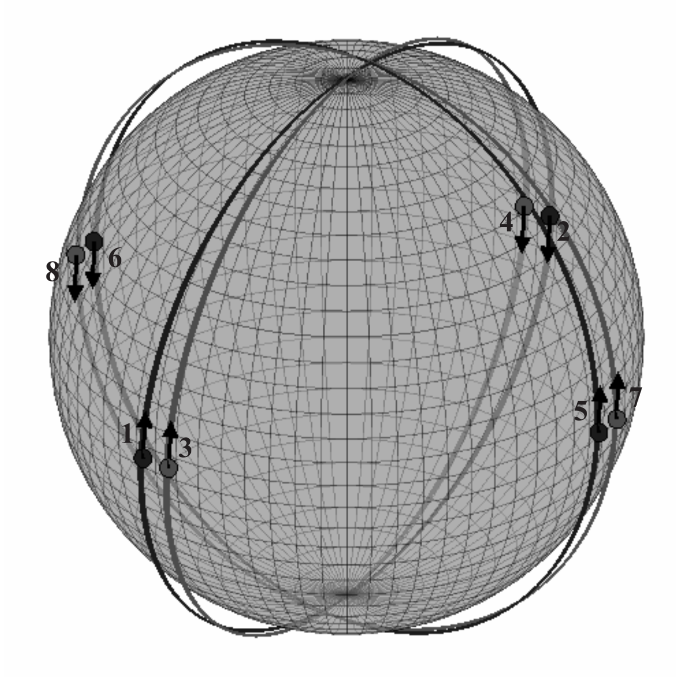


*Figure 4: Different 31/2-repeat-orbits on same (black) and interleaved (grey) ground tracks*

**Assessment of different approaches for gravity recovery from kinematic CHAMP orbits**

The classical method for gravity recovery from GPS-tracked satellite orbits - the dynamical or variational approach - directly uses the GPS-pseudoranges and carrier-phases as observations. However, the link between these GPS-observations and the gravity field parameters is non-linear, which leads to an iterative solution of the systems of equations. Additionally, the so-called variational equations and the orbit have to be integrated in each iteration-step. This means a large computational effort. As a further problem of this method, long-wavelength errors of tidal models and accelerometer-measurements may sum up due to the process of integration. To overcome these problems, alternative approaches have been studied, which can be classified as two-step-methods. Since kinematic orbits can be determined nowadays with a very high absolute accuracy of 1-2cm, in the first step the kinematic orbits of the satellite are determined from the GPS-tracking-data. In the second step, the kinematic orbits can be analyzed by various methods, which form a linear relation between the gravity field parameters and the orbit (or derived pseudo-observations as accelerations or potential). Such linear methods are the acceleration approach (for point wise and average accelerations), the boundary value problem for short arcs and the energy balance approach. These 4 methods have been tested for a simulated 1-month CHAMP kinematic orbit as weighted and unweighted estimations. Besides white orbit errors also correlated orbit errors have been chosen as simulation-scenario since kinematic orbit errors show a clear correlated behavior ($\rho$ = 0.93, correlation length of 25 minutes), as shown by D. Svehla (IAPG/TU Munich). The results for correlated orbit errors are visualized in Figure 5. The energy balance approach leads to worse results than the other methods (factor 1.5-2), which might be caused by the lower redundancy (factor $1/\sqrt{3}$) of this approach (energy is a scalar). The other approaches result in a similar accuracy, provided that data-weighting was applied for the boundary value problem. The influence of data-weighting on the acceleration approaches (as well as on the energy-balance approach) can be considered as marginal. Finally, the acceleration approaches are suggested, since (i) they produce the best results (together with the weighted boundary value problem), (ii) they are easy to implement, (iii) they need the shortest computation time (no integration necessary compared to the other methods), (iv) correlations can be neglected in data-weighting and (v) accelerometer data can be neglected (for the other approaches this is uncertain since the accelerometer-data has to be integrated).

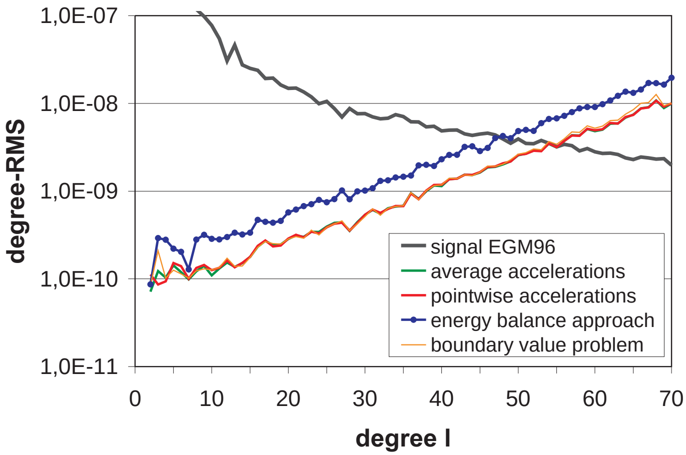


*Figure 5: degree-RMS of the different approaches*

## GOCE Gravity Field Recovery

Due for launch in May 2008, 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“.

The sensors onboard the GOCE satellite will collect hundreds of millions observations during the 12 month mission period. The observations are used to determine the Earth's gravity field, which will be described by tens of thousands of parameters. Global gravity field modeling is typically based on spherical harmonic expansion of the potential function. Legendre functions, and thus surface spherical harmonics, are defined globally and satisfy the orthogonality relations on the sphere. However, due to the sun-synchronous orbit of the GOCE satellite, the sampling does not cover a double polar cap, each with a radius of about six degrees. There exist numerous ways to approach this problem. We have analyzed 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 two other solutions are developed with (1) incorporating additional measurements over the polar regions and (2) introducing prior knowledge about the gravity field, which is known as regularization.

The external observations and prior information, which will have to be supplied in order to „fill" 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 forthcoming Earth Gravity Model 2007 (EGM07) developed by the American National Geospatial-Intelligence Agency (NGA), which is a modern model up to 2160 degrees and order combined with CHAMP / GRACE and terrestrial data. The terrestrial record includes the results from NGA Arctic Gravity Project. For these combinations possible approaches have been studied, such as mixed estimator with prior information as stochastic linear restrictions, and the light constraint solutions.

For the regularization the $\alpha$-Weighted BLE (Best Linear Estimation) is applied, a uniform Tykhonov-Phillips regularization. In this context, the optimal determination of the regularization parameter $\alpha$ is of prime importance. It balances the variance and the squared bias, cf. Figure 6. A method has been developed in order to compute the optimal regularization parameter (or weight factor) $\alpha$ by A-optimal design. The regularization matrix, i.e. the prior knowledge, may be chosen to the Gramian matrix, Kaula matrix or a priori information in the low-order domain.

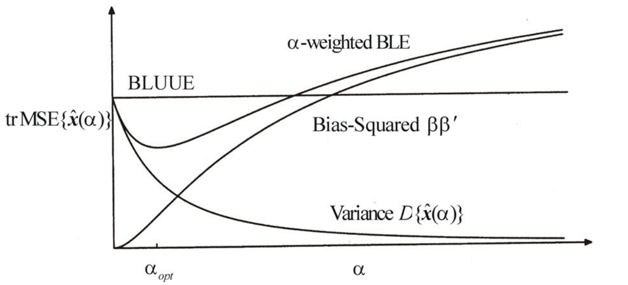


*Figure 6: Relationship between variance, squared bias and weight factor $\alpha$. The variance term decreases as $\alpha$ increases while squared bias increases with $\alpha$.*

**Modeling of regional gravity fields by Slepian- and radial base functions**

The representation of the gravity field in a truncated series of spherical harmonics cannot model all the local details. To derive a regional solution, the field model can be separated into a global representation and a residual signal. The residual signal itself is calculated by subtracting the global representation in terms of spherical harmonics from the observations. Besides some numerical effects, the error of the coefficients, and the noise of the measurements, the residual signal mainly contains the local details.

To extract these details, the signal is approximated by a set of localizing base functions. In the current research two different sets of base functions are investigated for the analysis. The symmetric system of the radial base functions and the set of the orthogonal Slepian functions.

The radial base functions are common practice to model regional fields. Each base function is mainly dependent on the spherical distance to their centre point, but also on a shape parameter and a scale factor. In many applications the shape parameter is defined e.g. by Kaula's rule and a fixed grid of base functions is used, to estimate the scale factors. For a good resolution a narrow grid is necessary, so that the problem might become ill-posed and demands regularization. In order to avoid this, the number of unknown base functions has to be reduced. This can be done by searching the optimal positions of a few base functions in the data instead of using a fixed grid. Different searching algorithms are investigated, but they all have to deal with a non linear problem and a high closeness of the parameters.

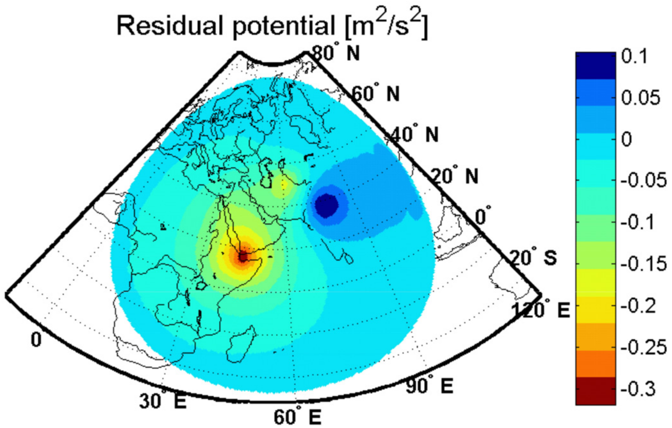


*Figure 7: Residual potential of 6 buried masses, which cause a maximum signal of 0.3 $m^2/s^2$ in the potential values*

On the other hand Slepian functions form an orthogonal set of base function which are band limited and optimally concentrated within any arbitrarily shaped area of interest. Thus, it is an alternative but powerful tool for local gravity field recovery. The Slepian functions are found by solving an algebraic eigenvalue problem in the spectral domain which ensures the orthogonality of these base functions. The eigenvalues itself are a measure for the spatiospectral concentration. Using the eigenvectors, a direct transformation of spherical harmonic to Slepian coefficients and vice-versa is possible. A spatial analysis using least-squares with the Slepians as base functions yields a set of Slepian coefficients which models the area of interest.

To test this approach a CHAMP-like scenario was chosen. The global field was represented by EGM96 and the residual field was generated by a small number of buried masses in the region of interest. Using the energy-balance technique synthetic potential observations are created along CHAMP-arcs across the region. By subtracting the potential values of the reference field at the same positions, the residual signal is created, which contains the information about the buried masses.

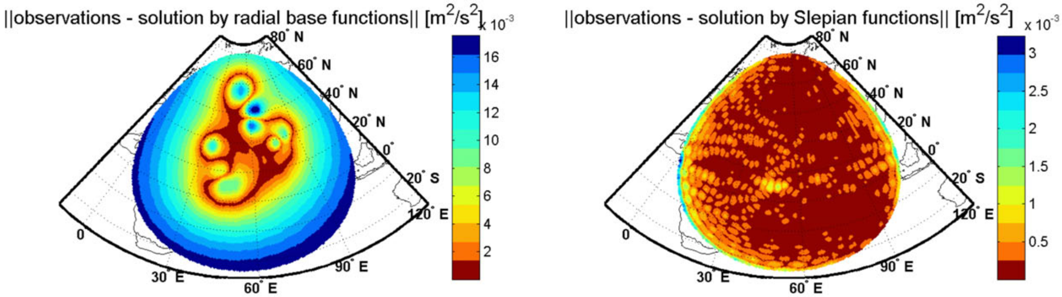


*Figure 8: Modulus of the differences between the residual signal and the solution of radial base and Slepian functions*

The residual fields are analyzed by the Slepian- and the radial bases functions and the solutions are compared to the simulated potential of the buried masses. In most of the cases the radial base functions are able to approximate the observations up to 90 % of the signal, but the resolutions of the Slepian functions are usually better by a factor of 2-10. In the example, the 6 buried masses are modeled by 10 radial base functions with an RMS of $2.1\text{m}^2/\text{s}^2$, and by 888 Slepian functions and an RMS of $0.057\text{m}^2/\text{s}^2$.

The resolutions of the Slepian functions can be achieved by solving a linear adjustment, whereas the radial base functions cause a non linear problem with the necessity of initial values and iterations. On the other hand, the searching algorithms of the radial base functions reduce the number of base functions by a factor of 10 as compared to the Slepian functions and they can easily be interpreted as extra masses in the region. The calculating time decreases from 2-2.5 hours in case of the Slepian functions to 5-10 minutes for the radial base functions.

**Gravity field recovery in high-latitude areas by Slepian functions**

Monthly global gravity field solutions from CHAMP data are influenced by the ground track pattern as a global spherical harmonic analysis is limited by the equatorial data spacing. Further, the ground track changes constantly since the satellite is slowly decaying. Due to the near polar orbit the data density is higher in polar areas. Obviously, the analysis using a set of global base functions is suboptimal in this case and a local gravity field determination can make use of the full potential of the measurements in these areas.

Slepian functions form an orthogonal set of base function which are band limited and optimally concentrated within any arbitrarily shaped area of interest. It is an alternative but powerful tool for local gravity field recovery. The Slepian functions are found by solving an algebraic eigenvalue problem in the spectral domain which ensures the orthogonality of these base functions. The eigenvalues itself are a measure for the spatiospectral concentration. Using the eigenvectors, a direct transformation of spherical harmonic to Slepian coefficients and vice-versa is possible. A spatial analysis using least-squares with the Slepians as base functions yields a set of coefficients which models the area of interest. Practically, the method incorporates a classical remove-restore technique. Long wavelength features are removed using a global spherical harmonic solution. The residual field is then analyzed with the Slepian functions and the long-wavelength features are added back to the coefficients. By this method an improvement in high-latitude areas can be achieved. The improvement depends on the ground track density and the quality of the a priori long-wavelength field. In January 2004 the ground track was dense and consequently the spherical harmonic solution is of high quality but nevertheless an improvement of up to 5$m^2/s^2$ in potential values or 50cm in geoid height is achieved.

In June 2003 the ground track is sparse and the spherical harmonic solution is comparably poor. Due to the convergence of the orbit towards the pole the data density in high-latitude areas is comparable to the one of January 2004. Consequently, an improvement of 16.45$m^2/s^2$ or 1.64m in geoid height is achievable.

Future work will focus primarily on the refinement of the procedure. For example, the procedure of determining the Slepian base functions is numerically cumbersome. Using just spherical caps as the outline of the area of interest analytical formulas for the determination are available and should yield more stable equations systems with less computational effort. At the same time, the research methodology can be directly transferred to the more accurate GRACE mission. The orbit configuration of the GRACE mission is similar to the CHAMP scenario and thus it is expected that this methodology will have an equivalent impact.

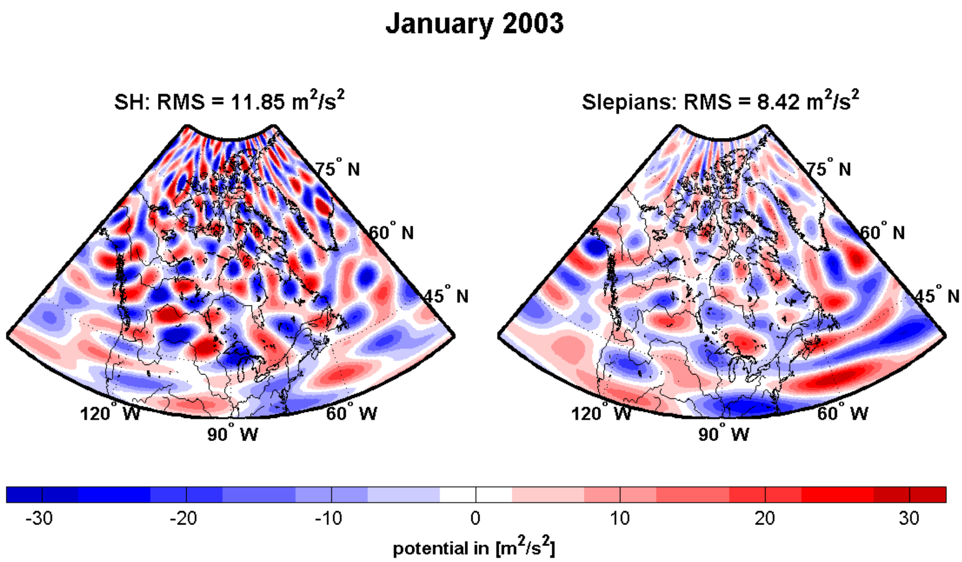


*Figure 9: Spherical harmonic solution (left) and Slepian solution (right) w.r.t. GGM02s in January 2003*

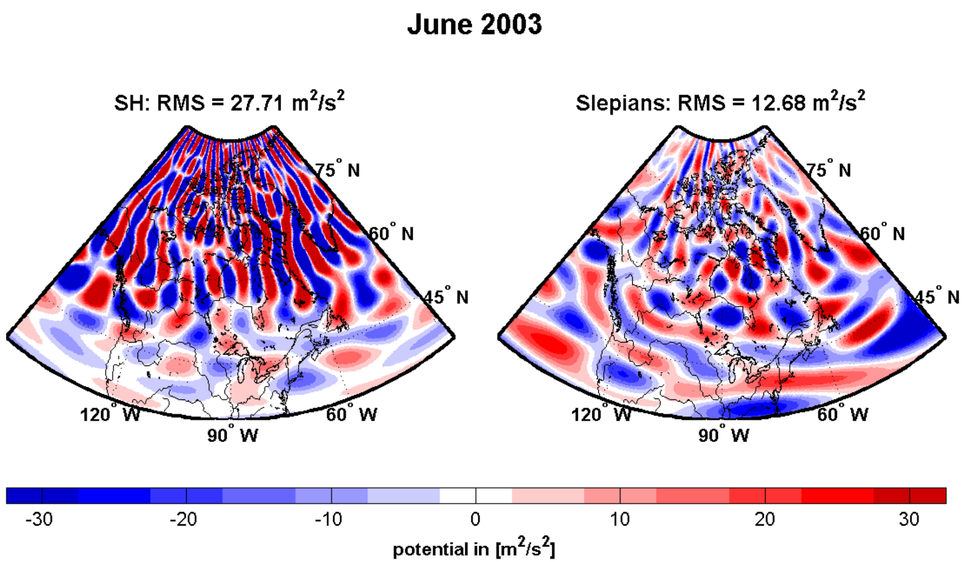


*Figure 10: Spherical harmonic solution (left) and Slepian solution (right) w.r.t. GGM02s in June 2003*

**GRACE Hydrology: Direct Water Balance**

GRACE gravity-field mission provides monthly solutions of the gravity-field from which monthly mass deviations can be derived. On land, these mass deviations are assumed to be representative of water storage changes. Water storage change is an important component in the global water balance equation, and hence, the measurements from GRACE can, in principle, be directly used in the water balance equation. This is the primary objective of the Direct Water Balance (DWB) project, funded by the DFG Special Priority Programme „Mass transport and mass distribution in the Earth system".

Precipitation - Actual evapotranspiration - Runoff - Storage change = 0

The storage change measurements from GRACE can only be applied to large catchments, because of limited spatial resolution. However, this can be done only after validating the GRACE data with available in-situ data. GRACE data is also contaminated with large amounts of noise as the spatial resolving limits are approached, i.e. at shorter wavelengths. This noise is large enough to overshadow the signal from the large-scale features, which result in wiggly north-south stripes (left panel of Figure 11). These stripes exemplify that the error structure of the data is anisotropic.

In order to reduce the noise from shorter wavelengths, GRACE data were filtered and then validated. A number of filters have been designed for this purpose: Gaussian, Hann, Hamming, Non-isotropic, Decorrelation, and Wiener-type filters. Due to the anisotropic nature of the noise in GRACE signal, filters imbibing anisotropy perform better than the isotropic filters. In addition to anisotropy, filters that can also use the stochastic information associated with the data are far more effective in filtering noise, because stochastic information clarifies what is noise and what is signal to a certain extent. With this insight Wiener-type filters, isotropic and anisotropic, were designed as they utilize the stochastic information that are provided with the data. However, it should also be noted that the formal/calibrated noise provided with GRACE data do not completely describe the noise present in the spherical harmonic coefficients. Although filtering reduces noise in the shorter wavelengths, it also reduces the signal content in the longer wavelengths. An example of such a reduction is the change in the range of the mass deviation estimates by an order of two in Figure 11.

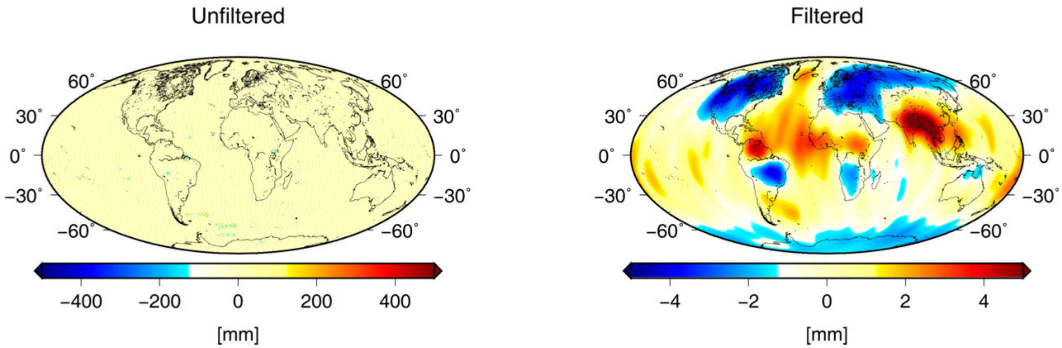


*Figure 11: Effect of filtering on the GRACE mass deviation estimates. Without filtering only stripe-like features are seen*

The amount of signal reduction depends entirely on the filter used, thus producing a biased estimate every time a filter is used. For example, the time series of storage changes derived from GRACE for Amazon and Ganges catchments show the bias in using different filters, depicted in Figure 12. Therefore, care has to be exercised in validating the filtered GRACE data, which demands further analysis of filters.

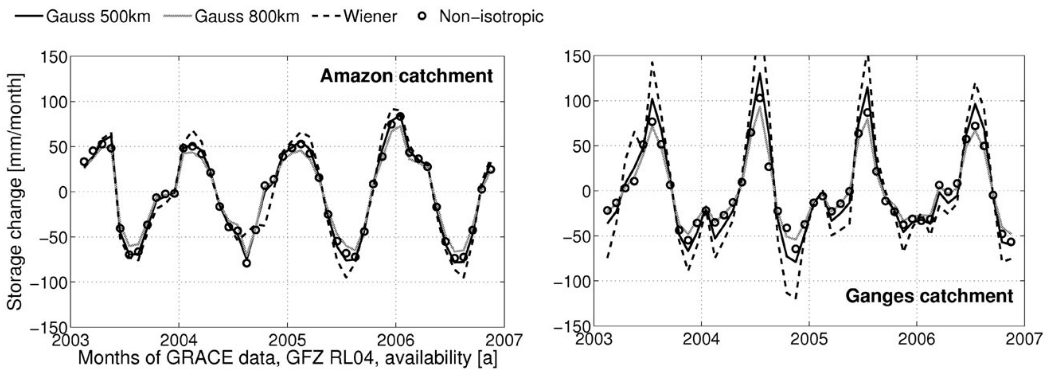


*Figure 12: Amazon and Ganges catchments show significant variations within the time series generated using different filters*

**Survey of vertical gravity gradients in Baden-Württemberg and Bavaria for GOCE-GRAND II project**

For the GOCE GRAND II validation project the Bundesamt für Kartographie und Geodäsie (BKG) measured new gravity data sets of existing gravity points all over Germany. For 14 of these observation points in Baden-Württemberg and Bavaria the Institute of Geodesy supported the BKG in the gradient measurements. The points were surveyed with the absolute gravimeter Micro-g A10 of the BKG. The sensor height of the A10 is approximately 70cm. To bring down the absolute gravity value to the benchmark information about the accurate local gravity gradient is required. This is one field in the range of applications of a gravimeter like the Scintrex CG-5.

All measurements were accomplished within 3 long survey days. Planning the measurements was done on basis of the official drafts of the survey offices, new snapshots made during the preceding absolute measurements and standard mapping-and-routing services available on the web. Compared to the drafts the up to date photos were the best help on site to find the benchmarks easily. It took 2 sometimes 3 hours to reach each of the widespread points in the field. This was mostly dependent on traffic situation and transport connection/accessibility between the points. Measuring a single gradient took around 45 minutes.

The gradient was surveyed with a special tripod, made by the BKG. Each of the 2 levels of the tripod can be leveled independently. So it was possible to „jump" between the 2 levels to take 3 observations per level fast and precise. One observation was averaged out of 3 readings which took 45 seconds. These data were analyzed, drift corrected and checked for outliers (Grubbs algorithm). A plot (Figure 15) of the measurement data verified the numerical output of the gravity gradient and its accuracy.

With a normal observed accuracy of $\sigma_{\Delta g}$ = 7$\mu$Gal for a gravity difference (no wind, solid ground) a value of $\sigma$ = 9$\mu$Gal/m for the gradient could be achieved. Here a tripod height of $\Delta h \approx$ 0.8m and a measurement accuracy of $\sigma_{\Delta h}$ = 3mm was assumed. Accuracy of the gradient:

$$\sigma^2 = \Delta h^{-2}\sigma^2_{\Delta g} + (\Delta g/\Delta h^2)^2\sigma^2_{\Delta h}$$

As seen in the error propagation formula, the influence of the difference in height is about 1$\mu$Gal/m on the gradient. On the other hand the gradient accuracy is directly dependent on the accuracy of the gravity measurements. In theory it would be possible to enlarge $\Delta h$ to increase gradient accuracy. Because the gradient decreases with height above ground, it is not done in practice.

Figure 13: Tripod of BKG with CG-5 in the upper level

Figure 14: Measurement at Buchenberg

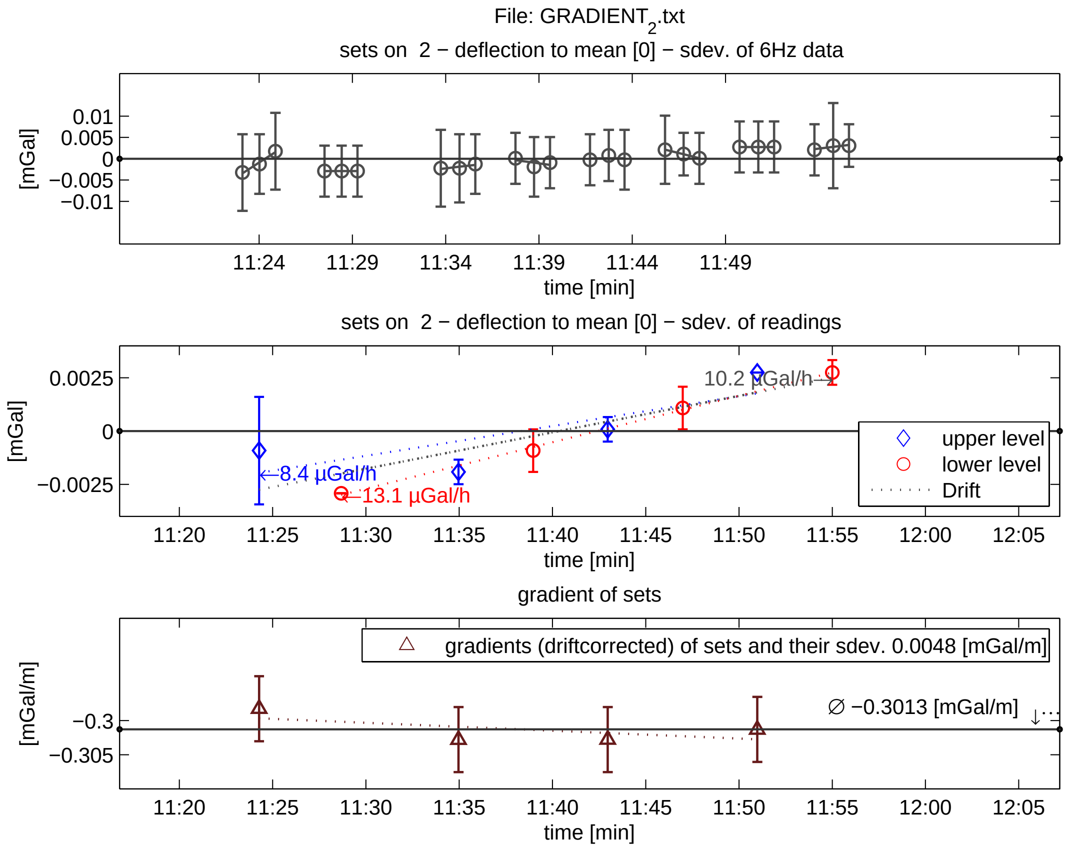


*Figure 15: Plot of gradient*

**Statistical property of the GPS carrier phase observables**

Although GNSS carrier phase measurements are the basic observables for high accuracy GPS Geodesy and Navigation their statistical properties have not yet been studied in detail. Until now they are applied more or less under the assumption of having a Gauss-Laplace normal distribution. Ever since von Mises (1918) introduced the von Mises normal distribution on the circle, its importance has not been recognized by the data analysts. Actually von Mises developed his normal distribution for a circular (directional, angular) random variable by investigating the distribution of the fractional parts of atomic weights, which is just appropriate to the GPS carrier phase observables, the measurements of the fractional phase. Here the statistical properties of the GNSS DD carrier phase observations have been investigated with their DD residuals from the adjustment of the mixed linear model. In order to avoid possible systematic errors and random effects from the GPS receivers and the atmosphere together with multi-path effects relative short baseline (2 - 3 km) GPS real data and even zero-baseline data have been examined. In detail the main points can be summarized as follows:

The statistical property of the fractional phase measurements of the GPS double difference carrier phase is validated as von Mises distribution by applying series analyses with the Test of Uniformity, Test of Goodness-of Fit and Tests on von Mises distributions, see Figure 16

- ▷ The classical testing theory based on the assumption of Gauss-Laplace normal distribution (such as,$\chi^2$-test, F-test and related ratio tests) can not be simply applied within the GPS data analysis since the GPS carrier phase observables are not Gauss-Laplace normally distributed anymore

- ▷ The proper hypothesis tests based on the von Mises normal distribution should be further studied and applied in GNSS carrier phase data analysis.

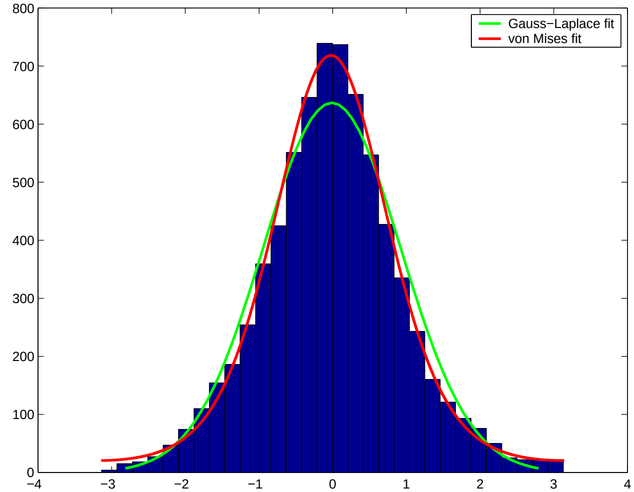


*Figure 16: Linear histogram of 7198 L1 double difference phase observables with von Mises and Gauss-Laplace fits*

The fundamental recognition of the statistical properties of the von Mises (circular) normal distribution of GPS carrier phase observables, and the related hypothesis tests about the von Mises distribution are two main results of this study, which will not only substantially improve the theoretical background and application reality of GPS geodesy and navigation, but also be significant to the forthcoming Galileo, Europe's new civilian Global Navigation Satellite System (GNSS).

## Theses

### Doctoral Theses

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

BAUR O: The invariants representation in satellite gradiometry: theoretical considerations and numerical realization in the framework of the case study GOCE

MOGHTASED-AZAR K: Surface deformation analysis of dense GPS networks based on intrinsic geometry: deterministic and stochastic aspects

WEIGELT M: Global and Local Gravity Field Recovery from Satellite-to-Satellite Tracking

### Diploma Theses

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

DAUBRAWA J: Orbit Perturbations induced by Ocean Tides

MOGHTASED-AZAR K: Surface deformation analysis of GPS dense networks based on intrinsic approach

### Study Theses

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

DAUBRAWA J: Modelling of Stationary Processes for the Analysis of Residuals

DENG Z: Sphärische Slepian-Funktionen

GUO R: Systematical Analysis of the Transformation Procedures in Baden-Württemberg with Least Squares and Total Least Squares methods

LERKE O: GRACE-Eismassenbilanz

## Publications

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

### Refereed Journal Publications

BAUR O, G AUSTEN and J KUSCHE: Efficient GOCE satellite gravity field recovery based on LSQR. Journal of Geodesy, DOI 10.1007/s00190-007-0171-z

BAUR O, N SNEEUW and E GRAFAREND: Methodology and use of tensor invariants for satellite gravity recovery. Journal of Geodesy, DOI 10.1007/s00190-007-0178-5

CAI J and E GRAFAREND: Statistical analysis of geodetic deformation (strain rate) derived from the space geodetic measurements of BIFROST Project in Fennoscandia. Journal of Geodynamics 43 (2007) 214-238

CAI J and E GRAFAREND: Statistical analysis of the eigenspace components of the two-dimensional, symmetric rank-two strain rate tensor derived from the space geodetic measurements (ITRF92-ITRF2000 data sets) in central Mediterranean and Western Europe. Geophysical Journal International 168 (2007) 449-472, DOI 10.1111/j.1365-246X.2006.0315.x

CAI J, J WANG, J WU, C HU, E GRAFAREND and J CHEN: Horizontal deformation rate analysis based on multi-epoch GPS measurements in Shanghai. Journal of Surveying Engineering, accepted, 2007

FLEMING K, Z MARTINEC and D WOLF: Glacial-isostatic adjustment and the viscosity structure underlying Vatnajökull. Pure Appl. Geophys. 164 (2007) 751-768, DOI 10.1007/s00024-007-0187-6

HAGEDOORN J, D WOLF, and Z MARTINEC: An estimate of global mean sea-level rise inferred from tide-gauge measurements using glacial-isostatic models consistent with the relative sea-level record. Pure Appl. Geophys. 164 (2007) 791-818, DOI 10.1007/s00024-007-0186-7

KLEMANN V and D WOLF: Using fuzzy logic for the analysis of sea-level indicators with respect to glacial-isostatic adjustment: an application to the Richmond-Gulf region, Hudson Bay. Pure Appl. Geophys. 164 (2007) 683-696, DOI 10.1007/s00024-007-0191-x

PALÁNCZ B, J AWANGE and E GRAFAREND: Computer algebra solution of the GPS N-points problem. GPS Solutions 11 (2007) 295-299

SNEEUW N and J KUSCHE: Preface. Special issue: Satellite Gravimetry and Inverse Problems. Journal of Geodesy 81 (2007) 1-3

WOLF D and J FERNANDEZ: Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change. Pure Appl. Geophys. 164 (2007) 633-635, DOI 10.1007/s00024-007-0195-6

XU C, M WEIGELT, M SIDERIS and N SNEEUW: Spaceborne Gravimetry and Gravity Field Recovery. Submitted to Canadian Aeronautics and Space Journal, Canadian Aeronautics and Space Institute (CASI), accepted

**Other Refereed Contributions**

AUSTEN G and W KELLER: On an ellipsoidal approach to the singularity-free gravity space theory. In: Xu P, J Liu and A Dermanis (Eds., 2007): Proc. IAG Symp. 132 „VI Hotine-Marussi Symp. on Theoretical and Computational Geodesy“, Wuhan, China, 29.5.-2.6.2006, Springer, Berlin, Heidelberg

CAI J, C HU and E GRAFAREND: The Optimal Regularization Method and its Application in GNSS Rapid Static Positioning. Proc. ION GNSS 2007 Meeting 20th Int. Technical Meeting of the Satellite Division, 25.-28.9.2007, Fort Worth, TX, pp. 299-305, 2007

CAI J, C HU, E GRAFAREND and J WANG: The uniform Tykhonov-Phillips regularization ($\alpha$-weighted S-homBLE) and its application in GPS rapid static positioning in Fennoscandia. In: Xu P, J Liu and A Dermanis (Eds., 2007): Proc. IAG Symp. 132 „VI Hotine-Marussi Symp. on Theoretical and Computational Geodesy“, Wuhan, China, 29.5.-2.6.2006, pp. 221-229, Springer, Berlin, Heidelberg

CAI J, E GRAFAREND and C HU: The Statistical Property of the GNSS Carrier Phase Observations and its Effects on the Hypothesis Testing of the Related Estimators. Proc. ION GNSS 2007 Meeting 20th Int. Technical Meeting of the Satellite Division, 25.-28.9.2007, Fort Worth, TX, pp. 331-338, 2007

CAI J, E KOIVULA, E 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., 2007): Proc. IAG Symposia 132 „VI Hotine-Marussi Symp. on Theoretical and Computational Geodesy“, Wuhan, China, 29.5.-2.6.2006, pp. 79-87, Springer, Berlin, Heidelberg

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., 2007): Proc. IAG Symp. 132 „VI Hotine-Marussi Symp. on Theoretical and Computational Geodesy“, Wuhan, China, 29.5.-2.6.2006, pp. 10-16, Springer, Berlin, Heidelberg

KELLER W: Self-adaptive choice of a system of localizing base function for regional gravity field recovery. IUGG General Assembly, Perugia, June 2007

SHARIFI M, N SNEEUW and W KELLER: Gravity recovery capability of four generic satellite formations. In: Kiliçoglu A and R Forsberg (Eds., 2007): Gravity field of the Earth, General Command of Mapping, ISSN 1300-5790, Special Issue 18, pp. 211-216, 1st Int. Symposium of the International Gravity Field Service, 28.8.-1.9.2006, Istanbul, Turkey

XU C, N SNEEUW and MG SIDERIS: Joint SST and SGG Gravity Field Solutions Using the Torus Approach. In: Kiliçoglu A and R Forsberg (Eds., 2007): Gravity field of the Earth, General Command of Mapping, ISSN 1300-5790, Special Issue 18, pp 169-174, 1st Int. Symposium of the International Gravity Field Service, 28.8.-1.9.2006, Istanbul, Turkey

**Non-refereed Contributions**

HARTMANN O, W JACOBY, D WOLF, V KLEMANN and I SASGEN: Interpretation glazial-isostatischer Ausgleichsvorgänge im Südosten Islands unter Berücksichtigung des Island-Plumes. Sci. Techn. Rep. GFZ Potsdam, STR07/07, 43 pp.

SASGEN I, R MULVANY, Y KLEMANN and D WOLF: Glacial-isostatic adjustment and sea-level change near Berkner Island, Antarctica. Sci. Techn. Rep. GFZ Potsdam, STR07/05, 26 pp

SIEMES C, W SCHUH, J CAI, N SNEEUW and O BAUR: GOCE data processing: the numerical challenge of data gaps. In: GEOTECHNOLOGIEN Science Report No 11, Status Seminar, 22-23.11.2007, Munich, pp. 99-105

**Guest Lectures and Lectures on special occasions**

BAUR O, Dr.-Ing. (Geodätisches Institut, Universität Stuttgart): Die Invariantendarstellung in der Satellitengradiometrie - Theoretische Betrachtungen und numerische Realisierung anhand der Fallstudie GOCE (Doctoral Presentation, Universität Stuttgart, 20.3.2007)

CAI J, Dr.-Ing. (Geodätisches Institut, Universität Stuttgart): Optimal regularization ((-weighted S-homBLE) and its application in GPS rapid static positioning (Interfakultatives Kolloquium Statistik, 15.2.2007)

CAI J, Dr.-Ing. (Geodätisches Institut, Universität Stuttgart): The statistical analysis of geodetic strain rate tensors derived from FinnRef GPS measurements (1997-2004) (with the contributions from H. Koivula, M. Poutanen and E. Grafarend), Masala, (7.9.2007)

ENGELS J, PD Dr. habil. (Geodätisches Institut, Universität Stuttgart): Zeit-Frequenz-Analyse am Beispiel von Polbewegungsdaten (Inaugural Lecture, 16.2.2007)

HU C, Prof. (Department of Surveying and Geo-Informatics, University of Tongji, Shanghai): GPS signal acquisition and tracking based on software GPS receiver (18.9.2007)

HU C, Prof. (Department of Surveying and Geo-Informatics, University of Tongji, Shanghai): GPS kinematic precise point positioning (18.9.2007)

KERN M, Dr. (ESA/ESTEC, Noordwijk/NL): Satellitenmissionen zur Beobachtung des Systems Erde (Geodätisches Kolloquium Universität Stuttgart, 9.2.2007)

RENGANATHAN V (Department of Geomatics Engineering, University of Calgary, Canada): Sea-ice freeboard and thickness from Satellite Altimetry (28.6.2007)

VARGA P, Prof. Dr. (GGKI Seismological Observatory Budapest, Hungary): Some common problems of Geodesy and Seismology (19.2.2007)

ZALETNYIK P (Department of Geodesy and Surveying, Budapest University of Technology and Economics, Hungary): Symbolic-numeric computations in geodesy (26.2.2007)

### Lectures at other universities

BAUR O: Some aspects on satellite gradiometry. Curtin University of Technology, Perth, Australia, 12.5.2007

CAI J: GPS rapid static positioning with optimal regularization method and the statistical property of GPS ambiguity resolution. Tongji University, Tongji, 24.5.2007

CAI J: GPS rapid static positioning with optimal regularization method and the statistical property of GPS ambiguity resolution. Wuhan University, Wuhan, 7.6.2007

GRAFAREND E: Gravity gradients: Space observational techniques, boundary problems and ellipsoidal harmonics. Geodeetinen Laitos, The Finnish Geodetic Institute, Masala/Helsinki, Finnland, 6.8.2007

GRAFAREND E: Harmonic maps. Kungl. Tekniska Högskolan Institutionen för Geodesie, Stockholm, Schweden, 30.8.2007

SNEEUW N: Satellitengeodäsie: von Kepler zu Formationsflügen (Geodätisches Kolloquium, Universität Hannover, 16.-17.1.2007)

### Conference Presentations

ANTONI M, W KELLER and M WEIGELT: Regionale Schwerefeldmodellierung durch Slepian- und radiale Basisfunktionen. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

ANTONI M, W KELLER and M WEIGELT: Representation of Regional Gravity Fields by Radial Base Functions. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

CAI J and E GRAFAREND: Directional statistics and its application in the hypothesis testing of GPS integer ambiguity resolution. Geophysical Research Abstracts, Vol. 9, 08768, European Geophysical Union 2007, General Assembly 2007, Vienna, Austria, 15.-20.4.2007

CAI J, E GRAFAREND and C HU: The total optimal criterion in solving the mixed Integer linear model with GNSS carrier phase observations. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

CAI J, N SNEEUW and R GUO: Systematic analysis of 2-d and 3-d coordinate transformations with least-squares and total least-squares methods. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

DEVARAJU B and N SNEEUW: Stochastic averaging of GRACE data. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

FINN G and E GRAFAREND: FINN2007: The New Geoid Model for Finland. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

FINN G and E GRAFAREND: Single Step Approach for Geoid Determination. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

GRAFAREND E, G FINN and AA ARDALAN: Ellipsoidal Vertical Deflections based on the Somigliana-Pizzetti Ellipsoidal Reference Gravity Field. Geophysical Research Abstracts, Vol. 9, 07514, European Geophysical Union 2007, General Assembly 2007, Vienna, Austria, 15.-20.4.2007

GRAFAREND E: Kinematische und dynamische Gleichungen zur Erdrotation: Messexperimente, Präzession / Nutation versus Tageslängenschwankungen (LOD) / Polbewegung (PM). Leibniz-Sozietät, Plenarsitzung zum 300. Todestag von Leonhard Euler, Berlin, 12.4.2007

HU C, N SNEEUW, J CAI, L AN and X LI: GPS Signal Acquisition and Tracking Based on Software GPS Receiver. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

JIANG W, Y CHU, N SNEEUW and J LI: Measuring Qinghai Lake Level Fluctuations using ENVISAT Altimeter Data (2002-2006). Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

KELLER W: Self-adaptive choice of a system of localizing base function for regional gravity field recovery. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

KING M, T VAN DAM, P VISSER, T GRUBER, N SNEEUW, J BAMBER, M BIERKENS, M LOSCH, J BOUMAN, M KERN and R HAAGMANS: Modelling Individual Sources of Mass Distribution and Transport in the Earth System by means of Satellites - European Space Agency Mass Transport Study 20403. AGU Fall Meeting, San Francisco, California, USA, 10.-14.12.2007

KOOP R, T GRUBER, P VISSER and N SNEEUW: Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the Earth System by means of Satellites. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

MOGHTASED-AZAR K and E GRAFAREND: Deformation analysis based on intrinsic geometry. European Geophysical Union 2007, General Assembly 2007, Vienna, Austria, 15.-20.4.2007

MOGHTASED-AZAR K and P ZALETNYIK: Crustal velocity field modelling with neural network and with polynomials. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

SNEEUW N and M SHARIFI: Spatiotemporal resolution of multi-satellite missions. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

SNEEUW N, T REUBELT and M SHARIFI: Raum-Zeit-Auflösung und künftige Satellitenkonfigurationen. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

SNEEUW N: Future Mission Concepts, Workshop on the Future of Satellite Gravimetry. Estec, Noordwijk, The Netherlands, 12.-13.4.2007

SNEEUW N: Report of Working Group on Satellite Gravity Theory. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

WEIGELT M and N SNEEUW: Demonstration of the sampling capabilities of multi-satellite missions. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

WEIGELT M, O BAUR, W van der WAL, N SNEEUW and W KELLER: Time variable gravity field recovery in local areas by means of Slepian functions. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

WEIGELT M, W KELLER and N SNEEUW: Gravity field recovery in high latitude areas. Geodätische Woche, Leipzig, Germany, 25.-27.9.2007

XU C, MG SIDERIS and N SNEEUW: Evaluation of the Regularization Methods used in the Torus-based semi-analytical approach for Gravity Field Recovery. IUGG XXIV General Assembly, Perugia, Italy, 2.-13.7.2007

XU C, MG SIDERIS and N SNEEUW: Spherical Harmonic Analysis and Synthesis in Satellite Gravity Gradiometry Using the Torus Approach. Canadian Geophysical Union (CGU) Annual Meeting, St. John's, Newfoundland, 29.5.-1.6.2007

**Research Stays**

BAUR O: Department of Spatial Sciences, Curtin University of Technology, Perth, Australia, 1.4.-30.9.2007

CAI J: Department of Surveying and Geoinformatics, Tongji University, Shanghai, 16.-31.5.2007

CAI J: Finnish Geodetic Institute, Masala, Finland, 31.8.-9.9.2007

CAI J: Center for Space Research (CSR), The University of Texas at Austin, 29.9.-2.10.2007

GRAFAREND E: Finnish Geodetic Institute, Masala, Finnland, 19.7.-24.8.2007

GRAFAREND E: Kungl. Tekniska Högskolan, Institutionen för Geodesie, Stockholm, Schweden, 24.8.-6.9.2007

KELLER W: Agricultural Academy Wroclaw, Poland 28.5.-2.6.2007

**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
Foundations of Satellite Geodesy, 51 pages

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

SNEEUW N

Adjustment Theory, 100 pages
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
Dynamic Satellite Geodesy, 90 pages

WOLF D

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

**Participation in Conferences, Meetings and Workshops**

ANTONI M

DFG-SPP1257 Workshop (Oceanography, Tides, Hydrology, gravity field), Gummersbach, 21.3.-23.3.2007
XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
Geodätische Woche, Leipzig, 25.-27.9.2007
Joint international GRACE Science Team Meeting and DFG SPP1257 Symposium, Potsdam, 15.-17.10.2007

BAUR O

Status Seminar GEOTECHNOLOGIEN II - Observation of the system Earth from space, Bavarian Academy of Sciences and Humanities, Munich, 22.-23.11.2007

CAI J

European Geosciences Union (EGU) General Assembly, Vienna, Austria, 14.-19.4.2007
GOCE-GRAND II, Projekttreffen, Potsdam, 10.-11.5.2007
XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
ION GNSS 2007, Fort Worth Convention Center, Fort Worth, Texas, USA, 25.-28.9.2007
GEOTECHNOLOGIEN Status Seminar, Munich, 22.-23.11.2007

DEVARAJU B

SPP1257 Workshop (Oceanography, Tides, Hydrology, gravity field), Gummersbach, 21.3.-23.3.2007
Geodätische Woche 2007, Leipzig, 25.-27.9.2007
Joint international GRACE Science Team Meeting and DFG SPP1257 Symposium, Potsdam, 15.-17.10.2007

FINN G

XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
Geodätische Woche, Leipzig, 25.-27.9.2007

GRAFAREND E

Generalversammlung der Leibniz-Sozietät, 11.-13.4.2007

European Geosciences Union (EGU) General Assembly, Vienna, Austria, 14.-19.4.2007
Generalversammlung der IAG, Perugia, Italy, 2.-15.7.2007

KELLER W

XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
Geodätische Woche, Leipzig, 25.-27.9.2007

REUBELT T

Progress Meeting 1 and 2 of the project „Mass Transport Study", ESA Contract 20403, SRON, Utrecht, The Netherlands, 26.4.2007, Mid Term review of the project „Mass Transport Study", ESA Contract 20403, ESA/ESTEC, Noordwijk, The Netherlands, 12.11.2007

SNEEUW N

DFG-SPP1257 Workshop (Oceanography, Tides, Hydrology, gravity field), Gummersbach, 21.3.-23.3.2007
Future Gravity Mission Workshop, Noordwijk, The Netherlands, 12.-13.4.2007
XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
Geodätische Woche, Leipzig, 25.-27.9.2007
Geodätische Kommissionen DGK / ÖGK / SGC, St. Gilgen, 10.-12.10.2007
Joint international GRACE Science Team Meeting and DFG SPP1257 Symposium, Potsdam, 15.-17.10.2007
Statusseminar GEOTECHNOLOGIEN, Munich, 22.-23.11.2007

WEIGELT M

DFG-SPP1257 Workshop (Oceanography, Tides, Hydrology, gravity field), Gummersbach, 21.3.-23.3.2007
XXIV General Assembly of the IUGG 2007, Perugia, Italy, 2.-13.7.2007
Geodätische Woche, Leipzig, 25.-27.9.2007

SCHLESINGER R

Workshop Geodäsie/Geophysik 2008, Freudenstadt, 16.-19.10.2007

**University Service**

FINN G

Member Advisory Council of High Performance Computing Center
Member Public Relation Commission of Department of Geodesy
Member Administrating Board Studentenwerk Stuttgart A. d. ö. R.

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 Examining Board of the Faculty of Aerospace Engineering and Geodesy

Member Study Commission Geodäsie & Geoinformatik and GEOENGINE
Member Council of the Faculty of Civil- and Environmental Engineering

KRUMM F
Member Study Commission Geodäsie & Geoinformatik and GEOENGINE

SNEEUW N
Associate Dean (Academic) Geodäsie & Geoinformatik and GEOENGINE
Member Examining Board of the Faculty of Aerospace Engineering and Geodesy
Member Search Committee Flugzeugastronomie und Extraterrestrische Raumfahrtmissionen
Member Search Committee Juniorprofessur ESPACE, TU Munich

**Professional Service (National)**

CAI J
Member Deutscher Verein für Vermessungswesen

GRAFAREND E
Emeritus member German Geodetic Commission (DGK)

HINTZSCHE M
Member Gesellschaft für Immobilienwirtschaftliche Forschung (gif)
Vice President Gutachterausschuss für die Ermittlung von Grundstückswerten in der Landeshauptstadt Stuttgart
Member Verband Deutscher Städtestatistiker (VDSt)
Member Ingenieurkammer Baden-Württemberg

KELLER W
Member Mathematical Society, Germany

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

**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)

FINN G

Member IAG Special Study Group Spatial and Temporal Gravity Field and Geoid Modeling

GRAFAREND E

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

KELLER W

Society of Industrial and Applied Mathematics

SNEEUW N

Präsident of IAG InterCommission Committee on Theory (ICCT)
Corresponding member of the Joint Working Group (JWG) between International Gravity Field Service (IGFS) and the IAG Commission 2
Member Editorial board of Studia Geophysica et Geodaetica
Member Editorial board of Journal of Geodesy
Elected Fellow of the International Association of Geodesy (IAG)
Chair IAG Inter-Commission Working Group Satellite Gravity Theory

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 (Krumm, Baur) | 2/1/0 |
| Coordinates and Reference Systems (Krumm, Reubelt) | 1/1/0 |
| Geodesy and Geodynamics (Sneeuw, Finn) | 2/1/0 |
| Measurement Techniques of Physical Geodesy (Sneeuw, Finn) | 2/1/0 |
| Modeling and Data Analysis in the Field of Physical Geodesy (Engels, Reubelt) | 2/1/0 |
| Foundations of Satellite Geodesy (Keller) | 1/1/0 |
| Observation Techniques and Evaluation Procedures of Satellite Geodesy (Keller, Weigelt) | 1/1/0 |
| Satellite Geodesy Observation Techniques (Keller, Weigelt) | 2/1/0 |
| Dynamic Satellite Geodesy (Keller, Weigelt) | 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, Sneeuw) | 0/0/4 |

| | |
|---|---|
| Integrated Field Work Geodesy and Geoinformatics (Keller, Sneeuw) | 10 days |
| Gravity Field Modeling (Keller, Weigelt) | 2/1/0 |
| Analytic Orbit Computation of Artificial Satellites (Sneeuw) | 2/1/0 |
| Orbit Determination and Analysis of Artificial Satellites (Sneeuw) | 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 |
| Geodetic Excursion (Keller, Weigelt) | 5 days |
| Physical Geodesy (Sneeuw, Finn) | 2/1/0 |
| Map Projections and Geodetic Coordinate Systems (Krumm, Reubelt) | 2/1/0 |

# Institute of Navigation

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## Head of Institute

Prof. Dr.-Ing. A. K l e u s b e r g

Deputy: Dr.-Ing. Karl-Heinz Thiel
Secretary: Helga Mehrbrodt

Emeritus: Prof. em. Dr.-Ing. Ph. Hartl

## Staff

| | |
|---|---|
| Dipl.-Ing. Jürgen M i n g, Akad. Rat | Administration |
| Dipl.-Ing. Doris B e c k e r | Navigation Systems |
| M.Sc. Shan C h e n | Navigation Systems |
| Ing. grad. Hans-Georg K l a e d t k e | Remote Sensing |
| Dipl.-Ing. Roland P f i s t e r e r | Laser Systems |
| Dipl.-Phys. Manfred R e i c h | Interferometry |
| Dipl.-Ing. Oliver S c h i e l e | Navigation Systems |
| Dipl.-Ing. Wolfgang S c h ö l l e r | Education/Navigation Systems |
| Dipl.-Ing. Alexandra S e i f e r t | Navigation Systems |
| Dr.-Ing. Aloysius W e h r | Laser Systems |
| Dipl.-Ing. (FH) Martin T h o m a s | Laser Systems |

## EDP and Networking

Regine S c h l o t h a n

### Laboratory and Technical Shop (ZLW)

Dr.-Ing. Aloysius W e h r (Head of ZLW)
Dipl.-Ing. (FH) Erhard C y r a n k a
Technician Peter S e l i g - E d e r
Mech. Master Michael P f e i f f e r

### 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

### An optimal system for receiving data of Giove-A

With the launch of the first test satellite, GIOVE-A, the European satellite navigation system „GALILEO“ made the first step into space. This test satellite provides a platform for testing the new navigation signals, under which binary offset carrier (BOC) signals are of our concern. Under the project UNITAS III funded by the DLR, the Institute of Navigation has made an analysis of GIOVE-A L1 open service (OS) signals. Our focus is the investigation of an optimal system for receiving this new navigation signal. In the following the research activities and the results are summarized.

## DATA COLLECTION

Firstly, we have developed a labor system to collect the signal, which is shown in figure 1.

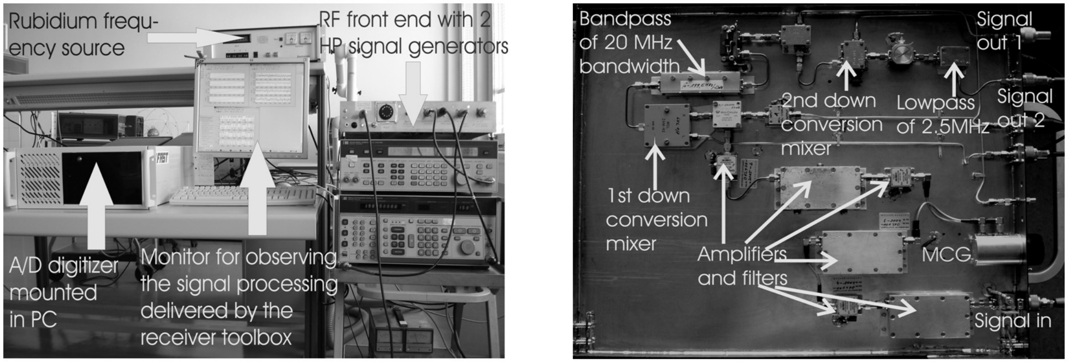



*Fig. 1: Labor system for data collection: complete system (left); RF front end (right)*

## SIGNAL ANALYSIS

Then, we made an analysis of the collected signal. The GIOVE-A L1 OS signal uses binary off-set carrier modulation, in contrast to the BPSK modulation traditionally used by GPS. Its signal spectrum shows „split“ characteristic (see the red curve in the left plot), that is, the mainlobe is shift to sub-carrier components. And its autocorrelation function consists of multiple peaks, which arouses the ambiguity problem.

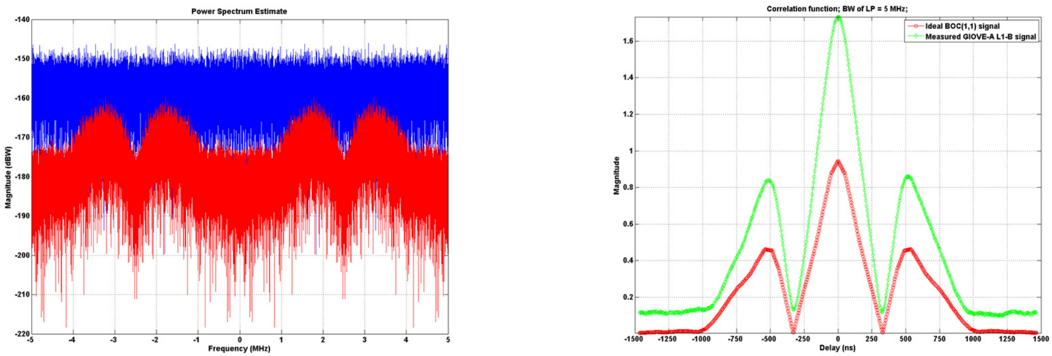



*Fig. 2: Power spectral density (left) and autocorrelation function (right) of the GIOVE-A L1 open service signal*

## SIGNAL QUALITY MEASURES

Based on the correlation function the signal quality was furthermore assessed. The important characteristics are:

- ▹ Correlation peak power
- ▹ Correlation peak delay
- ▹ Separation in delay of the correlation sidelobes relative to the main peak
- ▹ Separation in magnitude of the correlation sidelobes relative to the main peak
- ▹ S-curve zero crossing
- ▹ Early minus Late value at the zero crossing
- ▹ S-curve slope at the zero crossing
- ▹ The largest allowable early-late spacing

## ACQUISITION AND TRACKING PROCESSING

Followed by the analysis the collected signal from the GIOVE-A L1 was then processed, where the characteristics of acquisition and tracking were investigated. The processing flow is shown in figure 3.

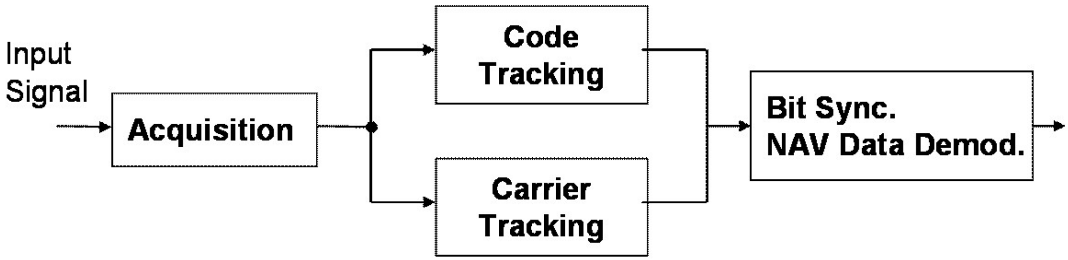



*Fig. 3: Flow diagram of the signal processing.*

The acquisition gives rough estimates of signal parameters, namely code phase and carrier frequency. These parameters are refined by the two tracking blocks. Figure 4 shows the construction of the tracking loop, where both tracking blocks are combined and simultaneously performed.

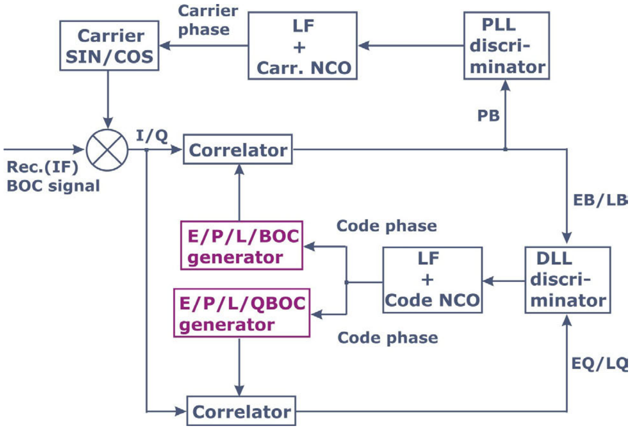
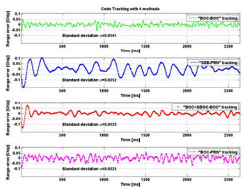
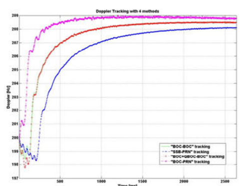



*Fig. 4: Block diagram of the combined tracking loop*

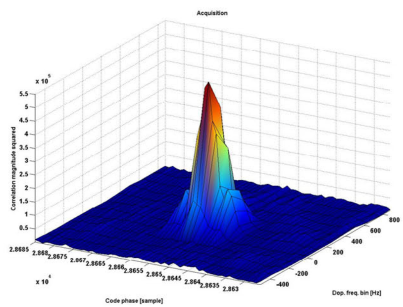
The results of acquisition and tracking of the GIOVE-A L1 OS signal are presented in figure 5. The 3-D acquisition plot on the right shows the correlation function output, where the search space is made up of the code phase on one axis and the carrier Doppler frequency on the other axis. Based on the location of the main peak the code phase and Doppler frequency can be found out. In the next stage the code phase and carrier frequency obtained from the acquisition are fed to the tracking module as the initial estimates. The tracking outputs are shown in the left plots: (a) is the code phase error; (b) is the Doppler frequency tracking; and (c) is the data bit stream after demodulation.

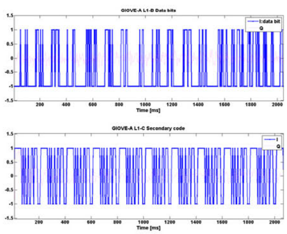


(a)



(b)





(c)

*Fig 5: Acquisition and tracking results*

## Remote sensing - Quality Test of a Digital Ground Model for Germany

The E-Plus Mobilfunk GmbH has obtained a new Digital Terrain Model for Germany. The product NEXTMap Deutschland/Europe of Intermap Technologies (www.intermap.com) has been selected for this purpose. A contract between the E-Plus Mobilfunk GmbH and the Institute of Navigation (INS) has been signed, whereby the INS has been charged with the quality test of the NEXTMap Deutschland product.

In 2007 the first step of the quality test has been performed for two test-areas Erfurt and Stuttgart. The NEXTMap datasets fort these two areas are two sections of the NEXTMap Deutschland product. Besides these DGM (Digital Ground Model) data additional DSM (Digital Surface Model) data with 5 m resolution and also an ORI (Orthorectified Radar Image) with 1.25 m raster has been provided by Intermap Technologies. Additional reference datasets have been provided by E-Plus: A DGM in 5m raster created by photogrammetric methods, an Orthofoto in 0.4 m raster, as well as a series of vector datasets for buildings, vegetation and settlement classes. Besides these rasterized land-use data with 36 land-use classes and a digital topographical map for the whole area of Germany has been made available.

The 5m-DGMs provided by E-Plus have been created as parts of city models and therefore do not contain agricultural areas and large forests. Additional reference data for this kind of areas have been ordered from the geodetic authorities (Landesamt für Vermessung und Geoinformation Erfurt und Landesbetrieb Vermessung Stuttgart). High precise height reference data acquired from Laser flight measurements have been selected fort this purpose. The comparison of height information from the reference data with the NEXTMap DGM provided a quantitative measure for the accuracy of the NEXTMap DGM and a measure for the correct removal of the vegetation and man-made structures from the DSM to create the DGM. The central part of the quality test was the checking of the quality parameters of Intermap Technologies for the horizontal and vertical accuracy of the NEXTMap Deutschland product and the statements concerning the removal of vegetation and man-made structures when producing the DGM from the DSM created by radar interferometry.

The evaluation of the horizontal position accuracy was performed using the NEXTMap ORI (1.25 m raster) compared with the high resolution Orthofoto datasets. Local displacements of the NEXTMap ORI radar image have been detected by the identification of pass-points on the ground belonging to identical points in both images. We could demonstrate that these displacements were usually less than two meters. However points not belonging to the ground surface (e.g. roofs of high buildings) provided displacements of 20 meters and even more according to the height of the buildings.

The accuracy of the reference models created from laser flight measurements has been found to be better by a factor of 3 than the photogrammetric E-Plus height models.

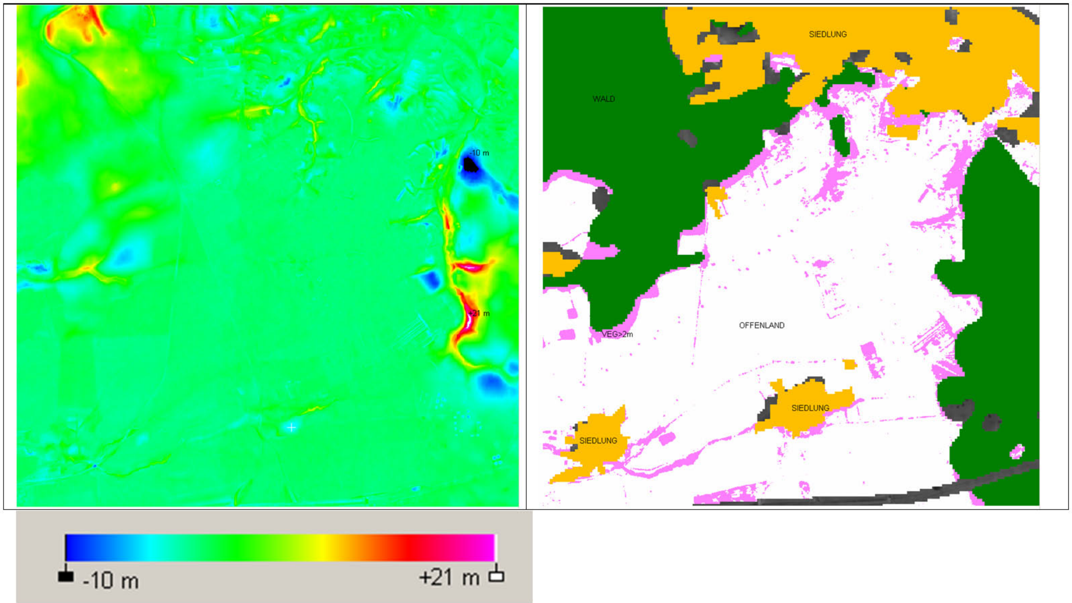



*Fig 6: (a) colour coded height difference NEXTMap DGM-LASER DGM (b) corresponding land-use data*

## 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.

High resolution maps of deposition loads and air concentration levels are calculated using GIS. They are compared with critical levels and critical loads in order to provide an impact assessment in the form of exceedance maps for ecosystems, human health aspects and, if applicable, material corrosion. 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 from 1998 onward:
http://www.nav.uni-stuttgart.de/navigation/forschung/critical_loads

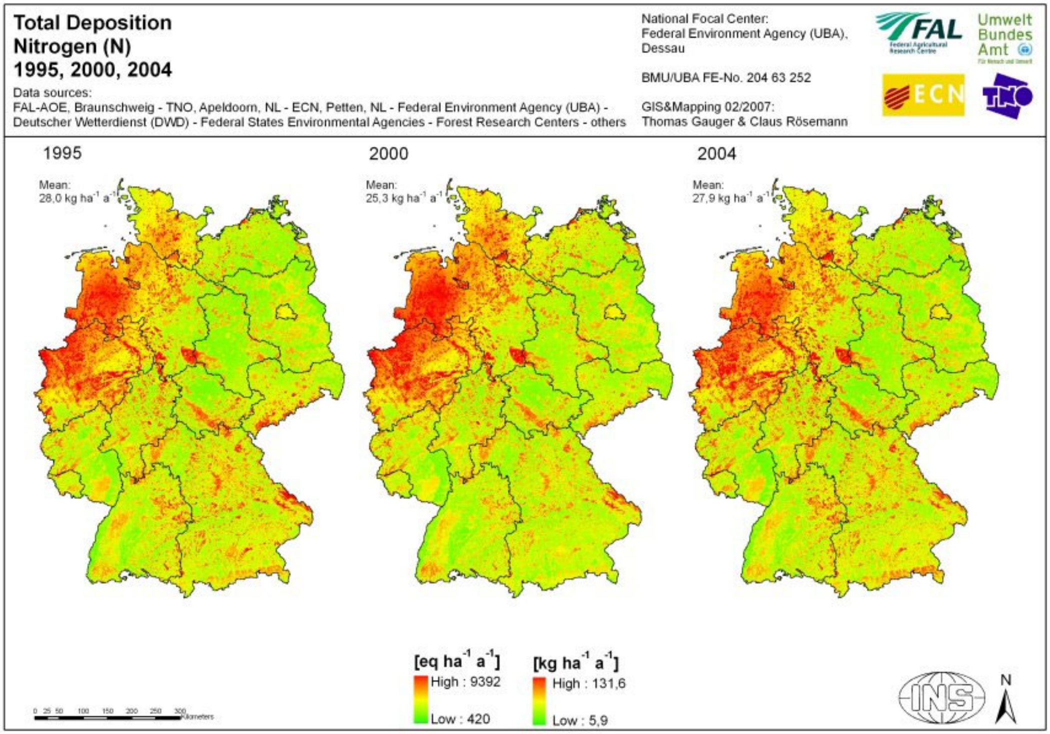



*Fig. 7: Total deposition of nitrogen (N) 1995, 2000, and 2004 in Germany*

## Publications and Presentations

Wild-Pfeiffer, F., Augustin, W., Heck, B.: „Optimierung der Rechenzeit bei der Berechnung der 2. Ableitungen des Gravitationspotentials von Massenelementen", ZfV, 132 (6/2007), S. 377-384.

## 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

## Education (Lecture / Practice / Training / Seminar)

| | |
|---|---|
| Navigation and Remote Sensing (Kleusberg) | 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 (Thiel) | 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 |
| Dipl.-Inf. Martin Kada | 3D-Visualisation |
| Dipl.-Ing. Michael Peter | Generalisation |

### Photogrammetry and Remote Sensing

| | |
|---|---|
| Head: Dr.-Ing. Michael Cramer | Digital Airborne Sensors |
| Dipl.-Geogr. Timo Balz | SAR Image Analysis |
| Dipl.-Ing. Susanne Becker | Resolution Enhancement |
| Dipl.-Ing.(FH) Markus Englich | Sensor Laboratory |
| M.Sc.Eng. Mohammed Othmann | 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 |
| Dipl.-Ing. Angela Budroni | Indoor Model Reconstruction |
| 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

### Generalisation of 3D-Building Models

The acquisition and presentation of 3D city models has been a topic of intensive research for more than 15 years. In general, such data sets include digital representations of the landscape, buildings and more frequently also vegetation and street furniture. A number of commercial software products and service companies exist nowadays for the reconstruction of buildings. For an efficient data collection of large areas, the objects are measured from aerial images or laser data. Therefore there is no facade information available in the source data which results in building models where the ground plan is simply extruded and intersected with the interpreted roof structure.

Besides the traditional analysis applications of 3D city models, which are e.g. the planning of mobile antennas, alignment of solar installations or noise propagation, the presentation of urban areas becomes more and more important. Real-time and web-based visualisation systems offer nowadays near photorealistic quality. To limit the amount of data that needs to be transferred over the network and to increase the rendering performance, objects are represented in different levels of detail depending on their distance to the viewer. For 3D city models the following classification of building objects in three discrete levels of detail is very common: block models with flat roofs and no facade structure, models with roof structures and architectural models with detailed roofs and facades. So far, cities have mostly collected data in the second level of detail with only a few selected landmarks being of higher detail. Because of the high costs involved in the acquisition, there are efforts to facilitate the exchange and interoperability between data and application providers.

A photorealistic visualisation is not always the most adequate tool to communicate spatial information. Architects and designers often produce sketch like hardcopy outputs to make their objects appear more alive or to express the preliminary status of their designs. Recent works on interactive visualisations of 3D city models explore non-photorealistic rendering techniques that imitate this style so that spatial situations are easier to perceive and comprehend. Such techniques, however, rely on information about the characteristic edges that best reflect the global shape of a building. This is basically what results from a cartographic simplification.

Another field of application for 3D city models are location based services or context-aware applications. Their users rely heavily on a location- or situation-dependent presentation of the information that is most relevant to their current task. To be useful anywhere at all times, such systems run on mobile devices like personal digital assistants (PDAs) or mobile phones. As their screen size and resolution will always be a limiting factor, a geometric simplification of 3D objects is necessary to guarantee the graphical minimum feature size required by maps or map-like presentations. Otherwise the high line density makes it impossible to recognize important aspects of the building object.

Because it is not reasonable to collect and store data for all requested levels of detail, an automatic process is necessary that transforms 3D building models towards more simplified shapes. Object features that are under a minimum size, which can be determined from the scale parameters of the map projection, should be removed without disturbing the global shape. Properties that are specific for the object itself as well as the object type, however, must be preserved. In the case of 3D building models, these are the parallel and right-angled arrangements of facade walls and the symmetries of the roof structures. Object specific features are especially important for landmarks. The simplified model of a church or cathedral, e.g., must not miss its towers after generalisation as otherwise the object is hardly recognisable anymore.

A simplification of solitary objects under these spatial constraints is one of the elemental operators of cartographic generalisation. In cartography, both the spatial objects themselves as well as their arrangement are transformed with the goal to create maps or map-like presentations that help to communicate a spatial situation. Other generalisation operators omit or emphasise objects depending on their importance, aggregate semantically similar objects, replace a number of objects by fewer entities or displace them to relax the spatial density in areas with many objects. The generation of a situation- and context-dependent abstraction level of the spatial data is therefore possible to help viewers apprehend the presented spatial information.

We developed a two-stage generalisation algorithm for the geometric simplification of solitary 3D building models. As can be seen from the intermediate results of the example in Figure 1, the two stages consist in a total of five steps. The first stage generates 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 (1), subdividing the infinite space along these planes (2) and identifying the resulting cells that feature a high percentage of overlap with the original ground plan polygon (3). The second stage reconstructs the simplified geometry of the roof. Here, a primitive instancing approach is shown where the roof parameters are determined individually for each cell so that they best fit the original model under distinct adjacency constraints (4). By altering those parameters, the simplification of the roof can be properly adjusted. A union operation of the resulting primitives composes the final 3D building model and concludes the generalisation (5).

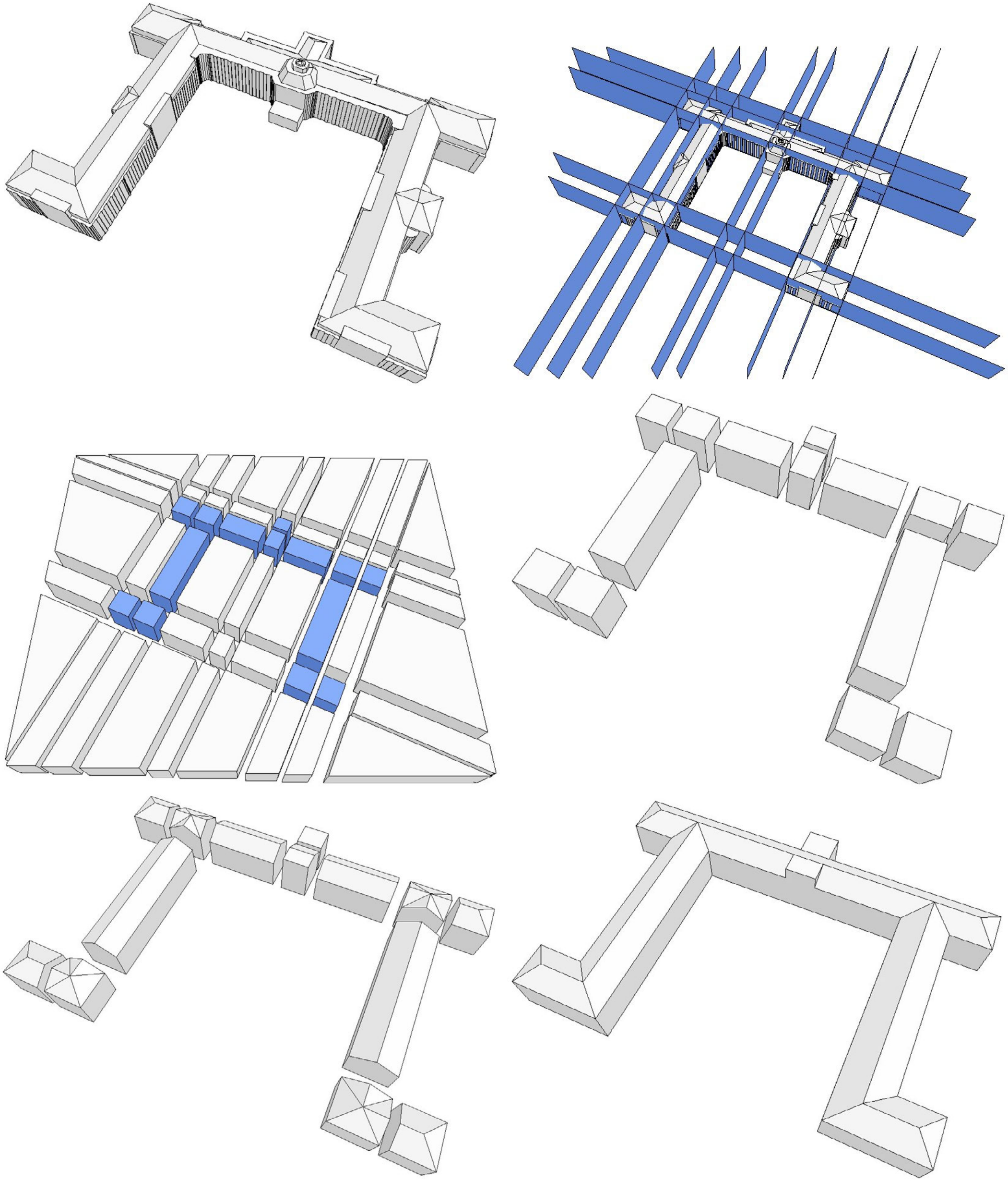

*Figure 1: Original 3D building model (top left) and the five steps of the generalisation algorithm.*

**Quality evaluation of generalization algorithms**

Cartographic maps can only contain a certain amount of information. If the information density is too high, the map becomes hard to comprehend for a human viewer. A common solution for this problem is to simplify the geometry of objects or even to delete some of them. In this cartographic generalization, the rate of simplification depends on the scale of the map. However, to preserve the readability, the simplification follows certain rules. These rules must not necessarily minimize a geometric error, but might rather accept a certain geometric deviation to better suit the cognitive capabilities of humans.

It should be noted, that for paper maps the geometrical accuracy is restricted by the drawing accuracy and the scale. Thus, the scale value of paper maps is an aggregated parameter, which characterizes the level of detail (LOD) of the cartographic appearance and its accuracy at the same time. For digital models, coordinates of an object are stored separately in a database and must not be determined graphically on a map as before. It means that the values of accuracy and level of detail can not be proportional associated with each other any more. Though the accuracy of the generalized geometry is affected by the rate of simplification, it is now only depending on the transformation rules. The reduction of geometrical details by the generalization can hardly be formalized and is only described by abstract operators. As a consequence, every individual algorithm presents its own interpretation of those procedures and offers a subjective implementation of the simplification task. However, neither of the existing methods gives any quality information about their generalized models.

In this project, the change of accuracy of an object that is caused by generalization will be discussed profoundly. As our example data set, we use building ground plans that have been generalized by the algorithm described in (Kada 2007). Objective characteristics will be developed for comparing the geometrical similarity of the initial and simplified ground plan polygons. As a final outcome, they allow an evaluation of the quality of the generalization and answer the question of how good the suggested algorithms are.

Because of the generalization, various geometrical distortions can be observed in the resulting object. Individual line segments might be displaced in different directions when compared to the initial ground plan. Also, the number of points and lines could be reduced, so it is hard to determine a correspondence between these basic primitives. This means that the geometric changes are difficult or even impossible to describe without having knowledge about the procedural method of the simplification algorithm. It is possible to overcome this problem by considering the contour of the ground plan polygon as a set of points. Now, two polygonal objects can be compared by means of the shortest distances of their points. The maximum reflects the largest deviation of the generalized ground plan compared to its original shape. This distance, also known as the Hausdorff-Distance, can be used as one of the parameters to describe the quality of generalization.

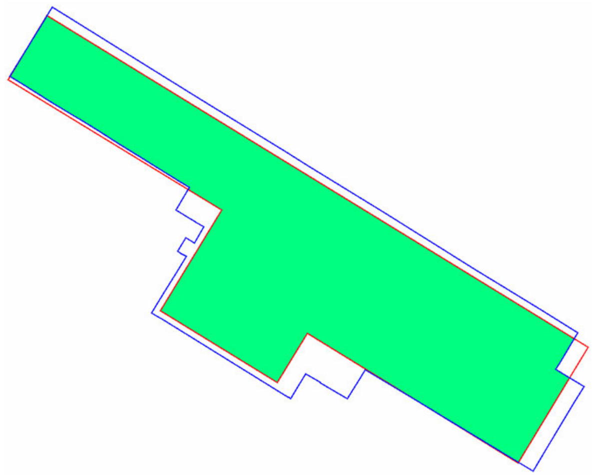

*Figure 2: Area intersection of original and generalized polygons.*

Changes in the geometry of polygons can not only be considered as the displacement of line segments, but also as the change of their areal extension. First of all, the total size change of the ground plan polygon can be determined as an areal ratio of the generalized and initial objects. But this value will not take into account the general translation of an object. From this aspect, geometrical modification can be described by the space that both objects occupy. It is identified as the intersection of two polygons. This mutual relation can be expressed as two percentage values that compare the common space with the area of the generalized and the initial object. The remainder of the original polygon identifies intrusions, whereas the remainder of the generalized polygon represents extrusions.

Various characteristics can be used for generating the feature-vector. For example, if the objects are considered as regions, they can be represented by their central moments. In this case, the feature-vector will express the area of the object, variance and skew or asymmetry with regard to the centroid of this region. As characteristic elements of a vector, the basic geometrical properties can be alternatively applied. Based on the minimal enclosing rectangle, the feature-vector will reflect the extension of this rectangle, its spatial area filling as whole and over each single quadrant. Both feature-vectors are translation invariant and can be especially useful when an object displacement takes place. For an estimation of the similarity of two feature-vectors, different distance functions can be used. Examples are quasi-Euclidean distance, Euclidean distance or its general form, the Minkowski-distance.

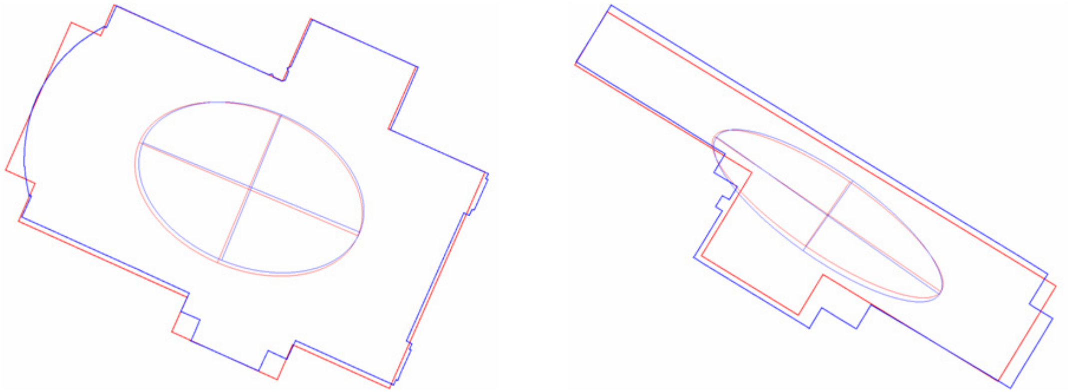

*Figure 3: Interpretation of central moments as centroid and variance of original and generalized polygons*

**Automatic interpretation of vector databases with a raster-based algorithm**

Spatial vector databases contain many implicit information that are visible for human persons but which are not stored explicitly in the database. For example, it is often possible for a human person to distinguish between inner city areas, rural areas or industrial areas only by looking at the object geometries. Further examples are the differentiation between main and side streets, flat and hilly areas, dense and thin populated areas, etc. Furthermore, a human person can easily identify and group objects that belong together (spatial clustering). Even the type of a map (street map, cadastral map, topographic map, etc.) can be identified only by looking at the object geometries. All these examples can be subsumed under the term „map interpretation".

Automatic map interpretation can be used to support other applications, like automatic map generalisation, matching of spatial datasets, data fusion or data update. Furthermore, automatic map interpretation can support data retrieval processes. In conjunction with search engines and digital globes complete new applications are thinkable. For example, the company Google explores techniques for the automatic indexing of audio files with speech recognition software. With such indexing techniques it would be possible to retrieve audio files automatically in the same way as normal web pages. The same idea can be transferred to digital maps. With automatic indexing techniques it would be possible to assign key words to maps or spatial parts of maps. Furthermore, the support of local searches can be improved. For example, if a user wants to get all maps that contain a golf course with ocean view, the corresponding maps can be found, even if this information is not stored explicitly.

The automatic derivation of unknown information from databases is also known under the term Data Mining or Knowledge Discovery. Data mining techniques are used to derive unknown informations that are not visible for a human person from huge data sets. This applies only partly to this work, because we want to derive information that are very well visible for human persons but which are not modelled and stored explicitly in the database. Automatic map interpretation is a mixture between data mining and automatic image interpretation.

The proposed algorithm works as follows. At the beginning of the process, an operator can define two different parameters for the map interpretation: the grid cell size of the resulting raster map and the radius around the centre of each grid cell, so that the area for which indicators have to be observed can be calculated (area of influence). After the operator has chosen the parameters, the area is subdivided into equally sized, square-shaped grid cells. Then, using the centre point of each grid cell, the area of influence is determined and different indicators are calculated. The result is a raster layer for each indicator. In order to join the different layers and to achieve a final categorization of each individual grid cell, a function has to be defined enabling the combination of the different raster layers. Before joining the different raster layers, it is possible to pre-process them with image processing techniques. For example a Gaussian filter can be used to smooth the raster layers or to decrease noise. This can also be done with the final result raster layer.

We tested our approach with vector street data from the Geographic Data Files (GDF) in order to calculate automatically areas of different degrees of urbanity. As indicators for recognizing different levels of urbanity, we use node density and rectangularity of streets, since we assume that (at least in Germany) in city centres there are usually more topological nodes and more irregular, non-orthogonal streets than in suburbs or rural areas. Figure 4 shows an example for calculating different areas of urbanity according to our approach. The image contains four classes. High urbanity is represented with dark grey pixels and low urbanity is represented with bright grey pixels.

The proposed approach is very powerful and can be implemented very easily. In order to segment vector data regarding other characteristics, other indicators can be defined and combined with the same techniques as described in this approach.

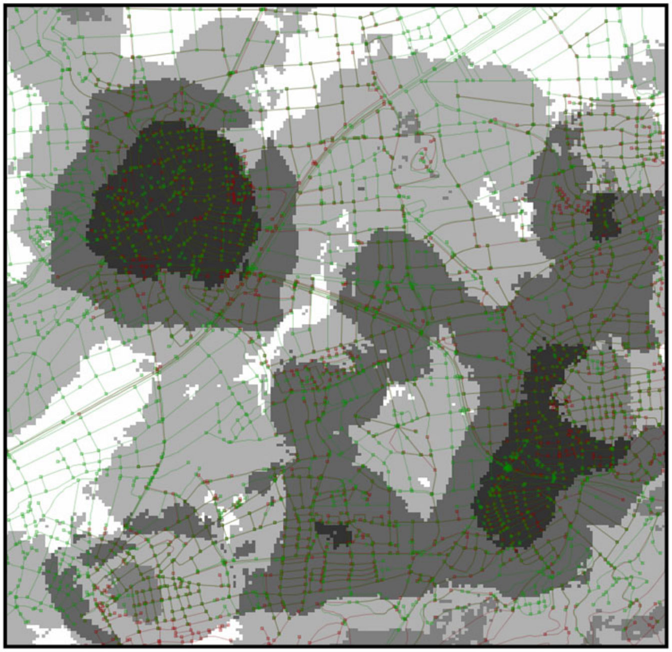

*Figure 4: Sample image displaying four classes of urbanity derived from the vector test data.*

## Photogrammetry and Remote Sensing

### Digital Airborne Camera Certification

In recent years digital airborne imaging has undergone a significant increase in importance for all kinds of mapping applications. It has become evident that large format digital cameras can not only fully compete with the traditional analogue mapping cameras, for some applications they are clearly of superior performance. Different to the well known analogue systems, the available large format digital cameras are of very different system design. This precludes the new systems from the classical certification process, as it was established for analogue mapping frame cameras. In addition a significant increase in medium format digital cameras, often used in combination with airborne laser scanning, can be observed. Figure 5 illustrates the variety of digital cameras already used in mapping applications. In many cases the availability of a recent calibration report has become a mandatory requirement for mapping applications, at least when the mapping has to conform to national rules.


*Figure 5: Today's state-of-the-art digital airborne camera systems used in mapping applications.*

For digital airborne cameras an individual camera specific certification process is not currently available. Some national activities are already established dealing with new concepts and processes of digital airborne camera certification. The strongest impact is driven by the investigations of the United States Geological Survey (USGS). Within Europe no initiative on this topic was evident to date although Europe also has to identify its own needs for digital airborne camera certification. Based on that a certification process has to be defined accepted not only in single countries but throughout Europe.

Traditional laboratory camera calibration is done by camera manufacturers (like Zeiss RMK series at Zeiss Oberkochen and Wild/Leica RC series at Wild/Leica Heerbrugg). The hardware and the processes are sometimes certified in conformity with national rules/organizations (like Deutscher Kalibrierdienst in Germany). In addition to system suppliers, national agencies are themselves responsible for such calibrations, as is the case for the USGS in camera calibration in the United States. Obviously, this calibration of airborne film mapping cameras, which simultaneously certifies the systems' performance, cannot be transferred to the new digital airborne camera systems. It is one of the most important findings of recent digital sensor performance tests that not only the camera but the whole data processing chain is of major impact on the obtained quality of final results. Thus, new ways of system certification covering the whole data generation process have to be identified and implemented.

This was the motivation to initiate a European based digital airborne mapping camera certification process called EuroDAC[2] (European Digital Airborne Camera Certification) under the umbrella of the European organization of Spatial Data Research EuroSDR (formerly known as OEEPE). Main process steps have already been identified by the core competence team from the support of several representatives from national mapping organizations. One of the main steps will be the certification of airborne test ranges and the corresponding processes for in-situ system validation.

Based on this the ifp test site Vaihingen/Enz was maintained and re-signalized in 2007 (Figure 6). About 200 points were identified and permanently marked (Figure 7). The overall spatial extension of the test area is 7.4 km (east-west) x 4.7 km (north-south). The point distribution is densified for the central part of the test site (5.1 km (east-west) x 2.8 km (north-south)). Since all points are coordinated through static GPS surveys with an estimated accuracy of 2cm, they may serve as discrete reference values for independent geometric performance tests (Figure 8).

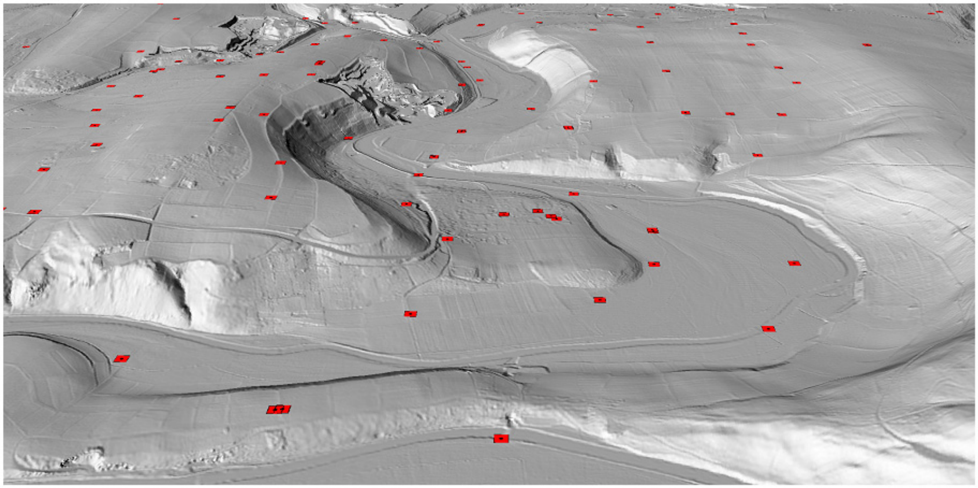

*Figure 6: Shaded relief view of the central part of the Vaihingen/Enz test range.*

*Figure 7: Signalized ground control point Vaihingen/Enz.*

*Figure 8: Control point measurements using static GPS surveys.*

Besides, a reference DTM obtained through airborne laser-scanning serves as area-wide height reference. This reference data was kindly provided by Landesvermessungsamt Baden-Württemberg. The laser flights were done in February 2001, using the Optech ALTM 1225 system (flying height 900m, scan frequency 25 Hz, scan angle $\pm$ 25deg, mean point distance on ground approx. 1.5m). The final DTM is available as 1m grid. Vertical accuracy is expected to be better than 0.5m. From analyses of absolute differences at available control points maximum differences in the vertical could have been proven non exceeding $\pm$ 20cm. Currently the re-flight of the test area with higher point density is discussed.

Finally, the Vaihingen/Enz test range is amended by additional geometrical (Figure 9) and radiometric resolution targets. All this then qualifies the area as one example of a fully equipped airborne test site, allowing for the geometric and radiometric analysis of the sensor and its products like the obtained digital height model. Being independent such test sites will have a major impact in future comprehensive sensor validation and certification activities.

*Figure 9: Siemens star for geometric resolution determination.*

## Automatic alignment of LIDAR and image data

The acquisition of 3D city and landscape models has been a topic of major interest within the photogrammetric community and a number of algorithms became available both for the automatic and semiautomatic data collection. These 3D models are mainly used for visualisation to generate realistic scenes and animations e.g. for planning and navigation purposes. Since area covering urban models are usually extracted from airborne data, a refinement is required especially if realistic visualisations from pedestrian viewpoints are aspired. Of particular interest are algorithms that allow for a fully automatic facade reconstruction process at different levels of detail. For this purpose, in our approach terrestrial LIDAR data as well as facade imagery is used to increase the quality and amount of detail for the respective 3D building models.

Images provide high resolution information and can be collected at little effort. On the other hand, densely sampled point clouds from terrestrial laser scanning usually show depth displacements between facade elements and can therefore efficiently support their segmentation. An integrated collection of images and 3D point clouds is feasible by mobile systems, where a laser scanner and a camera are mounted on a car. In contrast, we use standard equipment consisting of a terrestrial laser scanner (Leica HDS 3000) and a digital camera (NIKON D2x Lens NIKKOR 20mm), which is not directly integrated with the laser scanning system. Independent camera stations allow for a flexible data collection, but the registration of images to terrestrial laser scans typically involves manual effort if no specially designed targets are used for the control points. Additionally, complex areas like urban environments can only be completely covered by terrestrial laser scanning if data is collected from different viewpoints. Standard approaches align these scans from different viewpoints based on tie and control point information, which has to be measured at special targets.

Aiming at the fully automatic georeferencing of the collected LIDAR and image data, we propose a two-step approach which integrates existing 3D building models and image processing tools. The first step comprises the georeferencing of the LIDAR data. During collection of the 3D point clouds, a low-cost GPS and a digital compass are mounted on top of our HDS 3000 scanner. Thus, the position and orientation of the scanner can be measured for a direct georeferencing of the different scans. This approximate solution is then refined by an automatic registration of the laser scans against available 3D building models, which are used as reference data for the refinement of the georeferencing process. For this purpose, the standard iterative closest point algorithm is applied.

In a second step, the images are registered to the terrestrial laser scans. Common terrestrial laser scanners sample object surfaces in an approximately regular polar raster. Each sample provides 3D coordinates and an intensity value representing the reflectivity of the respective surface point. Based on the topological information inherent in data acquisition, the measured reflectivity data can be depicted in the form of an image. This allows for the application of image processing tools to connect the images collected by the photo camera to the LIDAR data. However, images generated from laser reflectivity considerably differ from images that have been collected by photo cameras. The measured laser intensities represent the reflectivity of the measured surface only in a narrow wavelength range (for example 532nm for the HDS 3000). Furthermore, the viewing direction and the direction of illumination are identical in case of laser scanning. By contrast, photo cameras usually work with ambient light sources, which may cause shadow areas on the object and therefore lead to grey value edges in the photograph. Imaging geometry is different, too. The laser image is not based on central projection but on polar geometry. Thus, straight 3D lines may appear curved in the reflectivity image. Another aspect is the sampling distance, which is often much higher for a laser scan compared to the spatial resolution of a photo captured by a camera. For these reasons, the determination of point correspondences between a laser reflectivity image and a photograph requires an algorithm, which is insensitive to changes in illumination and scale and uses region descriptors instead of edge detectors.

*Figure 10: Point correspondences for the laser reflectivity image (left) and a photograph (right).*

Figure 10 depicts the laser reflectivity image (left) and one of the photographs acquired by the NIKON camera (right) in real proportions. In order to have similar intensity values in both images, only the green channel of the photograph has been considered for the determination of corresponding points. The resulting key points were extracted and matched by means of the SIFT (scale invariant feature transform) algorithm. Using default settings 492 key points are detected in the laser reflectivity image and 5519 in the photograph. Of those 31 are matched to corresponding key points represented by the red dots and lines in Figure 10. As a result of the matching, control point information can be derived for a subsequent bundle block adjustment. Figure 11 shows an image sequence (left) and the reconstructed camera stations and 3D points (right).

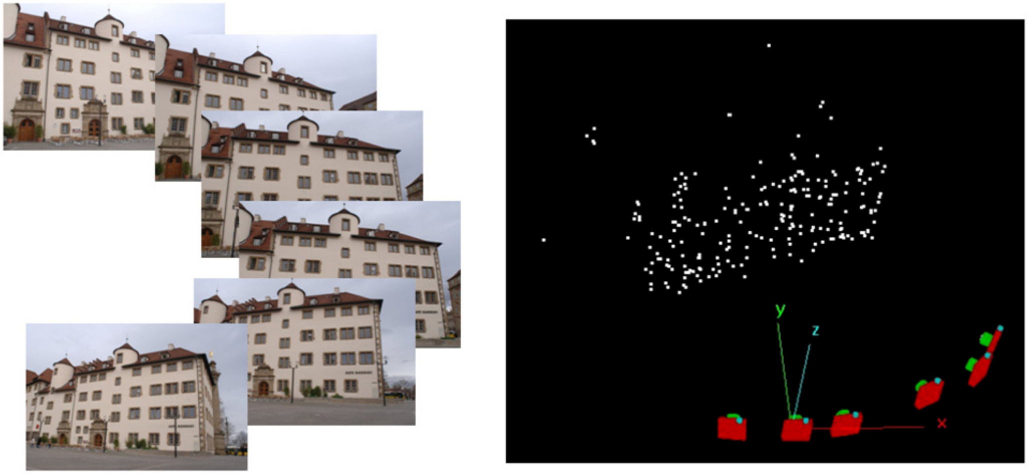

*Figure 11: Image sequence (left), reconstructed camera stations and 3D points (right).*

## Terrestrial Positioning Systems and Computer Vision

### Automatic Marker-Free Registration of Terrestrial Laser Scans

Commonly several separate stations are required to entirely collect the geometry of a scene with a terrestrial laser scanner. A crucial step in the data processing pipeline is the alignment of the stations into a common reference frame, usually referred to as registration. Many approaches have been proposed to address this issue. They differ in the prerequisites on the scene, prior knowledge, extra sensor measurements and the level of automation and robustness. The standard method for registration is marker-based registration. Either several markers have to be placed in the overlapping areas of the scans and measured with the laser scanner or their coordinates have to be pre-determined with a separate measurement instrument, commonly a total station. The marker-based registration is expected to achieve the highest accuracy. However, this approach requires extra effort for the placement and measurement of the targets. Furthermore, the placement of targets is prohibited for certain sites. Direct orientation of terrestrial laser scans has been investigated in an earlier study (Schuhmacher and Boehm, 2005). There we include GPS, compass and pan-tilt sensors to directly measure position and orientation of the laser scanner and thus determine the absolute pose of the data. While this approach not only solves the registration problem but also provides georeferencing of the data, it heavily depends on the quality of the additional sensors. For low-cost sensors, the approach is mainly suited to provide initial approximations for latter refinement. Feature-based registration approaches extract a certain type of features from the measured data and attempt to match features in-between the separate scans. From close-range scanning many curvature-based methods for feature point extraction are known. However, these methods fail in the case of urban scenes where planar surfaces are dominating. In image-based modeling the Scale Invariant Feature Transform (SIFT) proposed by Lowe is a very popular operator for the extraction of features. The operator works on an image pyramid and computes the difference-of-Gaussian for each level. Local extrema are candidate features. An invariant representation of the area around the feature points is used as a feature descriptor. The features have shown to be largely invariant to scale changes and varying illumination. Obviously, such robust features are also interesting for the registration of terrestrial laser scans. Here we explore the application of the SIFT method on laser reflectance data. Since scans are taken in an approximately regular polar grid, the collected reflectance data can be represented in the form of an image. Therefore the data can be directly used with standard SIFT implementations as shown in figure 12.

*Figure 12: The feature points extracted and matched using the SIFT method on the intensity data of a terrestrial laser scan.*

We show that the extracted features are good candidates for registration. Furthermore, we show that feature matching based only on the feature descriptor is sufficient for registration of terrestrial laser scans. The pairs of matched feature points contain a high degree of false matches. In our experiments, the number of outliers exceeds 90 percent. Including the geometry of the tie points, we are able to separate the outliers from the correct matches. This is shown in figure 13. From the resulting set of matches, we compute the rigid body transform for a pair-wise registration. It is interesting to observe, that the approach can be extended to not only automatically register terrestrial laser scans, but also automatically register intensity images taken with a separate camera to the laser data. This offers the possibility to strengthen the network geometry or simply to automate texturing from hand-held cameras. We demonstrate the results on an example dataset, which was acquired with a Leica HDS 3000 pulsed time-of-flight terrestrial laser scanner. The test scene is an old farm building, a typical application for terrestrial laser scanning. The data was acquired at an approximate sampling distance of 2cm on the object's surface. The data set is available for download from our web pages.


*Figure 13: Three corresponding feature points extracted in two different data sets. They represent the best consensus found through RANSAC. They are imported as tie points in Cyclone for registration.*

**Recording of the „Chartreuse de Valbonne"**

In cooperation with the Institut für Architekturgeschichte (IAG), Universitaet Stuttgart and the Laboratoire d'Archéologie Médiévale Méditerranéenne, Université de Provence we aid in the architectural documentation of the „Chartreuse de Valbonne" in Southern France. In repetitive campaigns we use our laser scanning and photogrammetric equipment to record parts of the monastery. This year's focus was on the main church, which is shown in Figure 14.

*Figure 14: Exterior photograph of the „Chartreuse de Valbonne“ showing the main church on the left in a view of the roof truss, which is located directly over the dome.*

Of particular interest was the dome of the church. It was scanned from inside the church on a single station. Additional scans were made from inside the roof truss. Eight stations were used to completely cover the outside surface of the dome. Both datasets were connected using classical surveying. A section through the combined data is shown in Figure 15.

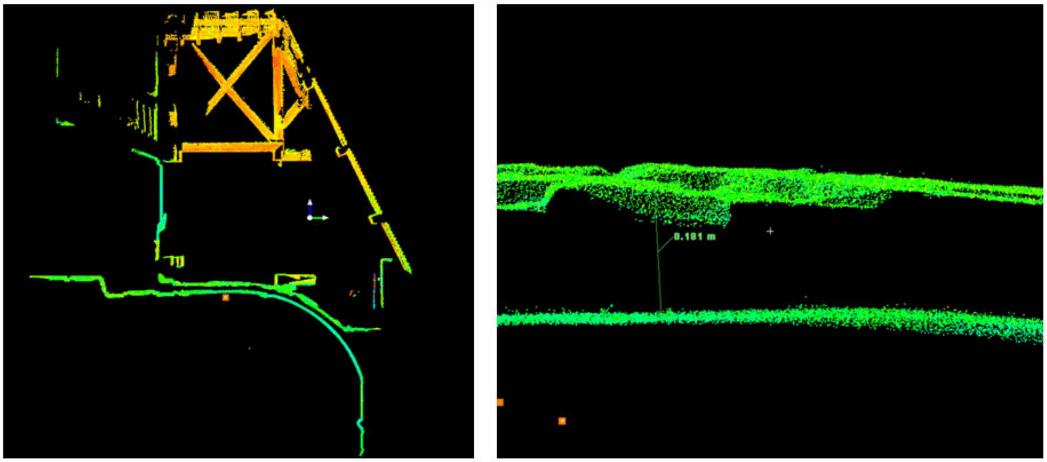


*Figure 15: Vertical section through the data, combining scan data from inside the church and from inside the truss. The thickness of the dome ceiling can be directly measured from the data.*

**Indoor Navigation using Image Sensors**

We address the task of indoor navigation by a concept of visual navigation using known landmarks extracted from terrestrial laser scans. The problem of image orientation consists of the determination of the rotation and translation of the image frame with respect to some external coordinate frame. Image orientation from image sequences is a classical problem in photogrammetry and computer vision. Applications are widespread and can range from pedestrian self-localization, autonomous robotics and augmented reality to object recognition under camera motion. Many approaches addressing the problem have been proposed. Some use direct orientation sensor such as inertial measurement units (IMUs) and GPS systems to determine orientation and position, others use a combination of a variety of sensors, such as ranging, imaging and orientation sensors. We propose a point-based environment model (PEM) to represent the absolute coordinate frame and to store the prior knowledge of the scene. A PEM is a dense pointwise sampling of the surface of the objects in a scene. Each sample consists of the three-dimensional coordinate of the location of the point and an associated intensity value. The novelty of the approach is the fact that we base the approach on a PEM that has been acquired from a separate sensor system, than we use for the actual tracking. The 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. Once this data has been acquired it can serve multiple purposes, our proposed application being only one in many. It is not the intention to acquire the point cloud specifically for the purpose of intensity image orientation. Other approaches would be more practical in that case. The PEM provides landmarks which are used for intensity image orientation. The landmarks are feature points which are tracked across the image sequence. The core of the orientation procedure is based on ideas from structure from motion algorithms, tracking algorithms and generally visual navigation. Figure 16 shows the sensors utilized for this study.

The method effectively aligns the image stream with a three-dimensional point cloud. A contribution of this work is the observation, that intensity features extracted from laser scanner point clouds provide sufficient landmarks for the orientation of intensity images. This enables the use of separately acquired point cloud data (possibly collected for completely different purposes) for self-localization and navigation tasks. The benefit of this approach is that no artificial landmarks, beacons, etc. have to be place in the environment. Still the mobile agent needs to be equipped with only an intensity camera. In Figure 17 we finally show the trajectory recovered with our approach in an example office environment.

*Figure 16: The sensors utilized for this study are a laser scanner and a machine vision camera. The laser scanner to the left is a Leica HDS 3000. The camera to the right is a Basler A302f. Both devices were mounted on a tripod during data acquisition. The camera was moved using a dolly.*

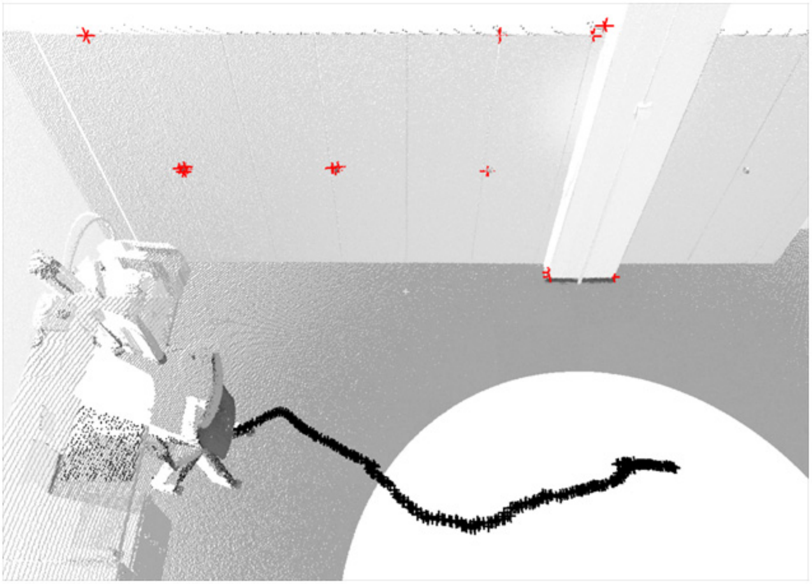

*Figure 17: Recovered trajectory over a sequence of 400 frames with arbitrary camera motion. The red crosses indicate the automatically extracted land-marks, which are used for tracking. The black crosses indicate the camera positions.*

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## Diploma Theses

Trigui, A.: Improved matching of scale invariant Intensity features using geometrical information. Supervisor: Böhm, J.

Fietz, A.: Experimenteller Genauigkeitsvergleich von trifokalen und bifokalen Messsystemen zur optischen Inspektion von Fahrzeugachsen. Supervisor: Gebhard, M. (Robert Bosch GmbH) and Haala, N.

Peter, M.: Segmentierung von 3D Punktwolken zur Verfeinerung existierender Stadtmodelle. Supervisor: Haala, N.

Ye, Z.: Untersuchung China-spezifischer Navigations- und Kartenmerkmale für neue Telematiksysteme. Supervisor: Walter, V., and Zou, P. (DaimlerChrysler AG).

Farkas, E.: Empirische Genauigkeitsuntersuchung der DigiCAM.H/22 Luftbildkamera. Supervisor: Cramer, M. and Kremer, J. (IGI).

## Study Theses

Bentel, K.: Detektion vertikaler Strukturen in bodengestützten LiDAR Daten. Supervisor: Böhm, J.

Peter, M.: Einsatz von Laserscanning in der Bauaufnahme. Supervisor: Böhm, J.

Fietz, A.: Detection, classification and fitting of quadric surfaces in 3D laserscanner pointclouds. Supervisor: Haala, N. and Lerma, J.L. (Universität Valencia).

## Activities in National and International Organizations

Balz, T.:

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Member Apple's University Education Forum (UEF)

Member Advisory Board Finnish Geodetic Institute

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Chairman Scientific Advisory Board "Baden-Württemberg International"

Haala, N.:

Co-Chair ISPRS WG III/4 - Automatic Image Interpretation for City-Modelling

Walter, V.:

Nationaler Berichterstatter für die ISPRS Kommission IV

## Education - Lectures/Exercises/Training/Seminars

### Diplomstudiengang Geodesie und Geoinformatik

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|---|---|
| Adjustment theory and Statistical Inference I, II (Fritsch, Sneeuw) | 4/2/0/0 |
| Advanced Projects in Photogrammetry and GIS (Böhm, Cramer, Haala, Walter) | 1/2/0/0 |
| 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 |

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| 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 |

**Master Course Geoengine**

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| Airborne Data Acquisition (Fritsch, Cramer) | 1/1/0/0 |
| Geoinformatics (Fritsch, Walter) | 2/1/0/0 |
| Signal Processing (Fritsch, Böhm) | 2/1/0/0 |
| Topology and Optimisation (Fritsch, Becker) | 2/1/0/0 |

**Master Courses Infrastructure Planning and Water Resource Management**

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| Advanced GIS (Walter) | 2/0/0/0 |

**Diplomstudiengang Geographie (Stuttgart and Tübingen)**

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| Geoinformatics I (Fritsch, Walter) | 2/1/0/0 |
| Geoinformatics II (Walter) | 2/1/0/0 |
| Practical Training in GIS (Walter) | 0/0/4/0 |

**Diplomstudiengang Luft- und Raumfahrt**

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| Introduction into Photogrammetry (Cramer) | 2/0/0/0 |

## Honors/Awards

Fritsch, D.: Honorary Professor of Wuhan University, Wuhan/China, 11/07