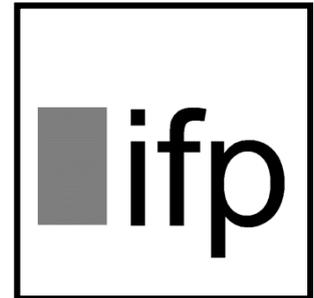
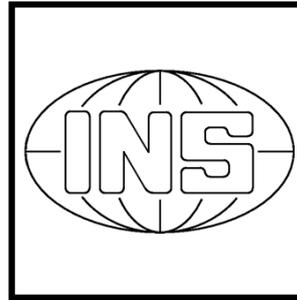


# The Department of Geodesy and Geoinformatics



Stuttgart University  
**2009**

**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<sup>1</sup> on the 2009 activities and academic highlights of the Department of Geodesy & Geoinformatics of Universität Stuttgart. The Department consists of the four institutes:

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

In the course of 2009 we have successfully filled the vacant chair of Engineering Geodesy and Geodetic Metrology. We are delighted to announce that Prof. Dr.-Ing. habil. Volker Schwieger was appointed to this chair and assumed the position of head of IAGB (formally as of April 2010).

## Research

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

## Teaching

Also Stuttgart is now participating in the Bologna process. Our first-year students entered the new BSc programme *Geodesy & Geoinformatics*. Total enrolment, in both the BSc and the Diploma programmes, is stable at about 130 students. Please visit our redesigned website [www.geodaesie.uni-stuttgart.de](http://www.geodaesie.uni-stuttgart.de) for additional information on the programme.

For the first time in its four-year existence, our international MSc programme Geomatics Engineering (GEOENGINE<sup>2</sup>) has achieved the enrolment target of 15 students. We attract the GEOENGINE student population from such diverse countries as China, Iran, Indonesia, Pakistan, Kenya, Uganda and Nigeria.

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

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<sup>1</sup>A version with colour graphics is downloadable from  
<http://www.ifp.uni-stuttgart.de/publications/jahresberichte/jahresbericht.html>

<sup>2</sup><http://www.geoengine.uni-stuttgart.de/>

We want to express our gratitude to our friends and sponsors, most notably

- ▷ Verein Freunde des Studienganges Geodäsie und Geoinformatik an der Universität Stuttgart e.V. (F2GeoS),
- ▷ Microsoft company Vexcel Imaging GmbH,
- ▷ Ingenieur-Gesellschaft für Interfaces mbH (IGI),
- ▷ DVW Landesverein Baden-Württemberg,

who support our programmes and our students with scholarships, awards and travel support.

### **Festivities**

The year 2009 abounded in festivities and celebrations. Four events stood out:

- ▷ A geodetic colloquium on November 6th in honour of Prof. Dr.-Ing. Dr.E.h. mult Fritz Ackermann in honour of his 80th birthday.
- ▷ A geodetic colloquium on December 4th in honour of Prof. Dr.-Ing.habil. Dr.tech.h.c.mult Dr.-Ing.E.h.mult Erik W. Grafarend in honour of his 70th birthday.
- ▷ 100th anniversary of Photogrammetric Week, organized by ifp at on September 7-11.
- ▷ The award of an honorary doctorate to Prof. Fernando Sanso of the Politecnico Milano for his scientific achievements in the area of theoretical geodesy at the annual Dies Academicus (November 13th).

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



## Institute for Applications of Geodesy to Engineering

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### Head of Institute

Prof. Dr.-Ing. Ulrich Rott, (Provisional Director) till March 2009  
Prof. Dr.-Ing. Ewald Krämer, (Provisional Director) since April 2009  
Dr.-Ing. Martin Metzner, Akad. Oberrat

### Secretary

Elke Rawe

### Emeritus

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

### Scientific Staff

Dipl.-Ing. Alexander Beetz	Sensor Integration
Dr.-Ing. Renate Czommer (till 30.09.2009)	Map Matching
Dipl.-Ing. Ralf Laufer	Quality Assurance
MSc Rainer Schützle	Information Quality
Dipl.-Ing. Jürgen Schweitzer	Construction Process
PD Dr.-Ing. Volker Schwieger	Engineering Geodesy
Dipl.-Ing. Matthias Wengert (till 30.09.2009)	Geodata and GIS Applications
Dipl.-Ing. Li Zhang (since 15.09.2009)	Construction Process
Dipl.-Ing. Bimin Zheng (since 01.04.2009)	Kinematic Positioning

### Technical Staff

Martin Knihs  
Lars Plate  
Doris Reichert

## External teaching staff

Dr.-Ing. Max Mayer - Landesamt für Flurneuordnung

## General View

After the retirement of Prof. Rott, until then provisionally head of the institute, Prof. Krämer provisionally is in charge of the institute. The work of the appointments committee on the new professorship is being continued throughout the year 2009. The Institute for Applications of Geodesy to Engineering is member of the faculty „Aerospace Engineering and Geodesy“. Furthermore, IAGB is still member of FOVUS (Traffic research Centre of the University of Stuttgart) and thus continues the close collaboration with the faculty „Civil and Environmental Engineering“.

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

In education, the institute is responsible for the above-mentioned fields within the curricula for „Geodesy and Geoinformatics“ as well as for „Geomatics Engineering“. In autumn 2009 the Bachelor „Geodäsie und Geoinformatik“ began for the first time. This curriculum in combination with the future Master will replace the diploma curriculum. In addition to the education in Surveying for Architects and Surveying for Civil Engineers, lectures on Acquisition and Management of Planning Data are presented to the diploma course of Technique and Economy of Real Estate. Furthermore, lectures are given to students of Geography and Traffic Engineering as well as two lectures in English within the master course Infrastructure Planning. Finally, eLearning modules are applied in different curricula e.g. for geodetic measurement techniques or for cartographic animations. The current research is reflected in most lectures and in diploma theses.

## Research and development

### Positioning by mobile phones

The basis of modern traffic control and management is the acquisition of the current traffic state and a reliable traffic prediction. Traditionally, local loop data and GPS-based floating car data (FCD) are the methods for traffic state acquisition. These methods are currently extended by so-called floating phone data (FPD) based on positions of mobile phones which are matched on the digital road network. Due to the required availability of all mobile phone positions at a particular time and at one computing centre, the positioning methods have to be network-based and not handset-based. The network-based approach is pursued within the project „Data Optimisation for integrated Telematics“ (Do-iT) until March 2009 and was granted by the German Federal Ministry of Economics and Technology.

If positions shall be determined in a high temporal and spatial resolution, the data of the so-called A-bis interface has to be used. Here the signal strength observations of the serving and six neighbouring GSM antennas received at the mobile phone are recorded in the GSM network. Positions are estimated with a frequency of 2Hz by matching these signal strength observations onto a signal strength map available for every GSM antenna. Different filter algorithms identify participants in the GSM network as pedestrian, cyclist, individual or public traffic participant. Kalman-filtered positions of one identified participant are generating a kind of corridor based on the uncertainties of the position estimation. Within this corridor, data of the road network are extracted from the digital map. Most probable trajectories are derived on the basis of shortest path algorithm (c.f. Figure 1).

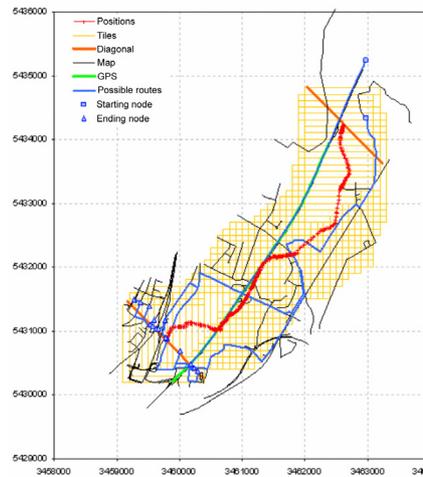
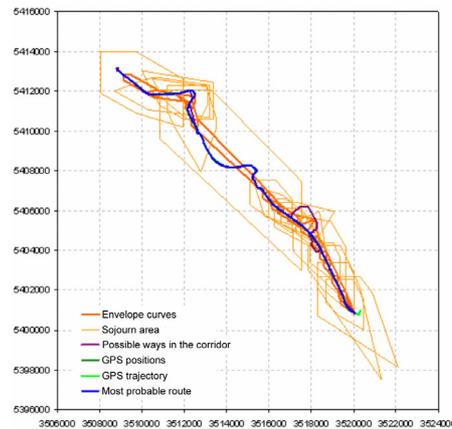


Figure 1: Computation of possible trajectories (blue) with computed positions (red) using Abis-data

Since Abis-data are only available during communication or connection the project Do-iT should also analyze the usability of A-data available at Mobile Switching Centers (MSC), which provide, in case of active connection, the change of one radio cell to another (handover). In stand-by mode only the old and new location area and the new radio cell are available. The street network will be matched with the cells of the mobile phone network, because there is no possibility to compute the positions directly with the information of the A-data. The intersections between the edges of both networks represent the most likely positions raes of the mobile phone users during the handovers. Consecutive most likely position areas are joined together to form a corridor limiting the digital road map. In this corridor all possible routes will be generated by shortest path algorithms between nodes at the first and last handover. The most common part of all possible routes is chosen as most probable route (c.f. Figure 2). At the end, a path-time diagram will be calculated with regard to the chosen route.



*Figure 2: Computation of a trajectory (blue) with a corridor defined by envelope curves (orange) using A-data*

Both methods were tested in real-time. The test-site for Abis-data was in Karlsruhe and consists of two Location Area Cells (LACs) which corresponds to the urban area of Karlsruhe. The test-site for A-data was in Fellbach and consists of 52 LACs which corresponds to the area between the four cities of Stuttgart-Heilbronn-Mannheim-Karlsruhe. The server for Abis-data was in operation from 12.11.2008 to 31.03.2009 and produced ca. 1300 trajectories a day. The server for A-data was in operation from 28.01.2009 to 31.03.2009 and produced ca. 30 000 trajectories a day. With the generated data and the respective path-time diagrams prediction of traffic states were computed. The results were displayed in the internet. Figure 3 shows the online representation in the internet. Red represents traffic jam, yellow represents stop-and-go traffic and green represents undisturbed flow of traffic. At the same time, it was possible to compare the computed predictions with the predictions of the commercial traffic service TMCpro. During the on-line operation, one

could detect that it wasn't possible to compute trajectories for all mobile phone users over one day. That means that for a commercial use it is essential to optimize the algorithms and to use more powerful computers. Altogether we could show that it is possible to make forecasts of the traffic state with floating phone data (FPD). Furthermore, FPD is a good source of information and a good addition to current methods for forecasts of traffic state.



Figure 3: Forecast of traffic state with A-data

### Quality Evaluation of vehicle trajectories generated by radiolocation of Mobile Phones

The project Do-iT was finished successfully in 2009. In a final step the usability of traffic information extracted from mobile network was analyzed within demonstrators of the project partners. Main task of the IAGB was the evaluation of FPD-trajectories, which are calculable with the developed algorithms using appropriate reference data. Besides a number of test-drives where a GPS-receiver was used for parallel recording of the driven reference trajectory, daily updated measurements of traffic data from stationary traffic data acquisition systems (SAS) were available within the project network.

Besides others, two quality parameters were defined for evaluation of the trajectories which quantify the mapping of calculated routes to the corresponding reference measured with GPS. One of these two parameters shows the correctly matched part of a route referring to the reference route measured by GPS (*mapping correctness type A*), the other parameter refers the correctly matched part to the FPD-route (*type B*). Type B shows the percentage of the FPD-trajectory that is matched on the correct GPS trajectory.

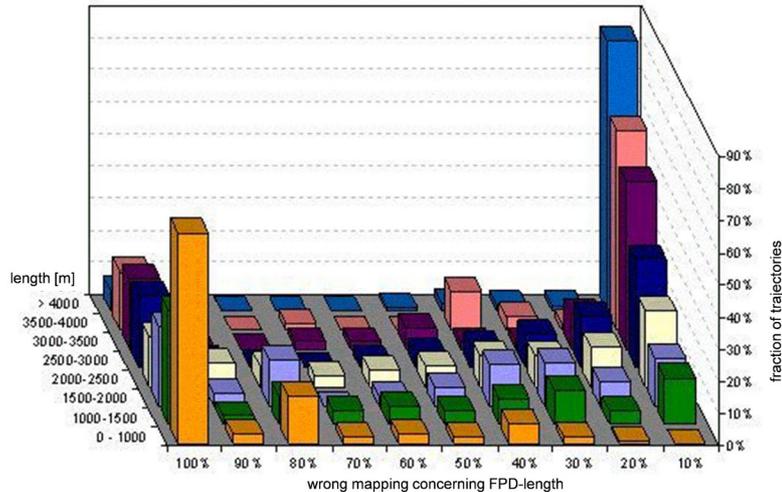


Figure 4: Mapping correctness type B with respect to the route-length (Abis-data)

The mapping correctness type B for the test-drives for evaluation of mobile phone data which are only available during calls (Abis-data) is shown in figure 4. The research shows a heavy connection of the route correlation with the length of the driven route of the mobile phone user. Starting with route-lengths exceeding 3 km, the investigated trajectories show less than 10 % of wrong information in more than 80 % of cases. However an average speed close to reality can be extracted correctly from the path-time-diagram beginning with a route length of 8 km.

Two more quality parameters for evaluation of trajectories using counted measurements of SAS were defined in addition. Approximately 170 measuring points were available to evaluate completeness and correctness of FPD-trajectories using the two parameters

- ▷ saturation in [%] (fraction of traffic detected by FPD from overall traffic) and
- ▷ rank correlation (correlation of diurnal cycle of traffic volume from FPD and SAS).

The period of evaluation lasted only from 23<sup>th</sup> – 31<sup>th</sup> March 2009 due to external time delays within the project. Figure 5 shows as an example the diurnal cycles of the traffic volume calculated from A-data for one day and two different sensors on motorways within the project network.

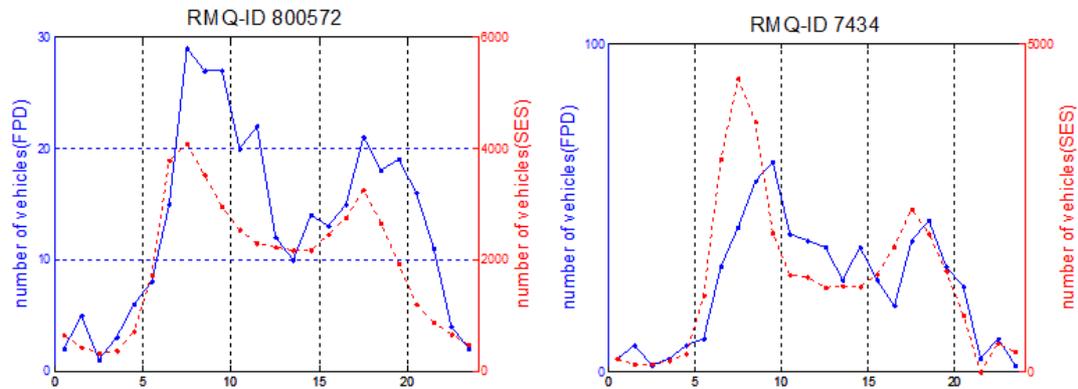


Figure 5: Typical diurnal cycles of traffic volume detected with FPD (continuous) and SES (dashed)

The mean saturation for all SAS with FPD from A-data, reaches an average of approx. 8.5 ‰, respectively up to 600 veh./day on motorways and declines with the rise of infrastructure density below 1 ‰ in the inner city of Karlsruhe, respectively less than 1 veh./h. The rank correlation of diurnal cycles reaches an average of more than 0.8 and declines in the city to less than 0.5.

Finally it can be concluded that GSM-based radiolocation is able to get dense traffic information which can be used for example to calculate the traffic state. However the potential is heavily depending on the density of the surrounding infrastructure as well as on the distances between intersections. Coverage of motorways with a quality which is even capable for estimation of traffic situation appears realistic. This applies as well for the coverage of the highway network within rural areas. But due to the GSM-network structure and the thereby limited spatial resolution, the radiolocation reaches natural limitations within the cities.

The combination of A- and Abis-data could be a chance. In rural areas the exclusive analysis of A-data seems to be sufficient and saves computing time. In areas with more dense infrastructure the use of Abis-data (which is much more complex and therefore computationally more intensive) can support the results due to a higher spatial resolution and position accuracy.

### Modular System for Construction Machine Guidance

The modular system for construction machine guidance (PoGuide) which was developed at the institute is subject to continuous improvement. The core of PoGuide is a simulator for Hardware-in-the-Loop simulations. It consists of a remote control, model truck, robot tachymeter (Leica TCRP 1201) and an interface between a PC and the remote control.

Meanwhile the simulator was enhanced with individual shiftable modules. These modules are for example various controllers (2-point-, 3-point-, P-, PI-, PID-controller) and also an improved Kalman filter which uses the geometric information of the predetermined trajectory for the prediction of the measured points. Furthermore, the simulator was upgraded with a module for automatic calibration of the steering. In the past, calibration of the steering needs one working day. Now, the calibration process is done in 30 minutes. The enhancement which can be achieved with new calibration parameters is shown in Figure 6. In the chart the lateral deviations of a test drive before and after a calibration will be compared.

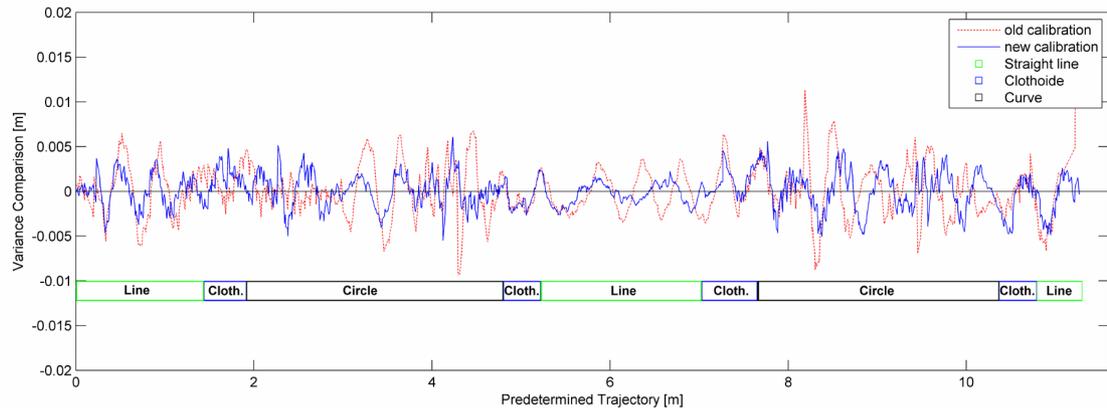


Figure 6: Lateral deviations before (red dotted line) and after (blue straight line) the calibration

It is obvious that the lateral deviations after the new calibration (blue straight line) are smaller than before (red dotted line). The remaining oscillation is damped and a little bit smoother. The drives with the new calibration parameters increase the mean RMS of the lateral deviations from 2.5 mm up to 1.8 mm.

In the future the computation of the vehicle azimuth will be stabilized with a MEMS inertial measurement unit (c.f. Figure 7). This inertial measurement unit (IMU) transmits data of three gyroscopes, three acceleration sensors and three magnetometers via a 2.4 GHz radio interface to the control PC. The current Kalman filter must be adapted to this implementation. Additionally robot tachymeters of different manufacturers should be integrated in the simulator system. Thereby the main focus is the modularity and easy exchangeability of the sensors. Furthermore, for upgrading of the vehicle models in the simulator system, a model of a dozer (scale 1:14, Figure 7) should be acquired which simulates the behavior of tracked vehicles.



Figure 7: On the left MEMS-IMU (source: Microstrain), on the right model dozer (source: Tamyia Carson)

### Kinematic GPS-Measurements for Evaluation of TanDEM-X Data

Based on the evaluation method of TanDEM-X Data developed in 2008, five tracks were evaluated last year using the method „Precise Point Positioning“ (PPP). Tracks were driven in China, Russia and the remaining three tracks are located in South America. Figure 8 shows an overview of the processed tracks.

The raw data (RINEX-files) are processed with the „GPS-Inferred Positioning SYstem and Orbit Analysis Simulation Software“ (GIPSY-OASIS (GOA II)) provided by „Jet Propulsion Laboratory“ (JPL) and with the „Canadian Spatial Reference System (CSRS) PPP Online service“ provided by the „Natural Resources Canada“ (NRCan). Finally, an evaluation of the result is realized using PDGPS. Therefore a reference station near the track has to be chosen. Only the points within a radius of 20 km are evaluated and compared with the PPP solution.

The track from Krasnojarsk to Belgorod in South Russia has a length of about 4585 km and is divided into 40 separated parts. Each part shows driving times between 63 to 481 minutes. A LEICA GX 1230 receiver and an AX 1202 antenna were used for the data acquisition.

In the figure 9 a track part of the results is visualized in ArcGIS. The grey coloured track consists of all gathered measurements. The red tracks are the selected measurements with a position difference smaller than 1 meter between the two solutions (GIPSY-OASIS and CSRS). The availability rate is approximately 84%. The next step is the evaluation of the tracks from South Africa, West Africa, Australia, USA, Canada and India.

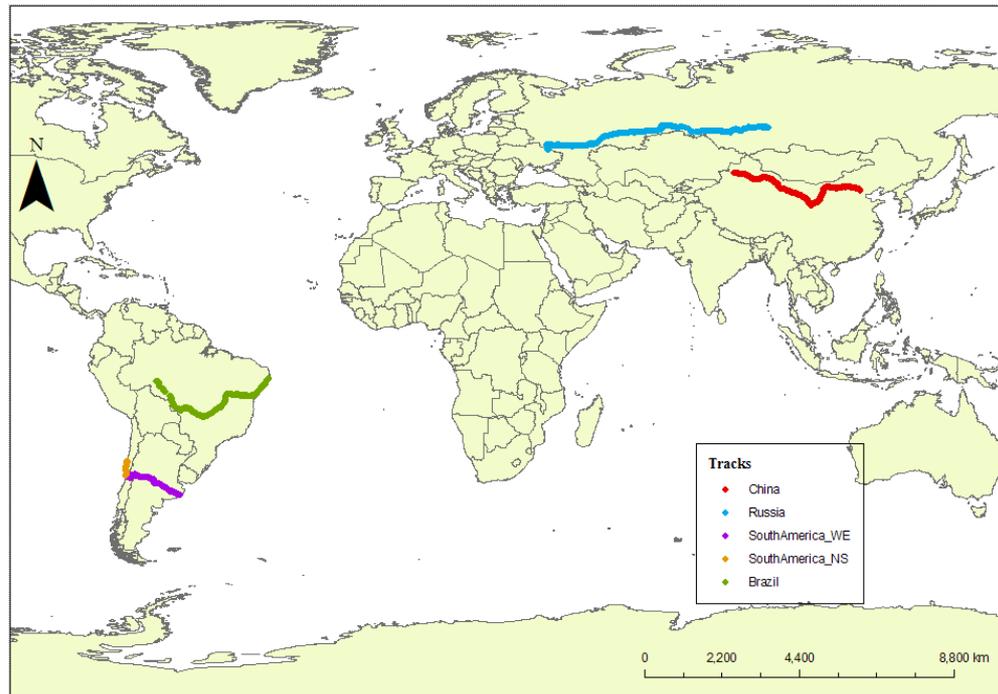


Figure 8: Overview of the tracks

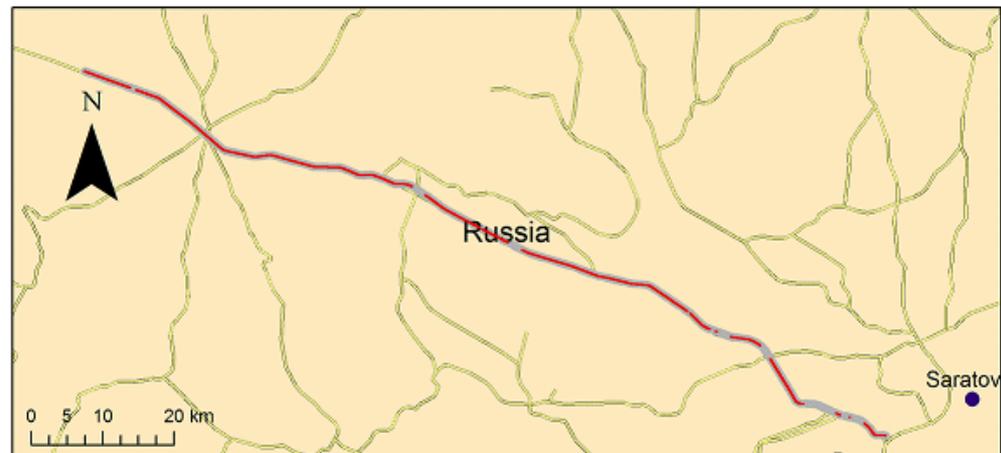


Figure 9: Track part of the track in South Russia  
(grey - all data; red - data used for TanDEM-X evaluation)

## Verification and Validation of a Road Safety Feature Exchange Infrastructure

The ROSATTE project aims to develop an infrastructure for quality assured exchange of road safety features, such as speed limits, warning signs and road restrictions, among others. The project especially focuses not on the exchange on complete datasets of such features, but on the exchange of incremental updates in case the situation on site changes. From an organizational point of view, partners from a local, regional and European level are involved, namely the local road authorities responsible for the provision of change notifications. Governmental authorities on state or country-wide level join these datasets in respective databases, from where potential users such as map manufacturers can obtain the update information.

The obtained road safety feature updates will, for instance, be integrated into European-wide digital road maps. These maps will then be used by navigation or in future by more Advanced Driver Assistance Systems (ADAS). Such systems like speed warning rely on the map data and its quality. Therefore there is a big need to only integrate information into the maps that can be trusted, meaning that fulfill certain quality requirements. In order to be able to check whether the developed and implemented exchange infrastructure delivers quality assured information, a quality management concept was developed. It is based on the Six Sigma principle that is a very well known methodology in the production industry.

Six Sigma concentrates on individual improvement projects that can be started and conducted independently from each other, which leads to a high degree of flexibility compared to other concepts. The Six Sigma concept also focuses on the processes that are to be controlled. This is optimal for research projects like ROSATTE, since the different partners can start individual improvement processes for the different parts of the ROSATTE data processing chain. The name Six Sigma originates from a concept where the deviations from the expectations or user requirements have to be minimized. The final goal was to reach a zero-defect strategy. For the individual quality parameters, a tolerance range was defined. The standard Six Sigma methodology is the so-called DMAIC model. The abbreviation stands for the five different phases, namely Define, Measure, Analyze, Improve and Control.

Further on the project deals with verification and validation methodologies. The verification step concentrates on assessing the functional requirements that have been derived at the very beginning of the project. The functional requirements describe the different parts of the data processing chain from the data acquisition at the local road authorities via the data processing and exchange within the different databases involved up to the final integration of the road safety feature updates at the users (e.g. commercial map manufacturers). It is therefore to be verified whether the implemented software tools, databases, acquisition procedures, and so forth work according to their specification. Such tests are all functional tests that can be answered with either yes or no.

The validation step aims to check whether the user requirements are fulfilled by what has been developed within the project. In contrast to the verification mentioned above, not the individual parts but the complete data processing chain is of interest here. It is also not relevant to check

the technical functioning but to concentrate on the update information that has been processed. This will be done using a set of pre-defined scenarios that have to be processed at the different test sites. In these scenarios a certain number of road safety feature updates of a certain type in pre-defined areas like urban, inter-urban and motorways have to be processed. The situation that has been entered into the system will be compared with the results after integration the update into the map providers' databases. The following parameters will be evaluated in detail:

- ▷ Update availability rate
- ▷ Completeness of individual Road Safety Features
- ▷ Completeness of a set of Road Safety Features
- ▷ Attribute Consistency
- ▷ Attributive Correctness
- ▷ Topological Correctness
- ▷ Database Actuality
- ▷ Data processing time
- ▷ Geometric Accuracy
- ▷ Efficiency / ease of usage
- ▷ Standardization / harmonization
- ▷ Ease of adoption in other countries

### **Quality model for residential houses construction processes**

To improve the possibilities of small and medium enterprises (SMEs) in the construction sector despite rising business competition, labour costs and material costs, the costs for construction should be minimized at the same time holding or even improving the quality. For this task a quality assurance system will be developed in the EU-project „Development of a Real Time Quality Support System for the Houses Construction Industry“ (QuCon), the system should enable the SMEs to document their recent project states and achieved quality targets in a simple and fast manner. A quality assurance software will be developed as the final product, that should be low-cost and able to check the quality of residential houses construction in 'Real Time'. This EU-project is granted by the AIF (Arbeitsgemeinschaft industrieller Forschungsvereinigungen), it began in February 2009 and will take two years.

For this project a construction process model was generated specially for residential houses construction. The sub-processes of the total construction process are chronologically arranged and relationships among the sub-processes and processes are also contained in this model.

The focus of IAGB within this project is the development of a consistent quality model for the building of residential houses and the definition of its parameters as well as quality indexes. If the

actual and target states of the required building and construction processes are compared in real time, this model will be able to calculate the quality assurance indexes. But the goal of the project QuCon is not only to evaluate the quality of the product but also to optimize the construction process, for this reason this quality model will distinguish between quality of products and of processes (figure 10).

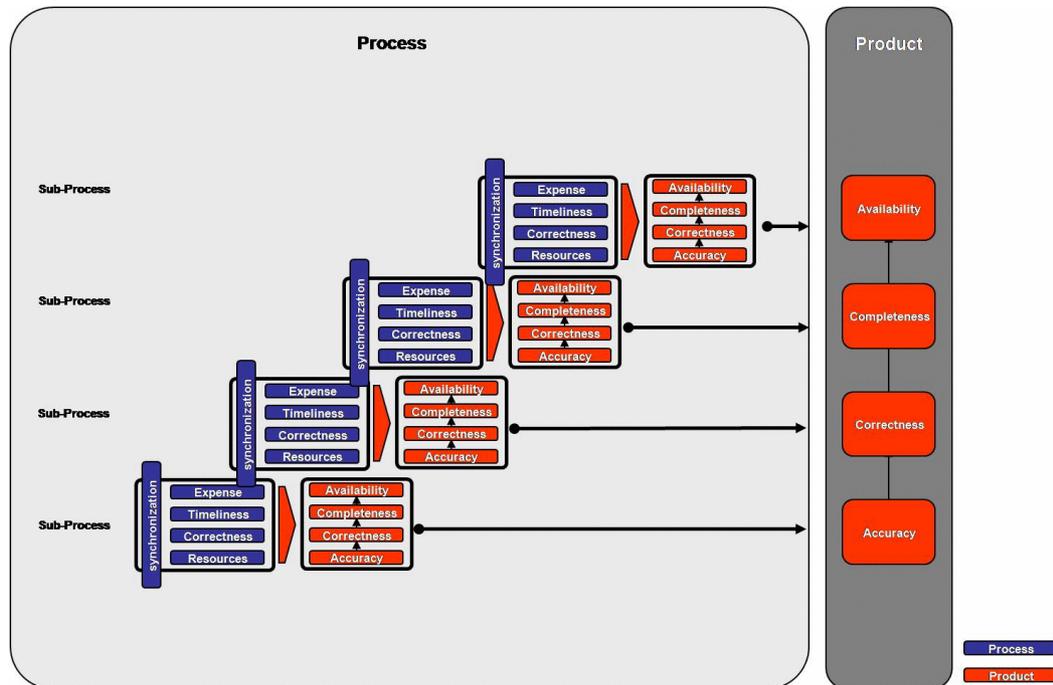


Figure 10: Quality model for residential houses construction processes

In the following the process- and the product-related characteristics are defined and described briefly.

#### Process related quality characteristics

- ▷ Expense - Adherence to the expense plan - relative expense rate in relation to the predetermined / planned Expense [%]
- ▷ Timeliness - Adherence to the time schedule. - Absolute time difference comparing with predetermined / planned schedule [days]
- ▷ Process-Correctness - Adherence to the predetermined procedure - binary decision: true/false [0, 1]

- ▷ Resource - Adherence to the predetermined resources - relative Resources rate in relation to the predetermined / planned resources [%]
- ▷ Synchronization - Adherence to the overall predetermined inter-process workflow -time difference of synchronal planned sub-processes [days]

The process related quality characteristics expense, timeliness, resource, synchronization as well as their parameter are defined in relation to the construction plan and the contract. The first four characteristics refer to the total process and sub-processes, only the fifth characteristic synchronization refers to the interaction among the sub-processes, it describes how far sub-processes, which dependent on each other, run synchronically.

#### Product related quality characteristics

- ▷ Availability: - Overall quality characteristic - availability index [dimensionless]
- ▷ Completeness - Adherence to defined completeness of product - completeness rate [%]
- ▷ Product-Correctness - Adherence to demands, requirements - binary decision: true/false [0, 1]
- ▷ Accuracy - Degree of adherence to demands, requirements - standard deviation [m]

The product related quality characteristic availability is defined as the overall quality characteristic that takes into account all other characteristics. The product related quality characteristics accuracy and product-correctness as well as the process related quality characteristic process-correctness can be concreted with parameters using standards, generally recognised codes of practice and technical demands written in the contract.

The quality characteristics should be concreted with the parameters and further on the measurement of the quality as well as the analysis method should be developed for this quality model. The surveyors can play an important role for the measurement of the quality.

#### Process modeling in building construction

In June of this year a project, supported by the DFG (German Research Foundation) has started. It is called „Optimisation of efficiency and quality assurance of engineering geodesy processes in civil engineering“ (german: Effizienzoptimierung und Qualitätssicherung ingenieurgeodätischer Prozesse im Bauwesen (EQuIP)) and has the goal to integrate the processes of engineering geodesy efficiently in building sequences with respect to quality control measures.

The first work package runs over 6 month and was carried through by four project partners: Geodetic Institute (University of Hannover), Institute of Construction Informatics (University of Hannover), Institute of Construction Management (University of Stuttgart), Institute for Applications of Geodesy to Engineering (University of Stuttgart).

The main aspect of the first work package was the formal description and modeling of the building process chain and the working-out of the interfaces to engineering geodesy.

As an example for the optimization of the integration of geodetic work in a building sequence the construction of a high-rise building with a climbing formwork was chosen. The modeling language Petri nets (also known as place/transition nets) are used.

Petri nets are mathematical modeling languages for the description, analysis and simulation of concurrent and dynamic systems and they offer a graphical notation as a mathematical formalism to describe asynchrony and discrete distributed systems.

Figure 11 shows a building sequence of a floor of a building in shell construction by means of the simplest Petri nets, the condition-event-nets (CEN). Rectangles represent transitions (i.e. discrete events that may occur) and circles represent places (i.e. conditions). Places may contain a natural number of tokens. A distribution of tokens over the places of a net is called a marking. With markings the state and dynamic aspects can be modeled.

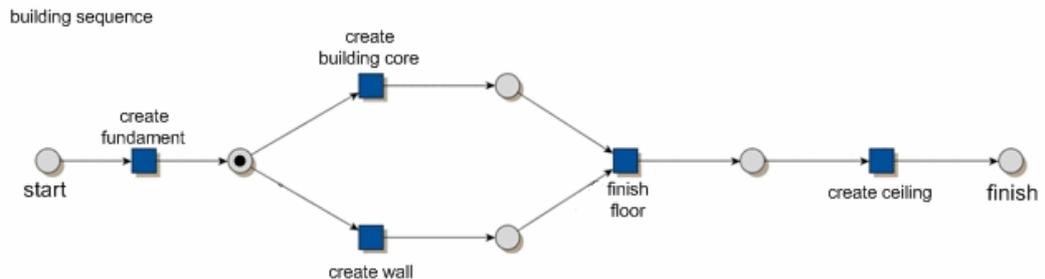


Figure 11: CEN for a floor of a high-rise building

Petri nets could also be nested, i.e. the process „create building core“ could contain a complete Petri net. In the next step it is planned to integrate methods of quality assurance in the whole process, based on a process orientated quality model with the goal to make a description of quality of the engineering geodesy processes and products in building sequences. It will be necessary to replace the simple CEN with high-level Petri nets (i.e. coloured Petri nets). Among others in high level Petri nets there can store additional information in tokens. This information could be e.g. the quality parameters.

## Activities of Prof. Dr.-Ing.Dr.sc.techn.h.c.Dr.h.c. Klaus W. Linkwitz in 2009

### 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 (COM-MAS)“ for foreign students. It was given as a 32-hour compact course in the summer semester

2009. The additional appertaining practical computer exercises were performed on windows-XP-computers of the CIP-pool of the course „Water Resource Engineering and Management (WAREM)“ of the department „Civil- and Environment Engineering“ in the University Campus Pfaffenwald. The exercises were intensified, since a final graded 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 given.

### **Symposia**

The following essential Symposia visited in 2009 have to be mentioned:

- ▷ IASS - International Association for shell and spatial structures, Valencia, 28.09.-02.10.2009. Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures - Form finding light plane load-bearing structures.
- ▷ Textile composites and inflatable structures III, Stuttgart 5.-7.10.2009; Organized by E. Oñate, Univ. Politecnica de Catalunya, Barcelona, Spain and B. Kröplin, University of Stuttgart, Germany

### **Publications**

- Beetz, A.: Signalstärken-Matching und Map-Aiding-Methoden zur Positionsbestimmung von Mobilfunkteilnehmern in Echtzeit. POSNAV - Positionierung und Navigation 2009, DGON-Symposium, Dresden, 27.-28.10.2009
- Laufer, R.; Beetz, A.; Czommer, R.; Schwieger, V.: Managing Data Quality - Exemplified for traffic data generated from mobile phone data. Proceedings on 16th ITS World Congress 2009, Stockholm, Sweden, 21.-25.09.2009.
- Laufer, R.: Evaluierung der Qualität von Verkehrsinformationen aus Mobilfunkdaten. POSNAV - Positionierung und Navigation 2009, DGON-Symposium, Dresden, 27.-28.10.2009.
- Linkwitz, K.: Grundbau Taschenbuch 07.Auflage, Herausgeber Karl Josef Witt, Teil I Geotechnische Grundlagen - 1.10 geodätische Überwachung von Geotechnischen Bauwerken (zusammen mit Otto Heunecke (Uni der Bundeswehr München), und Wilfried Schwarz (Bauhaus Universität Weimar)
- Huber, M., Wessel, B., Kosmann, D., Felbier, A., Schwieger, V., Habermayer, M., Wendleder, A., Roth, A.: Ensuring globally the TanDEM-X height accuracy: Analysis of the reference data

- sets ICESat, SRTM and KGPS-Tracks. International Geo Science and Remote Sensing Symposium, Kapstadt, Südafrika, 12.-17.07.2009.
- Rösch, N., Schweitzer, J., Pach, J. Die Auswirkung der Einführung von ETRS89/UTM auf Geofachdaten - Fallbeispiel eines EVU aus dem Bundesland Hessen. GIS.Science 4 (2009), S.123-129
- Schützle, R.: Quality Management in ROSATTE. ITS World Conference, Stockholm, Sweden, 21.-25.09.2009.
- Schweitzer, J. Kinematischen GPS Messungen als eine Methode zur Evaluierung eines globalen, digitalen Höhenmodells. Geodätische Woche 2009, Karlsruhe, 22.-24.09.2009.
- Schwieger, V.: High-Sensitivity GPS für geodätische Anwendungen. 83. DVW-Seminar, GNSS 2009: Systeme, Dienste, Anwendungen. Dresden, 18.-19.03.2009.
- Schwieger, V: Accurate High-Sensitivity GPS for Short Baselines. FIG Working Week, Eilat, Israel, 03.-08.05.2009.
- Schwieger, V., Lilje, M., Sarib, R.: GNSS CORS - Reference Frames and Services. 7th FIG Regional Conference, Hanoi, Vietnam, 19.-22.10.2009.
- Schwieger, V., Schweitzer, J., Kosmann, D.: GPS Precise Point Positioning as a Method to Evaluate Global TanDEM-X Digital Elevation Model. 7th FIG Regional Conference, Hanoi, Vietnam, 19.-22.10.2009.
- Schwieger, V.: High-Sensitivity GPS - an Availability, Reliability and Accuracy Test. INCT Bulletin des Sciences Geographiques, Institut National de Cartographie e de Teledetection (INCT), Algier, Algerien, No 23, September 2009.

### **Diploma Thesis**

- Lu, Bei: Fortführung einer Karte und Aufbau einer Internetpräsentation zu einem historisch angelegten Campusführer
- Radu, Diana: Beurteilung von Ausgleichungsrechnungssoftwarepaketen
- Xia, Jing: Qualitätsprüfung von Verarbeitungsprozessen für Geodaten am Beispiel AGORA

### **Master Thesis**

- Wang, Ruifen: Investigation on Precise Point Positioning for kinematic GPS tracks
- Shengzong, Su: Development of steady-state controllers and implementation of an up-dated version of a construction machine simulator

### Study works

- Bauer, Nina: Qualitätsbeurteilung der Mobilfunknetze mittels Daten stationärer Verkehrsdatenerfassungssysteme
- Frank, Jacek: Qualitätsmanagement für die Geodatenverarbeitung
- Fuchs, Thomas: Untersuchung des Umschaltverhaltens im GSM-Netz hinsichtlich geometrischer Reproduzierbarkeit
- Hoch, Alexander: Systeme zur vernetzten Zusammenarbeit in Bauprojekten (SA)
- Locher, Markus: Analyse des Bauprozesses im privaten Wohnhausbau
- Scheider, Annette: Entwicklung eines Qualitätsmanagementkonzeptes für die Erfassung und den Austausch von Geodaten

### Education

Basic Geodetic Field Work (Beetz, Wengert)	5 days
Geodetic Measurement Techniques II (Metzner, Wengert)	2/1/0/0
Geodetic Measurement Techniques I (Metzner, Zhang)	3/1/0/0
Geodetic Seminar I, II (Fritsch, Keller, Kleusberg, Schwieger, Sneeuw)	0/0/0/4
Integrated Field Work (in German) (Schwieger, Laufer)	10 days
Statistics and Error Theory II (Schwieger, Laufer)	1/1/0/0
Surveying (Czommer, Schweitzer)	2/1/0/0
Surveying Engineering I (Schwieger, Zheng)	2/1/0/0
Surveying Engineering II (Schwieger, Zheng)	2/1/0/0
Surveying Engineering III (Schwieger, Beetz)	2/1/0/0
Surveying Engineering IV (Czommer)	2/1/0/0
Thematic Cartography (in German) (Czommer, Schützle)	1/1/0/0
Multisensor Systems for Terrestrial Data Acquisition (in German) (Schwieger, Schweitzer)	1/1/0/0
Causes and Impacts of Deformations in Structures (Metzner)	1/1/0/0
Transport Telematics (in German) (Metzner, Czommer, Zheng)	2/1/0/0
Reorganisation of Rural Regions (Mayer)	1/0/0/0
Integrated Field Work (Schwieger, Laufer)	10 days
Terrestrial Multisensor Data Acquisition (Schwieger, Schützle)	2/1/0/0
Thematic Cartography (Metzner, Schützle)	1/1/0/0
Transport Telematics (Metzner, Czommer, Zheng)	2/1/0/0
Kinematic Measurements and Positioning (Schwieger, Beetz)	2/1/0/0
Acquisition and Management of Planning Data (Metzner, Wengert)	2/1/1/0
GIS-based Data Acquisition (Schwieger, Zheng)	1/1/0/0
Data Management and Analysis (Metzner, Laufer)	1/1/0/0
GIS-based design of traffic transport structures (Metzner)	1/1/0/0



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## Guests

BORKOWSKI A, Prof., Wroclaw/Poland (26.10.-1.11.)  
DETREKÖI Á, Prof. Dr., Budapest/Hungary (21.4.-18.7.)  
GHITAU D, Prof. Dr., Bukarest/Rumania (1.8.-29.9.)  
GROSS RS, Dr., Pasadena/USA (27.4.)  
HÁJKOVÁ J, Ing. Mgr., Pilsen, Czech Republic (2.11.-22.12.)  
JIANG W, Prof. Dr., Wuhan/China (1.8.-25.9.)  
LI H, Tongji/China (4.11.-31.12.)  
LI J, Prof. Dr., Wuhan/China (1.8.-31.8.)  
LIN Y, Dr., Tongji/China (2.3.-31.12.)  
MIRA S, Prof. Dr., Bandung/Indonesia (3.11.-13.11.)  
NIEMIEC M, M.Sc., Wroclaw/Poland (26.10.-1.11.)  
POUTANEN M, Prof. Dr., Masala/Finland (25.-28.3.)  
SANSO F, Prof., Milano/Italy (12.-13.11.)  
TSOULIS D, Ass. Prof. Dr., Thessaloniki/Greece (1.6.-31.8.)  
VARGA P, Prof. Dr., Budapest/Hungary (9.3.-5.4., 4.10.-1.11.)  
VIRTANEN J, Dr., Masala/Finland (25.-28.3.)  
WANG Z, Dr., Wuhan/China (1.8.-25.9.)  
XU X, Dr., Wuhan/China (2.3.- 31.12.)  
ZHANG X, Prof. Dr., Wuhan/China (1.8.-25.9.)  
ZOU X, Wuhan/China (1.1.-20.2.)

## Additional Lecturers

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HAUG G, Dr.-Ing., Stadtplanungs- und Stadtmessungsamt, Esslingen/Neckar  
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# Research

## Improvement of regional gravity fields by using SST observations

### 1. Modeling of the gravity field

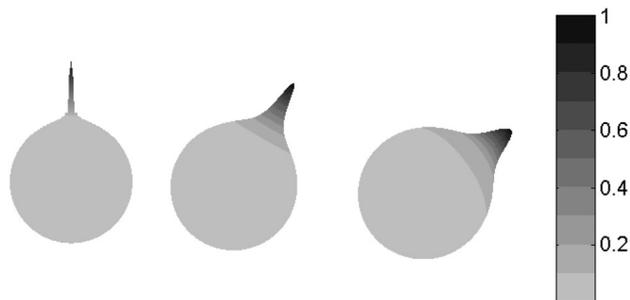
In the last decade the determination of the Earth's gravitational field was mainly based on satellite observations, especially of the CHAMP-, GRACE- and the up-coming GOCE-mission. From these observations a global solution can be derived, which is usually expressed in terms of spherical harmonics.

On the one hand, these base functions fulfill the Laplace equation outside of the body and they are well known and easily calculated, but on the other hand spherical harmonics always cause a loss of information because of their global support.

To improve a regional gravity field, the signal and the model are separated into a global and a residual part. The global one is still described by spherical harmonics and a known set of coefficients, which are used to calculate a synthetic signal. After reducing the observation by this signal, the residual part is analyzed by a second set of base functions.

## 2. Optimized radial base functions

For the modeling of the residual part the radial base functions are chosen, which form a system of non-orthogonal but harmonic functions on the sphere. Each base can be characterized by a centre, a scale factor and a shape parameter and the function trends to zero outside its centre. An example of three base functions with different centers and shapes is visualized in the Figure 1, where the height at each center is normalized to one.



*Figure 1: Example of three base functions for the analysis of a residual signal*

The analysis of gravity-field related data by radial base functions can be formulated as an optimization problem, concerning the base parameters, in such a way that the sum of the quadratic differences between the model and the residual signal is minimized. The optimization is often simplified by solving only the linear problem with fixed positions and shape parameters, but this requires many base functions and because of the over-parameterization also regularization.

Our alternative is the non-linear optimization of all parameters, in order to achieve a purely data based improvement of the field. After finding some initial values by an interpolation of the data in the orbit, the parameters are estimated by an iterative Levenberg-Marquadt method until a termination condition is fulfilled. Possible conditions are the number of iterations, the correlation between the signal and the approximation or the step size of the last improvement.

This technique is successfully implemented for the in-situ measurement of the potential and the line-of sight gradiometry in the orbit, but also for the range-rate observation of GRACE.

### 3. GPS-leveling in Poland

In cooperation with the University of Wrocław a scenario has been developed for testing the algorithm for practical surveying and to validate the results. The basic idea is the so-called GPS leveling, i.e. the substitution of the time consuming classical leveling by a known gravity field and the geometric height  $h$  of GPS, in order to achieve the height information at the observation points.

The two necessary height systems are illustrated in Figure 2. In case of the satellite observation the geoid is the reference for the gravity information and the geometric height  $h$  is separated into the geoid height  $N$  and the orthometric height  $H$ . On the other hand in Poland or Germany the surveying system is based on the quasigeoid with the normal height  $H^N$  and the height anomaly  $\zeta$  as the remaining distance to the ellipsoid.

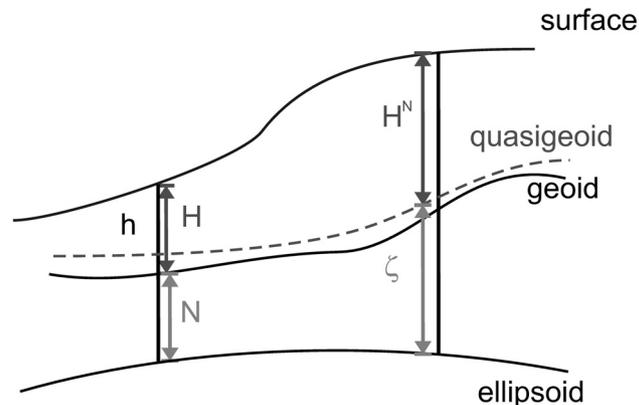


Figure 2: Orthometric and normal height

The aim of the project is to improve a satellite only model of the gravity field (GGM02s) by the optimized radial base functions and to compare the achieved geoid heights  $N$  with the height anomaly  $\zeta$  of the classical leveling. As the geoid and the quasigeoid are very similar in flat terrain, the improvement in the satellite gravity field must reduce the difference to the anomaly as well.

In Figure 3 the test scenario is illustrated for one month of satellite data. On the left hand side the geoid heights  $N$  are visualized, once by GGM0s only and the second time with 10 additional base functions, whose positions are shown in the last panel on the right hand side. Only the geoid solution with the base functions contains a similar curvature of the main (diagonal) structure like in the height anomalies, which are shown in the last picture on the left. The pictures on the right panel show the differences between the anomaly and the geoid height, which are reduced by almost one meter by the additional base functions.

The remaining error is mainly caused by the limited solution of the GRACE mission and the neglected distinction of the geoid and the quasigeoid.

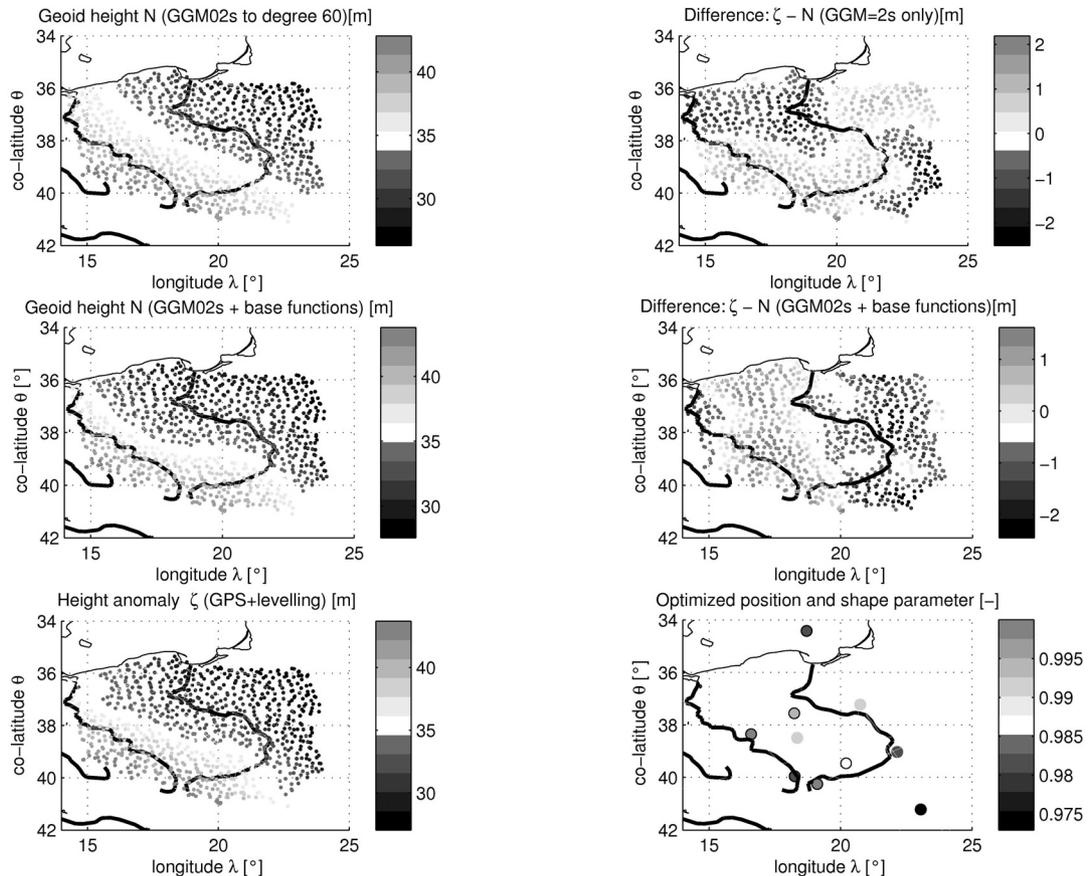


Figure 3: Validation of the optimized base function approach by comparing the Polish quasigeoid with the regional

#### 4. Range-rate observation

The original observation of the GRACE mission is the distance and the changing of the distance between two satellites, the so called range-rate (cf. Figure 4).

The challenge is to link the observations of GRACE to the parameters of the residual gravity field. Usually this is done by solving the variation equations numerically, but then every arc in the orbit, every variable and each iteration lead to a new equation system. Figure 5 illustrates the derivatives of the relative position changing with respect to the co-latitude coordinate of the base center in along-track, across-track and the radial component, where the base function is placed in the middle of the arc at  $t=300$  s.

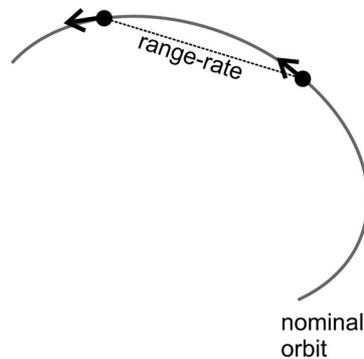


Figure 4: Scenario of the GRACE mission

The alternative is to find a closed solution, which approximates the changing in position and velocity of the satellites by the residual model, which can be derived with respect to the base parameters for the optimization. In order to do this, a rotating coordinate system is introduced, which is connected to a fictive reference satellite on a circular orbit. The changing in the relative positions is then described by the Hill (differential) equation. The disturbing force of a radial base function is parameterized by the Kepler elements in along-track, across-track and the radial direction.

After the assumption of constant rotation of the Earth, the solution is generated by a Laplace-transform. The changing in position contains an offset, a linear trend and some oscillations with frequencies depending on the motion of Earth and the satellite but also some special terms for the resonance cases. Figure 6 visualizes the differences between the variation equation and the closed solution for the co-latitude of a base function. The calculations fit quite well, and the remaining discrepancy can be explained by the numerical integration in the variation approach and the used approximations in closed solution.

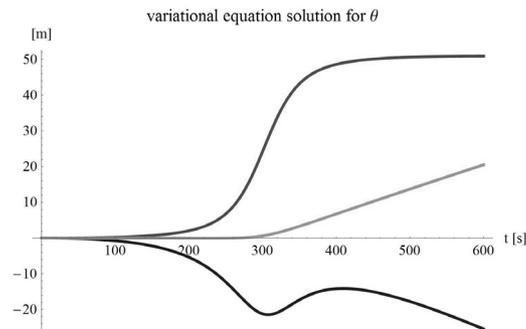


Figure 5: Derivates of the relative position changing of the satellite with respect to the co-latitude of the center of the base function, calculated by the variation equation

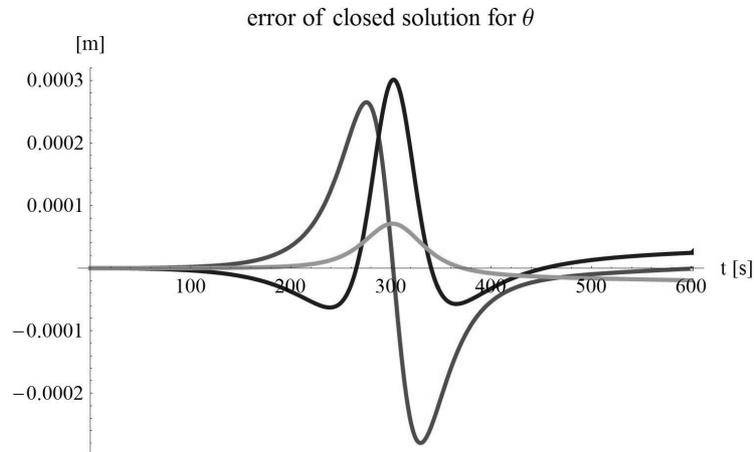


Figure 6: Differences between the variation equation and the closed solution for the derivatives with respect to the co-latitude

For the complete range-rate approach the algorithm has to be repeated for the second satellite and the final changing in the range rate and its derivatives are achieved by subtracting the results in a common coordinate system.

## Satellite gravity gradiometry on the path

On March 17, 2009, the Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite was lofted into a near-Sun-synchronous Earth orbit. The mission is one of the most fascinating and challenging space adventures in satellite geodesy history.

The GOCE satellite opens a new chapter in the observation of the system Earth from space. The mission results will revolutionize our present understanding of both the complex interactions and the dynamics of the planet Earth. Increased knowledge concerning ocean circulation will considerably contribute to improve climate-forecasting models. The detailed 3D mapping of density variations in the Earth's interior will bring forward earthquake prognosis. Furthermore, GOCE will provide valuable contributions to up-to-date problems, such as arising in sea level change research, the unification of height reference systems, and high-precision satellite orbit determination. Altogether, the GOCE mission outcome has not only a substantial impact on scientific activities, but likewise stands for significant social and socio-economic progress.

Solutions for present environmental and geo-scientific problems are directly related to the terrestrial gravity field. This is where GOCE comes in. In order to meet present-day precision requirements, for the first time ever, the spacecraft will realize three-dimensional satellite gradiometry. The mission's core is a state-of-the-art electrostatic gravity gradiometer incorporating six highly sensitive 3D accelerometers, mounted in pairs along three perpendicular axes. The innovative

gradiometer instrument allows recovering gravitational differences with an accuracy of one millionth of the terrestrial acceleration. As a consequence, the data will yield the geoid with an accuracy of 1-2cm. The spatial resolution will be improved from several hundreds or thousands of kilometres on previous missions to around 100km with GOCE.

In order to meet the mission requirements, in the last years a lot of effort has been put into the development of suitable data analysis algorithms. In Germany, most of these research activities are embedded in the GEOTECHNOLOGIEN II program funded by the Federal Ministry of Education and Research (BMBF). Since the very beginning, the GIS is member of the joint research group. In this context, the GIS is mainly concerned with data analysis based on the gravitational tensor invariants approach (cf. former annual report contributions). Well-established collaboration with the High Performance Computing Centre Stuttgart (HLRS) provides the necessary computing power to handle the huge loads of science data provided by the spacecraft.

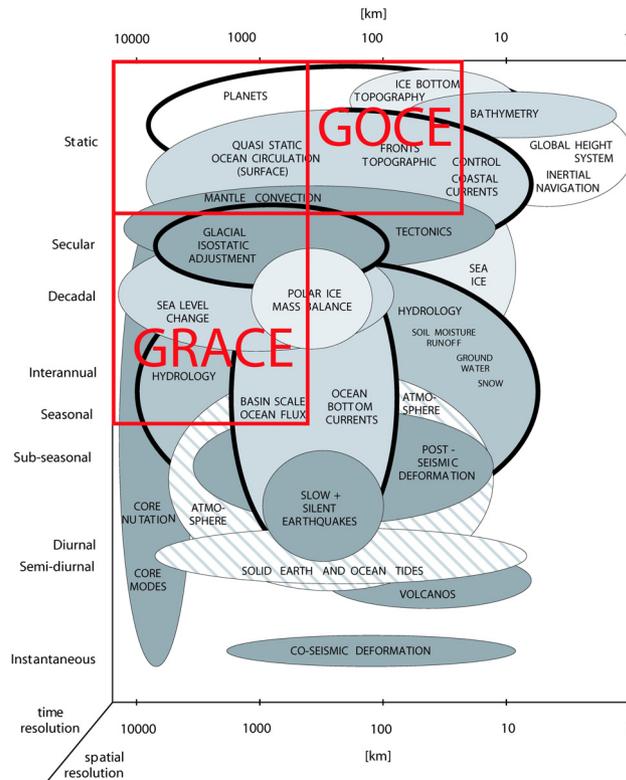


Figure 7: GRACE and GOCE-complementary satellite missions (Credits: GOCE Projektbüro Deutschland)

## GOCE Gravity Field Recovery - GOCE real data analysis by means of rotational invariants

Following the successful launch in March 2009 and in-orbit testing of the most sophisticated gravity mission ever built, ESA's GOCE satellite has been in 'measurement mode' since October 2009, provides the opportunity to determine the static Earth gravity field with an accuracy never reached before. Based on the results achieved from GOCE-GRAND I and II (GOCE GRavitationsfeldANalyse Deutschland) since 2001, a succeed joint research program REal data AnaLysis GOCE (REAL-GOCE) has been proposed by the German Institutes and approved to be funded by the Federal Ministry of Education and Research (BMBF) and the German research foundation (Deutsche Forschungsgemeinschaft) for period June 2009 to July 2012 within the GEOTECHNOLOGIEN II program „Observation of the System Earth from Space“. The Institute of Geodesy in Stuttgart (GIS) is member of this common project. The further participants are the Universities of Munich, Bonn and Hanover, Karlsruhe, Hamburg, the Federal Agency for Cartography and Geodesy (BKG), The German Geodetic Research Institute (DGFI) as well as the GeoForschungsZentrum (GFZ) Potsdam.

The goal of the national collaborative project REAL-GOCE in Germany is fully implement of the previously conceived GOCE data analysis chains and their application to the GOCE real data. To meet this objective, our institute is engaged in GOCE real data analysis by means of rotational invariants. The major objective of the individual project (WP 120) is the determination of the Earth gravity field from GOCE gradiometer observations in terms of the rotational invariants representation of the gravitational tensor.

In order to reach the aforementioned objective, first of all the real data need to be prepared for the alternative analysis approach (preparation of the functional model). The strong correlations between successive gradiometer measurements ('colored noise') induce the stochastic model of the observations to be of particular importance. Based on the results acquired by the project partners, the stochastic model of the gravitational gradients is used to derive and describe the stochastic properties of the invariants. After the preparation of both the functional and stochastic models, the computation of the gravity field parameters will be carried out. Solving the resulting system of equations by least-squares techniques provides the appropriate parameter estimate. For the numerical process itself, high performance computers come into operation. In the course of the adjustment procedure, the impact of the polar data gaps will be minimized by tailored regularization. Finally, both the comparison of the invariants solution with the results obtained by the project partners and its performance within the project-internal validation process allow to evaluate the optimal GOCE real data analysis scheme.

In summary, the following subtasks have to be tackled within the scope of WP120 (cf. Figure 8):

- ▷ Preparation of GOCE real data (Level 1b) for the invariants analysis approach
- ▷ Statistical investigations of the observation type „rotational invariant“
- ▷ Adaption and optimization of the stochastic model

- ▷ Polar gap problem elimination
- ▷ Computation of a GOCE-derived Earth gravity field model (Level 2)
- ▷ Validation of the obtained gravity field solution, and comparison with alternative analysis methods

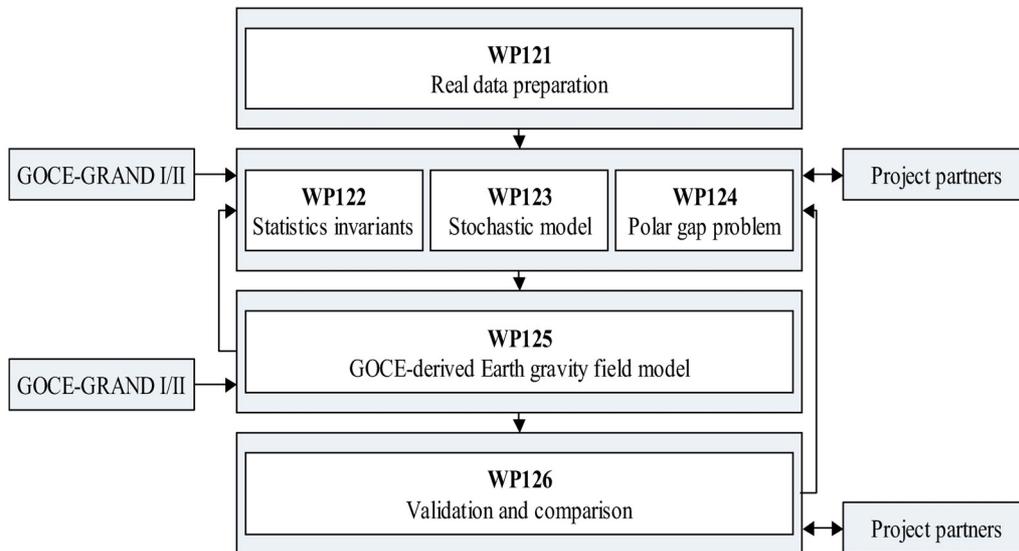


Figure 8: Overview of the individual project (WP 120) of REAL GOCE

## Future satellite concepts for the detection of time variable gravity fields

Within the two common projects „Assessment of a Next Generation Gravity Mission for Monitoring the Variations of Earth’s Gravity Field“ (ESA) and „Zukunftskonzepte für Schwerefeldsatellitenmissionen“ (BMBF) with project partners from science and industry 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 Geodetic Institute, 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 9): (i) the „Nyquist-theorem“  $\beta \geq 2L$  (or  $2M$ ), which determines the spatial resolution (maximum degree/order  $L/M$ ) and (ii) the „Heisenberg-theorem“  $D_{\text{space}} \times D_{\text{time}} = 2\pi\alpha / \beta = 2\pi T_{\text{Rev}} = \text{const.}$ , which means that the product of spatial resolution  $D_{\text{space}}$  and the time-resolution  $D_{\text{time}}$  is constant. If the spatial resolution of a satellite mission should be improved (Figure 9), 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. An alternative to the homogeneous ground track options is the heterogeneous ground track design (also called Bender-mission after its inventor Pete Bender from NASA), where the satellites fly on orbits with different repeat patterns and inclinations. By means of such a design, spatial and temporal sampling is improved simultaneously and the ground track spacing is densified around the poles.

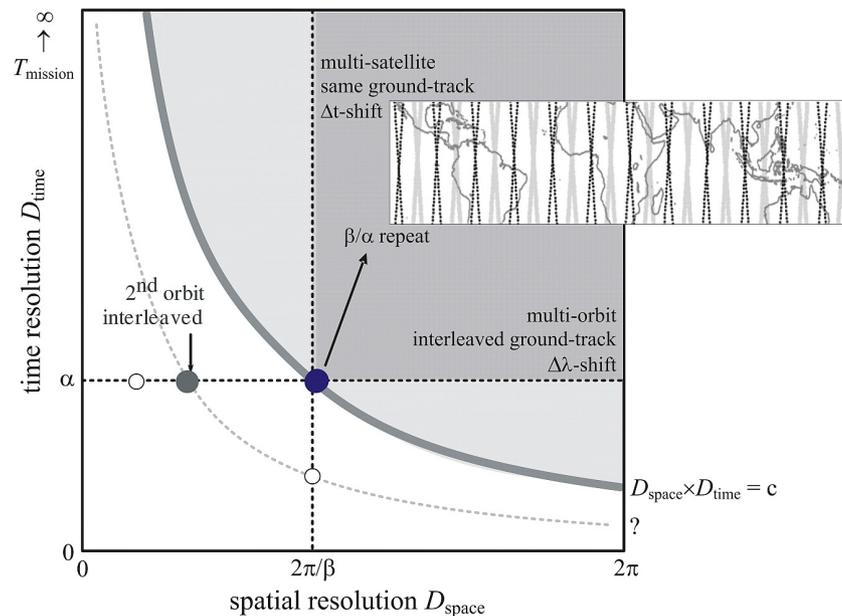


Figure 9: Multi satellite and multi-orbit concepts: relation between spatial and time resolution

Another problem of the GRACE-mission is the sensitivity of the range-rate measurements, which leads to the typical North-South striping error pattern of GRACE solutions. These striations are due to the anisotropy involved with the leader-follower formation of GRACE, which allows range-rate measurements only in North-South directions and neglects signals in East-West and radial directions. By means of sophisticated formations, the sensitivity and isotropy of the range-rate measurements can be improved. Such formations are (i) the PENDULUM, where the satellites fly approximately parallel at the equator (and behind each other at the poles), (ii) the CARTWHEEL, where the two satellites generate a 2:1 relative elliptic motion once per revolution in the orbit plane

and (iii) the LISA formation, a combination of pendulum and cartwheel, where the two satellites perform a circular motion in a plane tilted to the orbit plane. The relative motion of the satellites of these formations is shown in the Hill-frame in Figure 10. In contrast to the North-South directed measurements of GRACE, the PENDULUM generates measurements in East-West direction over the equator (and possibly in North-South direction over the poles), the CARTWHEEL produces measurements alternating twice per revolution in radial and North-South direction and LISA performs measurements alternating in all three directions. As shown by the geoid errors in Figure 10, the advanced formations are not only able to reduce the total error level, they also improve the isotropy. While distinct North-South striations are visible for the GRACE formation, this negative effect is eliminated by the other formations. The PENDULUM shows a slight EAST-WEST pattern, the CARTWHEEL and LISA produce the most homogeneous error pattern. The technical realisation of the sophisticated formations, which is comparatively difficult, is studied by industrial partners within the mentioned projects.

### **Ice mass balance over Greenland**

For the first time ever, the GRACE (Gravity Recovery And Climate Experiment) satellite mission allows the determination of global mass variations - such as ice melting in the polar areas - from changes in the Earth gravitational pull. The underlying measurement principle is as simple as stunning; it bases on the fact that the redistribution of masses on the Earth surface maps into changes of the terrestrial gravity field. Hence, scientists measure the spatio-temporal variations of the Earth's gravitational attraction on a test mass in space, i.e., the GRACE spacecraft.

Commonly, GRACE monthly gravity field solutions are exploited to derive secular and seasonal mass changes on the Earth's surface. The increased lifespan of the satellite mission, however, makes temporal characteristics of secular trends detectable. Fitting both linear and non-linear models to the mass-change time-series suggest accelerated melting of the Greenland ice sheets in recent years (cf. Figures 11 and 12).

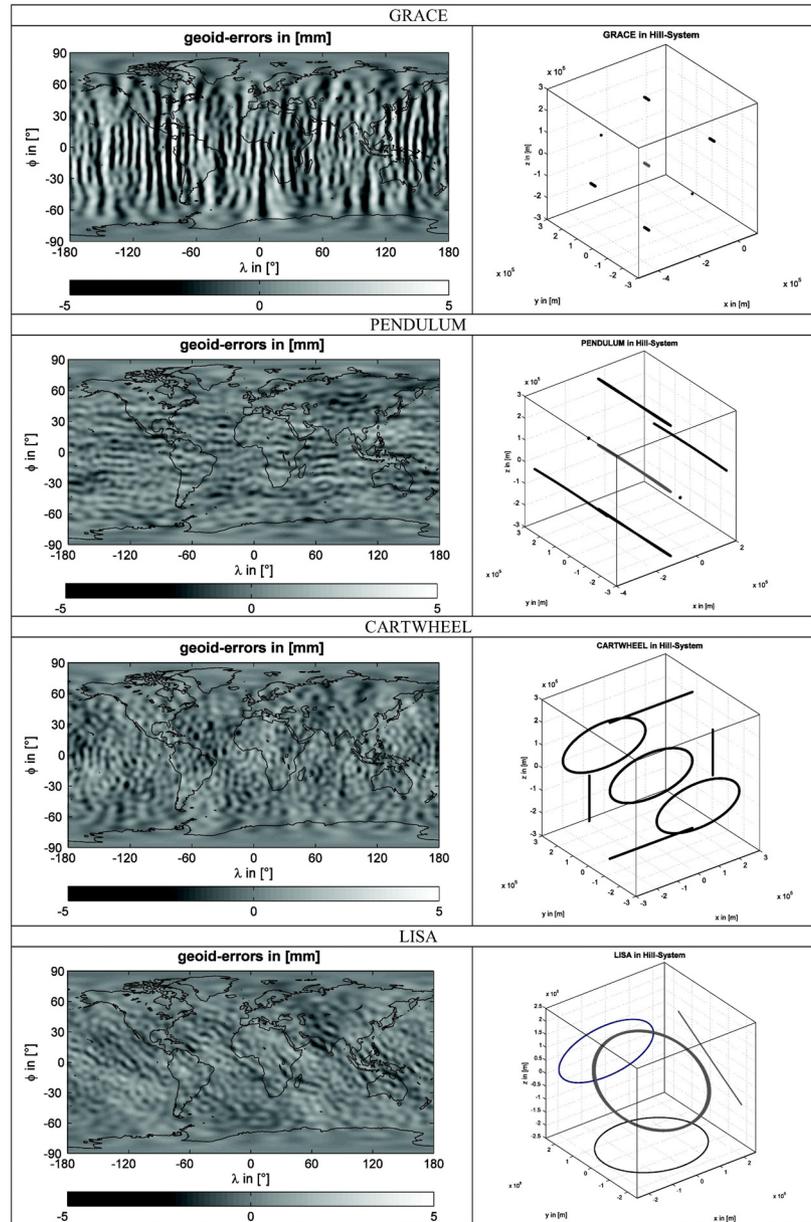


Figure 10: Geoid-errors produced by the range-rate measurements of different formations

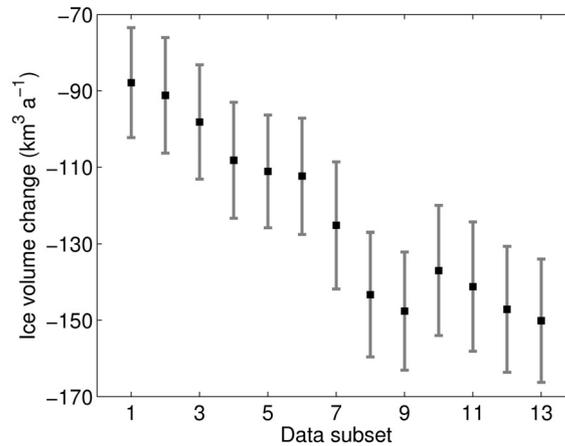


Figure 11: Greenland ice-volume change rates from April 2002 to March 2009 (CSR solutions; not corrected for signal leakage and GIA). Each data subset refers to four 4-year periods. Every period has an offset of 3 months to the previous one. The error bars indicate the standard deviations of the estimates. They were derived from the least-squares residuals of the polynomial fit.

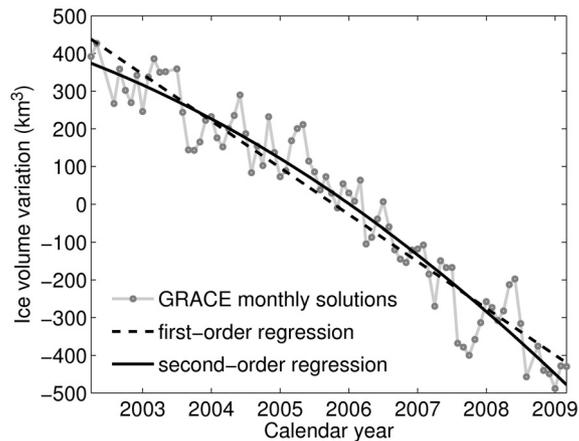


Figure 12: Greenland ice-volume variations from April 2002 to March 2009 (CSR solutions; not corrected for signal leakage and GIA). The residual monthly values are reduced by the temporal mean. Both the linear and quadratic fit provide comparable variations over the whole period ( $-858 \pm 70 \text{ km}^3$ ,  $-853 \pm 65 \text{ km}^3$  respectively). Model selection criteria (Table 1) show the quadratic model to be superior to the linear fit over Greenland.

These findings are supported by various model selection criteria, namely the (corrected) Akaike information criterion (AIC), the Bayesian information criterion (BIC), cross-validation (CV) and hypotheses testing of the polynomial coefficients. As highlighted in Table 1, the linear model is unable to describe recent deglaciation. From the Table, the linear approximation shows the poorest results, followed by the third-order and fifth-order polynomials. The second-order polynomial performs best. Furthermore, hypothesis testing reveals statistical significance for all model parameters only up to the second-order. For any higher-order polynomial, only the intercept is significant. Hence, the Greenland GRACE data trend is best represented by a second-order polynomial. As a result, deglaciation of the Greenland ice sheets increased by 250% between April 2002 and March 2009. Note that the total ice-volume variations given in Table 1 (last column) are not corrected for disturbing effects such as signal leakage and global isostatic adjustment (GIA). Disturbing effects mainly scale change-rates; they have minor impact on the temporal progress of deglaciation.

Polynomial order	AIC	BIC	CV	Variation [km <sup>3</sup> ]
1	10.5	8.3	5100.7	-858 ± 70
2	0	0	4430.0	-853 ± 65
3	1.3	3.4	4488.7	-815 ± 64
4	0.6	4.7	4407.3	-822 ± 63
5	2.2	8.3	4465.3	-858 ± 63

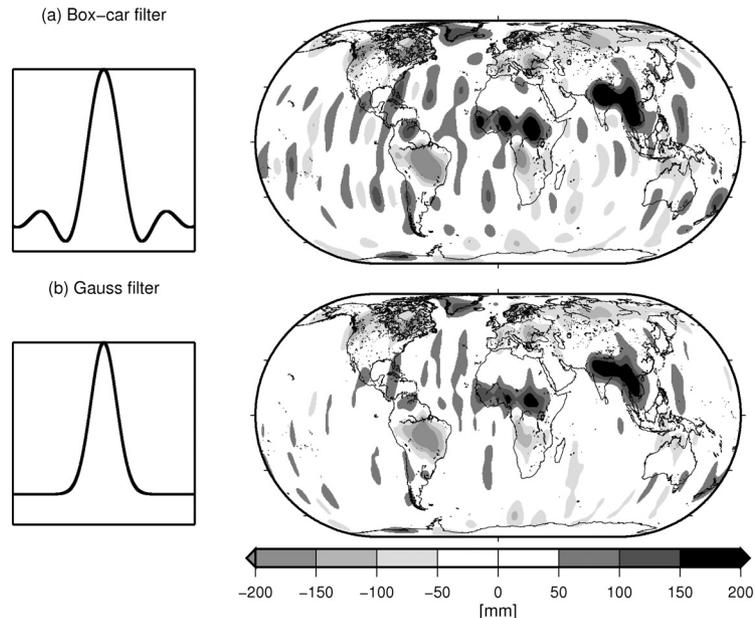
*Table 1: Model selection criteria and total ice-volume variations over the period April 2002 to March 2009 (CSR solutions), dependent on the order of polynomial fit.*

Extended time-series will pinpoint the validity of present-day results for future predictions. Furthermore, in order to substantiate GRACE-derived change-rate accelerations, comparison with alternative independent data or in-situ measurements is desirable.

## **Taking a critical look at mass change estimates from satellite observations**

Gravity Recovery and Climate Experiment (GRACE) satellite mission has revolutionized the ways of observing the mass changes in the earth system. GRACE mission provides monthly snapshots of the changes in the gravity-field of the earth, which is directly related to the mass changes in the earth system. For the first time, hydrologers, oceanographers, glaciologists, hydro meteorologists, geophysicists, and other earth scientists have been able to look at global scale mass changes. Prior to the launch of GRACE mission, this was only a wish and dream of Earth scientists, and they relied heavily on global models to deliver the mass changes at global and regional scales. In being the first mission of its kind, the GRACE mission poses severe challenges in terms of data processing, evaluation and validation. The observations from GRACE are wrought with heavy noise that filtering is more a necessity than an option, and this filtering is continuing to be a

challenging aspect in GRACE data analysis. The challenge that filtering poses comes from the fact that filters not only reduce noise, but also reduce the signal amplitude, which is but difficult to ascertain. Further, different filters provide different estimates of the mass change (for example, Figure 13), which in the absence of validation data poses the challenge of choosing the right filter.



*Figure 13: Mass estimates from box-car and Butterworth filters are shown here. Although both the filters show the same major signals, there are considerable differences in the signals from the oceans*

A framework has been developed for comparing the characteristics of the different filters, and thereby, choose the appropriate filter for the task in hand. This framework has been developed, initially, only for filters with isotropic weights, i.e. the filter assigns the same weights to points that are at the same spherical distance from the filter center. The framework consists of a set of metrics that describe certain properties of the filter, which directly reflect on their performance: Processing loss, main-lobe width, spatial leakage, highest side-lobe level, and side-lobe roll-off ratio. Processing loss and spatial leakage are the defining metrics while the other three are complementary. Processing loss describes, as a ratio, the amount of signal that has been lost due to filtering and spatial leakage describes how much unwanted signal has been thrown in. A scatter plot of processing loss and spatial leakage is shown in Figure 14, where a good filter would lie in the bottom left of the figure. It clearly shows that there is no filter that reduces signal loss as well as spatial leakage, but the figure clarifies the type of filters that are good in reducing leakage and those that have less signal loss. Further this figure also shows the difference between box-car and

Gauss filters. Gauss filter has minimal spatial leakage and heavy processing loss, while box-car filter has enormous spatial leakage and minimal processing loss. It is clear from this that though the mass estimates from Gauss filter are subdued, they are relatively more local and realistic than those from box-car. The spatial leakage of box-car also throws light on the big differences between the two filters in the ocean signal and the signal in Africa. Thus, apart from helping in choosing the right filter, the metrics developed also help in analyzing the mechanics of each filter, for example, leakage effects. Therefore, these metrics help in looking at the mass estimates from filtered GRACE data much more critically than was possible before.

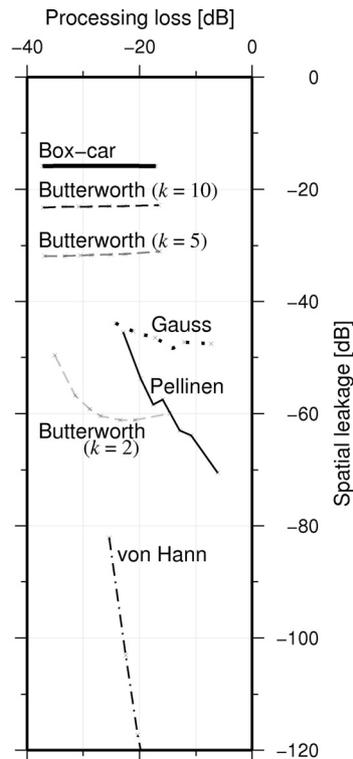


Figure 14: Scatter plot between processing loss and spatial leakage of five different filters

## Quantification of GRACE signal uncertainties to close the continental water balance

As a prior condition to achieve the main goal of the project, the direct determination of monthly actual evapotranspiration  $ET_a$  via a closed water balance by GRACE mass changes the uncertainties of GRACE and atmospheric moisture flux data have to be quantified. During the quantification of uncertainties, in the respective signals, positive and negative peaks are detected in GRACE

signals which do not correspond to the related hydrological or atmospheric signals. These peaks mainly occur at specific times for many catchments simultaneously and thus can be interpreted as outliers. Outliers in the GRACE signal are expected to deteriorate signal correlation with hydrology and atmosphere and increase the noise level significantly.

An algorithm is developed to detect and identify outliers. The procedure of outlier detection is verified by a comparison of GRACE signals and both the hydrological and atmospheric signals. After identification, outliers in the GRACE signal are replaced by appropriate mean or interpolated values. The results of this outlier handling show a significant improvement in the correlation of GRACE signals versus hydrology and atmosphere. Also, a significant reduction of noise level can be achieved. On the other hand, in order to quantify the uncertainties the correlations of aggregated GRACE signal have been investigated. The correlations of aggregated GRACE signal time series between different catchments (Inter Catchment Correlation) show a specific pattern mainly created by the periodic local climatic conditions. Inter Catchment Correlations of monthly residuals of GRACE signals - monthly values minus mean monthly values - show a sinusoidal dependence on latitude. This is surprising as monthly mass residuals on landmasses are supposed to originate from monthly water balance variations and correlations of climatic variability over the hemispheres are not expected. Monthly residuals of corresponding hydrologic storage changes (P-Eta-R) and atmospheric storage changes from moisture flux divergence (-divQ-R) do not show comparable correlation patterns. In fact, there is not enough runoff data available to certainly verify that there is no hydrological correlation existing for catchments on different hemispheres. Hence, an extension from catchments to a global coverage is needed in order to recognize differences between landmasses and oceans. Therefore, grid based ( $5^{\circ} \times 5^{\circ}$ ) time series are generated and correlated with respect to a reference cell. The spatial distribution of Inter Cell Correlations (ICC) of monthly GRACE signals reflect landmasses and oceans while ICC of monthly residuals doesn't show any reflection of landmasses and oceans. Instead, a dominant latitudinal and less dominant longitudinal dependence over the globe can be recognized. This means that there must be a signal component in the monthly GRACE residual over the globe not depending on the specific characteristics of landmasses and oceans. Neither its form nor origin is recognized so far, and thus is deteriorating the signal quality for hydrology and oceanography. The objective of this investigation is to identify this signal component in the GRACE residual and check possible sources. As possible sources of ICC, GRACE outliers and de-aliasing products are considered and EOF analysis is applied to identify possible modes responsible for the ICC.

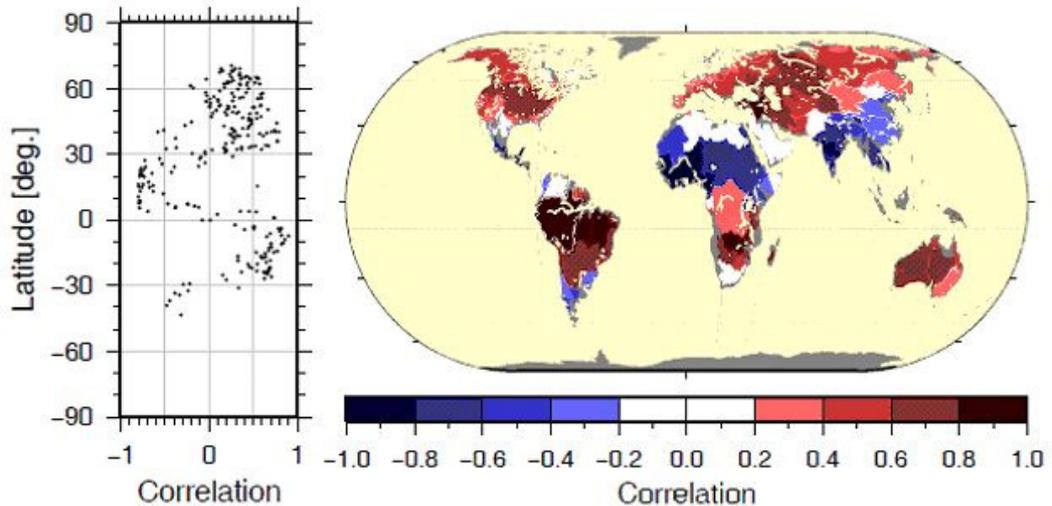


Figure 15: Inter catchment correlation of GRACE signal based on Amazon catchment

## Satellite altimetry waveforms over non-ocean surfaces for hydrological purposes

Over the past two decades, satellite altimetry has been used to measure non-ocean water level variation for hydrologic studies. Non-ocean surfaces are much rougher than oceans. Moreover, satellite corrections for atmospheric propagation normally include errors in non-ocean surfaces. Hence, due to (1) the effect of topography and heterogeneity of reflecting surface and (2) atmospheric propagation, the expected echo shape for altimeter returns over land differs from that over ocean surfaces. As a result, measurements over non-ocean area include erroneous and missing data. We have been working on a method for an unsupervised classification of the satellite waveforms and algorithm for waveform retracking. Balaton Lake and Urmia Lake have been chosen as case study for our work.

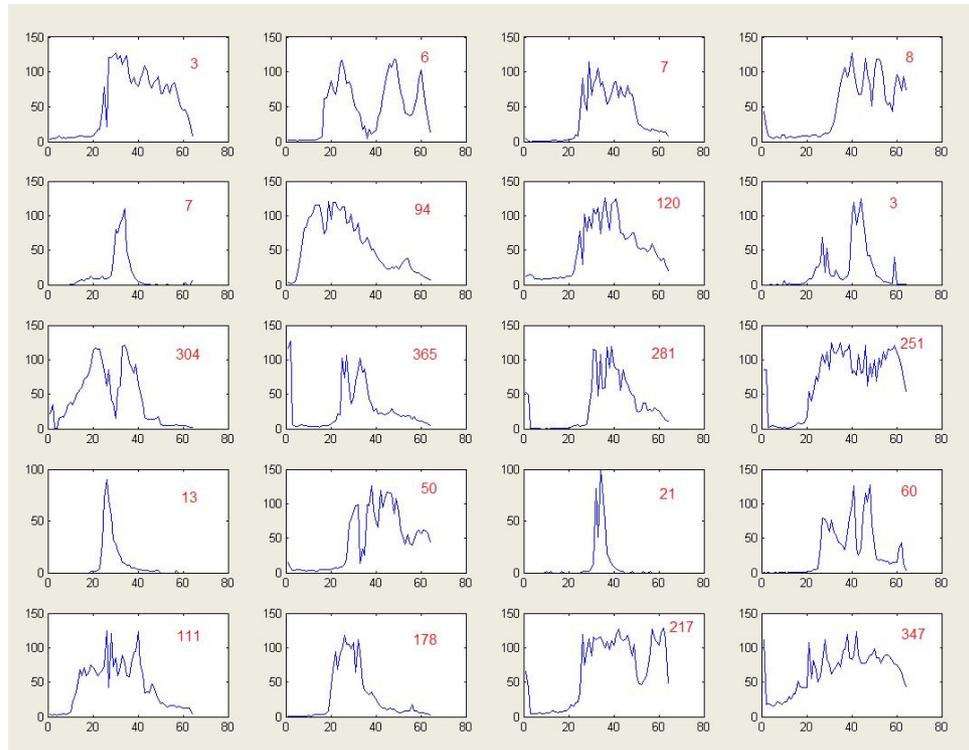


Figure 16: Twenty randomly selected waveforms among 5520 waveforms over Balaton Lake, which display a wide variety of waveforms

## Local gravity field refinement using base functions with strictly finite support

The recovery of local gravity features from satellite-to-satellite tracking is one of the current challenges in Physical Geodesy. The most common approach is to employ a global spherical harmonic analysis and select the area of interest later on. Typical side effects are leakage and loss of signal since the spherical surface functions are bases with global support. As a consequence, mass balance estimates in areas like the Amazon or Greenland do not coincide well with hydrological or ice models. The usage of locally supported base functions aims at the minimization of these side effects. So far, attempts to recover gravity features from spatially restricted data mostly concentrate on the usage of the so-called radial base functions which still allows analytical expressions for the entries of the design matrix. Although they decay rapidly, their support is not exactly local, since they are global functions as well. Leakage occurs again (though reduced) since different radial bases overlap.

A more rigorous approach is to use base functions with a strictly finite and distinct support. The gravity field quantity is modelled by a single layer potential which requires the integration over the surface of the area of interest. The unknowns are the surface mass densities in the corner points. For numerical implementation, the surface is decomposed into a finite number of basic shapes like e.g. triangles or quadrilaterals. This method is also known as boundary element method. The disadvantage is that the entries of the design matrix cannot be calculated by closed expressions anymore but have to be computed by numerical integration. Besides the usage of spatially restricted functions, one other strength of the method is its flexibility in the size of each surface element, i.e. the size of each element does not need to be constant and even the combination of different types of shapes is possible. The placement of the corner points can thus be optimized to each data set which is not a trivial problem, however. Additionally, the number and position of the surface mass densities will also depend on the assumption of their behaviour between the corners of each shape element, i.e. whether the surface mass density is assumed to be constant or to change linearly (or with higher order) within an element.

Figure 17 shows results of a simulation study. A residual potential field has been created using 4225 point masses at a depth of 120km. The signal is calculated at the position of a CHAMP-like satellite flying at an orbit height of approximately 400km and simulating a measurement every 5 seconds. Based on the triangular mesh in Figure 17 (right), the gravity signal is recovered and the difference plot in Figure 17 (middle) shows a nearly random pattern which proves that the method can be successfully applied to this type of data.

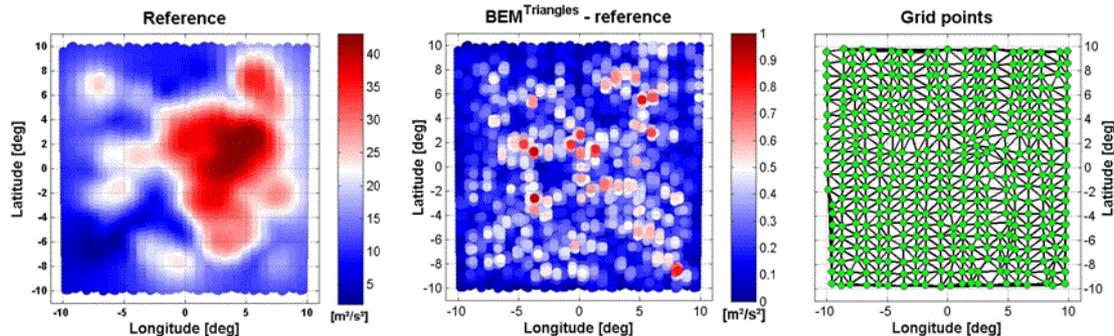


Figure 17: Simulated residual potential field at satellite height (left), difference between recovered and input signal (middle), triangular based grid and location of the surface mass densities (right)

The next steps will include the application to a residual tensor signal and the application to real GRACE data. The complete procedure consists then of two steps. First, in-situ observations are derived using the so-called line-of-sight gradiometry technique. The K-Band range rates measured by GRACE are connected by numerical differentiation to the second order derivative of the

gravitational potential of the Earth projected to the direction of the satellite motion. Subsequently, the second order derivative is connected to the single layer potential and the surface mass densities can be estimated. The procedure is computationally demanding as every surface element needs to be integrated but promises (from a theoretical point of view) to reduce leakage and to make best use of the signal content in the K-Band ranging measurement.

## Properties and applications of EOF-based filtering of GRACE solutions

The twin „Gravity Recovery and Climate Experiment“ (GRACE) satellites observe the time varying gravity which is the sum of all mass variations in the Earth System. However, the main problem in the GRACE solutions of Stokes coefficients is the increasing noise at higher degrees in the spherical harmonics (SH) coefficients (Swenson and Wahr, 2006). The noises appear as unphysical North-South striping patterns in the spatial domain maps (for example in the Equivalent Water Height (EWH) maps) which have a strong correlation between the even and odd degree coefficients. The stripes can be largely suppressed by weighting the SH coefficients by a Gaussian smoothing function, but since the errors have a non-isotropic character, while the function is isotropic, a large smoothing radius is required for removing the stripes which by itself causes a significant loss of information in the GRACE solutions (Chen et al., 2007). One approach to remove those stripes is using Empirical Orthogonal Functions (EOF) in combination with white-noise testing of the resulting time series in the spectral domain (Wouters and Schrama, 2007). The EOF procedure can be recast into a filter equation, i.e. the filter transfer is described explicitly. This also allows us to emphasize the characteristics of the EOF-based filter. Moreover, our formulation provides an easy means to propagate the GRACE fields into degree variances and spatial covariance functions.

The reconstructed EWH maps provided by the spectral domain analysis of the GRACE data show a strong capability of EOF analysis for de-striping the patterns which is due to the ability of performing EOF analysis for individual orders (Iran Pour et al., 2009). Also examples in the spectral domain show that the EOF analysis with white noise test but with smaller smoothing Gaussian filters result in maps comparable to those which are just smoothed by the Gaussian smoothing filters but with larger radii (Figure 18). The Kolmogorov-Smirnov test (KS test) is used as a tool for white noise recognition for the modes provided by EOF analysis which are performed through the filtering operators.

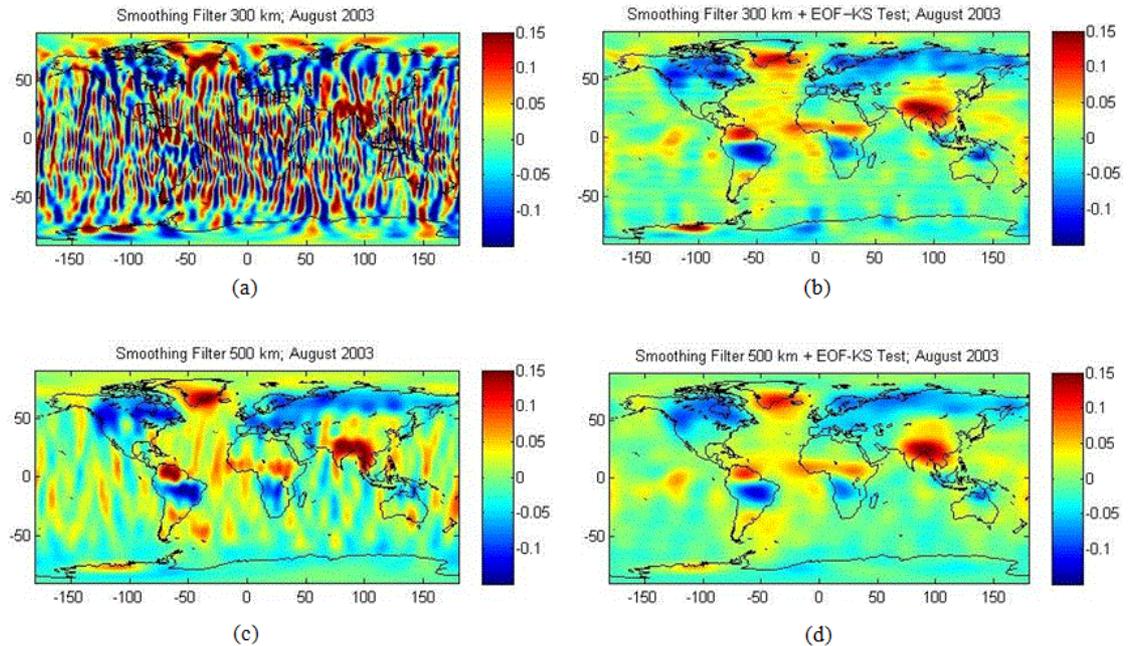


Figure 18: EWH anomaly maps for May 2008, smoothed by (a) only Gaussian filter 300 km radius, (b) Gaussian filter 300 km radius in addition to EOF-KS test, (c) only Gaussian filter 500 km radius, (d) Gaussian filter

This filtering operator model also allows us to investigate the properties of spatial covariance functions (Figure 19).

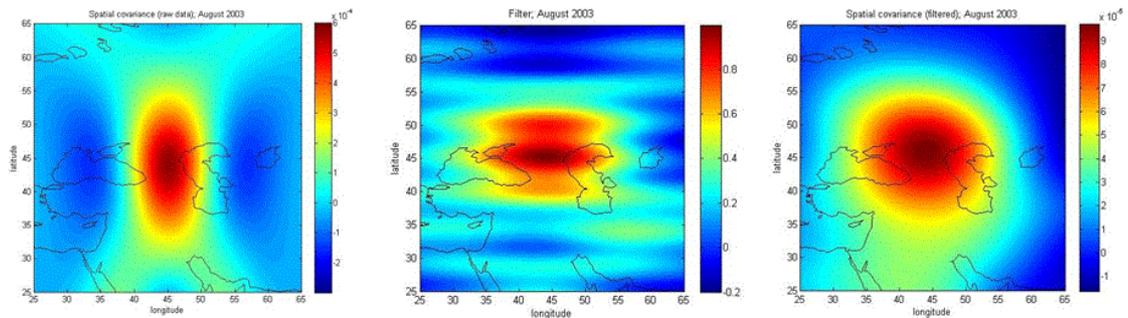


Figure 19: Spatial covariance of the raw data (left), the filter (middle) and the filtered data (right) for the location centered at longitude and latitude of 45 degrees

It is seen that some of the last modes of some orders pass the test (recognized as signals). This can be explained by the non-white noise property of the modes, although it is important to mention that those last modes have very small singular values and therefore their contributions to the data reconstruction are also very small.

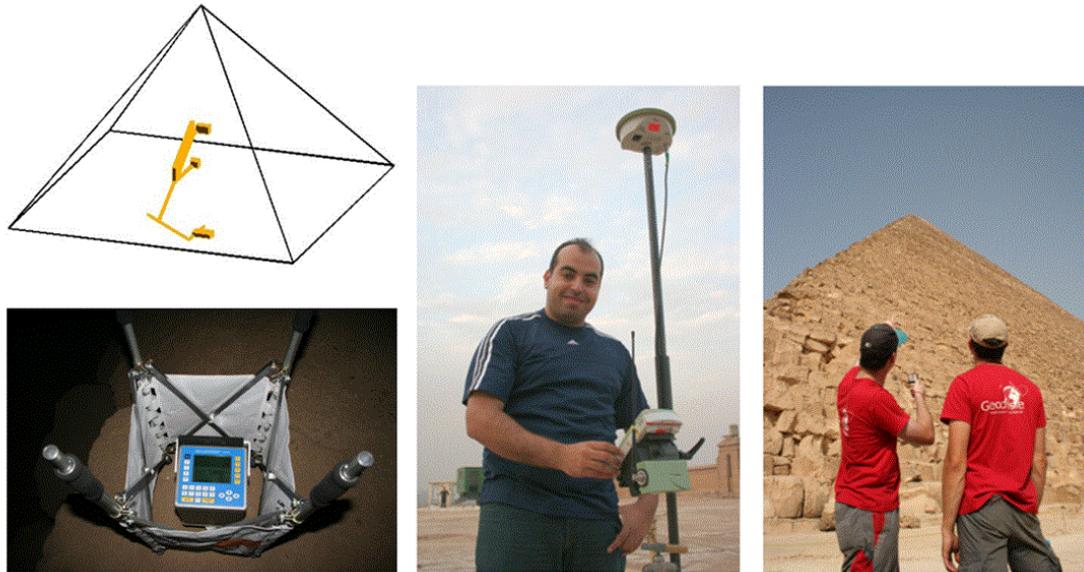
However, the test is claimed for the white noise recognition, while the modes could represent other types of noises which were not studied in this work. It can also be seen that the EOF analysis with the white noise test smoothes the patterns which may diminish the effects of some geophysical phenomena. This means that more investigations are needed for the testing strategies and the noise recognition methods in the future.

### **Microgravimetric survey of the Great Pyramid, Giza, Egypt**

The Institute of Geodesy is collaborating with the Ain Shams University and under the supervision of the Supreme Council of Antiquities in an international archaeological mission at the Giza Plateau, Egypt. The aim is to investigate the internal structure of the Great Pyramid, also known as the Cheops or Khufu pyramid. The project is called „Non-Destructive Archaeology using Gravimetry in the area of the Great Pyramids“ under the supervision of Dr. Elhabiby, director of the mission and assistant professor at Ain Shams University, and is partially funded by the BA/CSSP research grant of the Bibliotheca Alexandrina.

Till today, the construction of the Great Pyramid is a mystery and several theories exist, e.g. the usage of ramps, internal ramps and cable winches. The currently most popular theory is the idea of an internal ramp, which is coiling upwards on the outer edge of the pyramid. After construction, the ramp has been filled with material, e.g. sand and sandstone. The main problem for archaeologists is that excavations tend to destroy the site. Considering the cultural heritage and the international popularity of the Great Pyramid, any changes to its faces are not allowed. Gravimetry provides a way out of this dilemma. It enables to examine the internal structure of the Great Pyramid without any excavations or destructions of the surface.

The procedure consists of two steps: first, carefully executed gravimetric measurements on the surface of the pyramid using the Scintrex CG-5 of the Institute of Geodesy are collected and connected to a local reference frame by GPS measurements. Reductions are limited to instrumental corrections only. The second part consists of a forward modelling of the pyramid by taking all available information about the structure of the pyramid, the known voids and the density of the rocks into account. Figure 1 (top left) shows a simplified model as it was used in the preparation of the campaign. 3D surface modelling from photographic images is supporting the construction. The calculation of an expected gravity observation at the location of the gravimetric observation and the comparison and analysis of the residuals will reveal details about the interior structure of the Great Pyramid.



*Figure 20: Model of the interior of the Great Pyramid (top left), Scintrex CG-5 with windshield during the measurement (bottom left), Dr. Elhabiby with GPS equipment at one of the control points (middle), R. Schlesinger und M. Weigelt during exploration (right)*

In October 2009, the Institute of Geodesy sent two of its employees, namely R. Schlesinger and M. Weigelt, to Cairo for a first microgravimetric survey in order to join Dr. Elhabiby and his team which consists of another two researchers from Ain Shams University, namely Mohamed Ramadan and Mohamed Shebl. Besides a detailed exploration and selection of the measurement locations, approximately 130 gravimetric points were observed. The analysis of the measurements and the costly forward modeling is currently ongoing and first results are expected in the first half of 2010 that will pave the way to the second phase in the second half of the year.

We thank the Egyptian Supreme Council of Antiques, especially Dr. Zahi Hawass, for their tremendous and invaluable support in making this measurement campaign possible.

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

High-accurate GPS relative positioning is usually based on double-differenced (DD) carrier phase observables. When considering short baseline (less than 20 km), the linear model for DD phase may be simplified to a mixed integer linear model. Based on our new research results achieved in the first period of our DFG Project (Statistical estimation and hypothesis testing for the GPS mixed integer linear models) since 2005 (Cai, et al., 2007), the GPS carrier phase observables

that are actually measured on the unit circle have been statistically validated to have a von Mises normal distribution. The existing validation and hypothesis testing procedures (e.g.  $\chi^2$ -test, F-test, t-test, and ratio test etc.) should therefore be improved accordingly. As one of the modern statistical techniques since 1980s bootstrap method refers to a class of computer-intensive statistical procedures, which can often be helpful for carrying out a statistical test of a point estimate in situations where more usual statistical procedures are not valid and /or not available (e.g. the sampling distribution of a statistic is not known).

For the linear model, these bootstrap methods provide inference procedures (e.g. confidence sets) that are asymptotically more accurate than those produced by the other methods. This is just the case for the validation and hypothesis tests of the float and fixed estimates of GNSS mixed models in the directional context, with the emphasis on the determination of the confidence intervals of the estimates. In the second period of our DFG project we have successfully applied two bootstrap analysis methods for linear model, bootstrapping residuals and bootstrapping pairs, to determinate the confidence domains of the parameters of the GNSS mixed integer linear models. The analysis of the Bootstrapping confidence intervals for the float solutions with the real GPS observations shows that

- ▷ the Bootstrapping residuals and pairs for linear model provide us an efficient and accurate algorithm to construct the confidence domains of the GPS float solutions
- ▷ the Bootstrapping pairs method depends on the conditional number of the design matrix
- ▷ the Bootstrapping confidence intervals are consistent with the LS confidence intervals based on the t-test
- ▷ both kinds of the confidence intervals all cover the potential correct fixed ambiguity integers, which are important for searching process and fixed solution, see Figures 21 and 22
- ▷ the bootstrapping confidence intervals are derived without any assumption about the probability distribution of the observations

The fundamental recognition of the statistical properties of the von Mises (circular) normal distribution of GPS carrier phase observables and the successful construction of the related hypothesis tests with bootstrapping residuals and bootstrapping pairs for linear models provide a complete solution for the estimation and hypothesis tests on the parameters of the GPS mixed integer linear models in the directional context. These research achievements 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-managed Global Navigation Satellite System (GNSS).

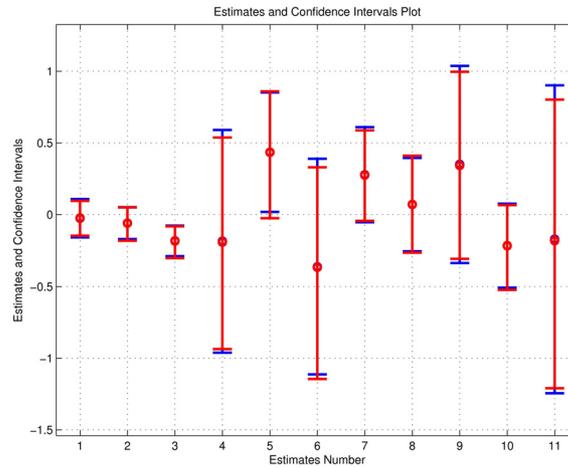


Figure 21: The comparison of the float estimates and their confidence intervals with the LS (in blue) and bootstrapping residuals methods (in red).

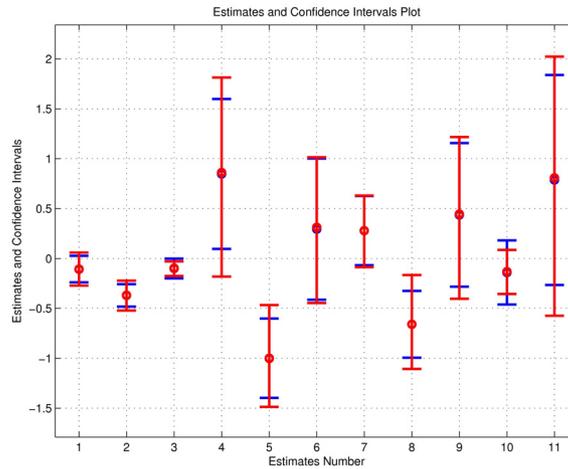


Figure 22: The comparison of the float estimates and their confidence intervals with the LS (in blue) and bootstrapping pairs methods (in red).

## Theses

### Diploma Theses

([http://www.uni-stuttgart.de/gi/education/dipl/diploma\\_theses.en.html](http://www.uni-stuttgart.de/gi/education/dipl/diploma_theses.en.html))

BENTEL K: Empirical Orthogonal Function Analysis of GRACE Gravity Data (Analyse von Schwerefelddaten der Satellitenmission GRACE mittels Zerlegung in Empirisch-Orthogonale Funktionen)

BRITCHI A: Rumänische Geodätische Netze und Koordinaten-Transformation (Rumania Geodetic Networks and Coordinate Transformation)

KARRER K: Impact of spatial and temporal resolution on the significance of GNSS performance results (Über den Einfluss räumlicher und zeitlicher Auflösung auf die Aussagekraft von GNSS Leistungsparametern)

LORENZ CH: Applying stochastic constraints on time-variable GRACE data (Anwendung stochastischer Bedingungen auf zeitvariable GRACE-Daten)

RAU D: Einfluss lateraler Variationen in Lithosphäre und oberem Mantel auf den glazial-isostatischen Ausgleich in der Antarktis (Influence of the varying thickness of the lithosphere and upper mantle on the regional glacial-isostatic adjustment (GIA) in Antarctica)

XUE Y: GOCE sensitivity studies in terms of cross-over analysis (GOCE Sensitivitätsstudien mittels Kreuzungspunktanalyse)

### Study Theses

([http://www.uni-stuttgart.de/gi/education/dipl/study\\_reports.en.html](http://www.uni-stuttgart.de/gi/education/dipl/study_reports.en.html))

DÜNKEL A: Java Applet zur Visualisierung der Erdorientierung (Visualization of the Earth Orientation with Java)

PETRESCU EP: Einfluss des direkten Strahlungsdrucks der Sonne auf CHAMP (Influence of the direct solar radiation pressure on CHAMP)

RADU D: Continental water storage derived from GRACE: A review of four years of literature

ROTH M: Marine Full Tensor Gravity Gradiometry Data Analysis and Euler Deconvolution (Voll-tensorgravitationsgradiometrie auf dem Meer: Datenanalyse und Euler-Dekonvolution)

YANG Z: Kollokation und deren Anwendung in der Koordinatentransformation (On the use of collocation in coordinate transformations)

## Publications

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

## Refereed Journal Publications

- ANTONI M, A BORKOWSKI, W KELLER AND M OWCZAREK: Verification of localized GRACE solutions by the Polish quasigeoid. *Geodesy and Cartography* 58 (2009) 21-36
- ANTONI M, W KELLER AND M WEIGELT: Representation of Regional Gravity Fields by Radial Base Functions. In: MG Sideris (Ed.): *Observation our Changing Earth. Proceedings of the 2007 IAG General Assembly, Perugia, Italy, July 2-13, 2007. IAG Symposia 133* (2009) pp 293-299
- AUSTEN G AND W KELLER: Singularity free formulations of the geodetic boundary value problem. *Journal of Geodesy* 83 (2009) 645-657
- AWANGE JL, MA SHARIFI, O BAUR, W KELLER, WE FEATHERSTONE AND M KUHN: GRACE hydrological monitoring of Australia: current limitations and future prospects. *Journal of Spatial Science* 54 (2009) 23-36
- BAUR O: Tailored least-squares solvers implementation for high-performance gravity field research. *Computers and Geosciences* 35 (2009) 548-556, doi:10.1016/j.cageo.2008.09.004
- BAUR O AND W KELLER: Computational considerations for satellite-based geopotential recovery. In: Nagel WE, DB Kröner and MM Resch (Eds.): *High Performance Computing in Science and Engineering '09*, Springer Berlin Heidelberg (2010) 511-521, doi:10.1007/978-3-642-04665-0\_35
- BAUR O, M KUHN AND WE FEATHERSTONE: GRACE-derived ice-mass variations over Greenland by accounting for leakage effects. *Journal of Geophysical Research* 114 (2009) 1-13, B06407, doi:10.1029/2008JB006239
- CAI J AND E GRAFAREND: Systematical analysis of the transformation between Gauss-Krueger-Coordinate/DHDN and UTM-Coordinate/ETRS89 in Baden-Württemberg with different estimation methods. In: Drewes H (Ed.): *Geodetic Reference Frames. Proceedings of the IAG Symposium Munich, Germany, October 9-14, 2006. IAG Symposia 134* (2009) 205-221
- CAI J, E GRAFAREND AND C HU: The total optimal criterion in solving the mixed integer linear model with GNSS carrier phase observations. *GPS Solutions* 13 (2009) 221-230, DOI:10.1007/s10291-008-0115-y
- KUHN M, WE FEATHERSTONE, O MAKARYNSKY AND W KELLER: Deglaciation-Induced Spatially Variable Sea-level Change: A Simple-Model Case Study for the Greenland and Antarctic Ice Sheets. *International Journal of Ocean and Climate Systems*, accepted

- MOGHTASED-AZAR K AND E GRAFAREND: Surface deformation analysis of dense GPS networks based on intrinsic geometry: deterministic and stochastic aspects. *Journal of Geodesy* 83 (2009) 431-454, DOI:10.1007/s00190-008-0252-7
- WEIGELT M, MG SIDERIS AND N SNEEUW: On the influence of the ground track on the gravity field recovery from high-low satellite-to-satellite tracking missions: CHAMP monthly gravity field recovery using the energy balance approach revisited. *Journal of Geodesy* 83 (2009) 1131-1143
- XU C, K DING, J CAI AND E GRAFAREND: Methods of determining weight scaling factors for geodetic-geophysical joint inversion. *Journal of Geodynamics* 47 (2009) 39-46, DOI:10.1016/j.jog.2008.06.005
- ZEILE O, M LACHENMANN, E BAUMSTARK, A MOHR, D BOCK, R LAUFER, N SNEEUW AND H-P RÖSER: Analysis of orbital lifetime and observation conditions of small lunar satellites. *Acta Astronautica* 66 (2010) 516-527, DOI:10.1016/j.actaastro.2009.07.008

### Other Refereed Contributions

- GRAFAREND E: Geodetic reference frames: The kinematical Euler equations: a review of their singularities or the benefit of the Lusternik - Schnirelmann Category  $CAT(SO(3))=4$ . In: A Volume dedicated to Milan Bursa on the occasion of his 80th birthday, pp 85-99, Prague, Czech Republic, 2009

### Non-refereed Contributions

- DEUTSCHE PRESSEAGENTUR (DPA): Die Erde ist eine Kartoffel, 25.5.2009
- MEDIENDIENST FORSCHUNG DER UNIVERSITÄT STUTTGART: Eisschmelze mit Turbo-Effekt, 8.11.2009
- PRESSEMITTEILUNG DER UNIVERSITÄT STUTTGART: Vom Vermessen der Erde, 23.3.2009
- RIGUZZI F, F KRUMM, K WANG, M MISZELY AND P VARGA: Influence of LOD variations on seismic energy release. *Geophysical Research Abstracts* 11 (2009) 2323

### Poster Presentations

- ANJASMARA IM, M KUHN AND O BAUR: Localized principal component analysis applied on GRACE time-variable gravity. IAG 2009, Buenos Aires, Argentina (31.8.-4.9.)
- ANTONI M, W KELLER AND M WEIGELT: Recovery of residual GRACE-observations by radial base functions. VII Hotine Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- BAUR O: Computational considerations for satellite-based geopotential recovery. The 12th Results and Review Workshop of the HLRS, Stuttgart (8.-9.10.)

- BAUR O, M KUHN AND WE FEATHERSTONE: Linear and non-linear secular mass variations from GRACE. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- BAUR O, M KUHN AND WE FEATHERSTONE: Accounting for leakage effects in GRACE-derived mass changes. IAG General Assembly 2009, Buenos Aires, Argentina (31.8.-4.9.)
- DEVARAJU B AND N SNEEUW: Performance analysis of isotropic spherical harmonic spectral windows. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- GRAFAREND E AND O BAUR: Orbital rotations of a satellite: Case study GOCE. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- IRAN POUR S AND N SNEEUW: Properties and applications of EOF-based filtering of GRACE solutions. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- IRAN POUR S, K BENTEL AND N SNEEUW: EOF-based filtering of GRACE gravity field solutions: A comparison between spectral and spatial approaches. EGU General Assembly, Vienna, Austria (19.-24.4.)
- KELLER W, M KUHN AND WE FEATHERSTONE: A set of analytical formulae to model deglaciation-induced polar wander. IAG General Assembly 2009, Buenos Aires, Argentina (31.8.-4.9.)
- TOURIAN MJ, N SNEEUW AND A BÁRDOSSY: Controls on satellite altimetry over non-ocean surfaces for hydrological purposes. Geophysical Research Abstracts 11 (2009) 2713

### Conference Presentations

- ANTONI M, W KELLER AND M WEIGELT: Analyse von GRACE-Beobachtungen durch optimierte radiale Basisfunktionen. Geodätische Woche Karlsruhe (22.-24.9.)
- BAUR O AND N SNEEUW: Punktmassenschätzung aus zeitvariablen GRACE Schwerefeldern. Geodätische Woche Karlsruhe (22.-24.9.)
- BAUR O, N SNEEUW AND J CAI: GOCE Realdatenauswertung unter Anwendung der Invariantendarstellung, Projekttreffen REAL-GOCE. Geodätische Woche Karlsruhe (22.-24.9.)
- CAI J: Bootstrap analysis methods for linear model and its applications in GNSS data processing. Geodätische Woche Karlsruhe (22.-24.9.)
- CAI J, E GRAFAREND AND C HU: Bootstrap method and its application to the hypothesis testing in GPS mixed integer linear model. EGU General Assembly, Vienna, Austria (19.-24.4.)
- CAI J, E GRAFAREND AND C HU: Reconciling different criteria for solving the mixed integer linear model with GNSS carrier phase observations. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)

- DEVARAJU B, MJ TOURIAN, N SNEEUW AND J RIEGGER: Inter-catchment correlation estimates from filtered GRACE monthly solutions. Geodätische Woche Karlsruhe (22.-24.9.)
- FERSCH B, H KUNSTMANN, B DEVARAJU AND N SNEEUW: Large scale water balance estimations through regional atmospheric moisture flux modeling and comparison to GRACE signals. 8th IAHS Scientific Assembly & 37th IAH Congress, Hyderabad, India (6.-12.9.)
- FERSCH B, H KUNSTMANN, N SNEEUW AND B DEVARAJU: Continental scale atmospheric and terrestrial water budget modeling and comparison to GRACE. EGU General Assembly, Vienna, Austria (19.-24.4.)
- GRAFAREND E: Intrinsic deformation analysis, synthesis of Earth deformation measures: surface Euler-Lagrange deformation tensors of first and second kind. IAG/ICCT Study Group 7 „Temporal variations of deformation and gravity“, Lanzarote, Spain (23.-26.2.)
- GRAFAREND E: The Marussi Legacy: the anholonomy problem, geodetic examples. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- GRAFAREND E AND Z MARTINEC: Space gradiometry, characteristic boundary value problems and regularized downward continuation. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- GRAFAREND E, J ENGELS AND P VARGA: The gravitational field of a deformable body like the Earth or other celestial bodies. EGU General Assembly, Vienna, Austria (19.-24.4.)
- IRAN POUR S, N SNEEUW AND B DEVARAJU: The EOF-based filtering of GRACE solutions - Properties and applications. Geodätische Woche Karlsruhe (22.-24.9.)
- KELLER W, M ANTONI AND M WEIGELT: A Closed Solution of the Variational Equations for Short-Arc SST. IAG General Assembly 2009, Buenos Aires, Argentina (31.8.-4.9.)
- LIN Y, S ZHANG, J CAI AND N SNEEUW: Application of Wavelet Support Vector Regression on SAR data Denoising. Geodätische Woche Karlsruhe (22.-24.9.)
- LORENZ C, B DEVARAJU AND N SNEEUW: On the computation of a reliable signal covariance for the stochastic filtering of time-variable gravity field from GRACE. EGU General Assembly, Vienna, Austria (19.-24.4.)
- REUBELT T, N SNEEUW AND E GRAFAREND: Comparison of kinematic orbit analysis methods for gravity field recovery. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)
- REUBELT T, N SNEEUW, P VISSER, T VAN DAM AND M LOSCH: Future satellite missions for time-variable geopotential recovery. EGU General Assembly, Vienna, Austria (19.-24.4.)
- RIGUZZI F, F KRUMM, K WANG , M MISZELY AND P VARGA: Influence of LOD variations on seismic energy release. EGU General Assembly, Vienna, Austria (19.-24.4.)
- SNEEUW N: Inclination functions: orthogonality and other properties. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)

SNEEUW N, EJO SCHRAMA, PNAM VISSER AND M WEIGELT: Spatial resolution from repeat orbit configurations: the Colombo-Nyquist rule revisited. EGU General Assembly, Vienna, Austria (19.-24.4.)

WEIGELT M, W KELLER AND M ANTONI: Comparing the local gravity field recovery based on radial base functions with the boundary element method. VII Hotine-Marussi Symposium on Theoretical Geodesy, Rome, Italy (6.-10.7.)

WEIGELT M, W KELLER AND M ANTONI: Lokale Schwerefeldbestimmung mit Hilfe der Randelementemethode und radialen Basisfunktionen. Geodätische Woche Karlsruhe (22.-24.9.)

### **Guest Lectures and Lectures on special occasions**

BRUNNER FK, Prof. Dr. (Institut für Ingenieurgeodäsie und Messsysteme, University Graz, Austria): Raum-Zeit Analyse von GPS Messungen mittels Turbulenztheorie (4.12.)

DETREKÖI A, Prof. Dr. (Geodetic and Geophysical Research Institute, Budapest University of Technology and Economics, Hungary): Some megatrends in Informatics - Influence on Geodesy (25.6.)

ELHABIBY M, Dr. (Department of Geomatics Engineering, University of Calgary, Canada): Wavelets for Geomatics Applications: De-Noising, Compression and Analysis Tool (21.9.)

FRITSCH D, Prof. Dr. (Institut für Photogrammetrie, Universität Stuttgart): Zur optimalen Punkteinschaltung im Raum - vorwärts, rückwärts, überbestimmt (4.12.)

GROSS R S, Dr. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA): Consistency of Earth Rotation, Gravity, and Shape Measurements (27.4.)

KLEUSBERG A, Prof. Dr. (Institut für Navigation, Universität Stuttgart): Von Kreiseln und Satelliten: Erik Grafarend's Beiträge zur Navigation (4.12.)

POUTANEN M, Prof. Dr. (Finnish Geodetic Institute, Masala, Finland): DynaQlim - a multidisciplinary program to better understand the dynamic Earth (26.3.)

SANSÒ F, Prof. (DIAR, Sezione Rilevamento, Politecnico di Milano, Italy): Ideas to combine satellite and terrestrial global models (12.11.)

VIRTANEN J, Dr. (Finnish Geodetic Institute, Masala, Finland): Improving GRACE mass estimates for the Baltic Sea and validation using in situ measurements (26.3.)

### **Lectures at other universities**

CAI J

New investigations of GNSS data analysis methods, Wuhan University (11.6.)

New developments of GNSS data analysis methods, Tongji University (19.6.)

**SNEEUW N**

Spaceborne Gravimetry as a Geodetic Remote Sensing Tool for Earth Sciences. Max-Planck-Institut für Gravitationsphysik, Hannover (9.4.)

The future of satellite gravimetry. Geodetic and Geophysical Research Institute, Sopron, Hungary (29.9.)

**Research Stays****ANTONI M**

Landwirtschaftliche Universität Wroclaw, Poland (15.-21.6.).

**CAI J**

School of Geodesy and Geomatics, Wuhan University, China (5.-19.6.)

**GRAFAREND E**

Geodetic and Geophysical Research Institute, Seismological Observatory, Budapest, Hungary (5.-13.9.)

**KELLER W**

Landwirtschaftliche Universität Wroclaw, Poland (15.-21.6.)

**SNEEUW N**

Geodetic and Geophysical Research Institute, Sopron, Hungary (28.-29.9.)

**Lecture Notes**

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

**GRAFAREND E AND F KRUMM**

Kartenprojektionen (Map Projections), 300 pages

**HAUG G**

Grundstücksbewertung I (Real Estate/Property Valuation I), 28 pages

Grundstücksbewertung II (Real Estate/Property Valuation II), 11 pages

**KELLER W**

Dynamic Satellite Geodesy, 90 pages

Foundations of Satellite Geodesy, 51 pages

Observation Techniques in Satellite Geodesy, 50 pages

**KRUMM F AND SNEEUW N**

Adjustment Theory, 102 pages

**SCHÖNHERR H**

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

## SNEEUW N

Analytic Orbit Computation of Artificial Satellites, 90 pages

Geodesy and Geodynamics, 68 pages

Physical Geodesy (Measurement Techniques of Physical Geodesy, Modeling and Data Analysis in the Field of Physical Geodesy), 137 pages

## WOLF D

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

**Participation in Conferences, Meetings and Workshops**

## ANTONI M

Geodätische Woche, Karlsruhe, Germany (22.-24.9.)

PPP-Projekt GPS-Levelling in Poland, Wroclaw (Breslau), Poland (16.-19.6.)

VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

## BAUR O

Geodätische Woche, Karlsruhe, Germany (22.-24.9.)

Project meeting REAL-GOCE, Karlsruhe, Germany (22.9.)

The 12th Results and Review Workshop of the HLRS, Stuttgart, Germany (8.-9.10.)

VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

## CAI J

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)

Geodätische Woche, Karlsruhe, Germany (22.-24.9.)

Project meeting REAL-GOCE, Karlsruhe, Germany (22.9.)

VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

## DEVARAJU B

DFG-SPP1257 Workshop „Mass transport and mass distribution in system Earth“, Eitorf (29.6.-1.7.)

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)

Geodätische Woche, Karlsruhe, Germany (22.-24.9.)

VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

## GRAFAREND E

DGK Jahressitzung, München (25.-27.11.)

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)

ICCT Study Group 7, Lanzarote, Spain (23.-26.2.)

VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

## IRAN POUR S

Kick-Off-Meeting of the project „Zukunftskonzepte für Schwerefeldsatellitenmissionen“ (BMBF/DFG Geotechnologien Programm, Projekt Nr. 03G0729A), Institute of Geodesy, University of Stuttgart, Germany (17.-18.9.)

Project Meeting 1 of the project „Zukunftskonzepte für Schwerefeldsatellitenmissionen“ (BMBF/DFG Geotechnologien Programm, Projekt Nr. 03G0729A), SpaceTech Industries, Immenstaad-Kippenhausen, Germany (2.-3.12.)

#### KELLER W

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)  
IAG General Assembly, Buenos Aires, Argentina (31.8.-4.9.)  
PPP-Projekt GPS-Levelling in Poland, Wroclaw (Breslau), Poland (16.-19.6.)

#### REUBELT T

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)  
GGOS/IGCP565-IAG-GEO-Workshop „Towards a Roadmap for Future Satellite Gravity Missions“, TU Graz, Austria (30.9.-2.10.)  
Kick-Off-Meeting of the project „Zukunftskonzepte für Schwerefeldsatellitenmissionen“ (BMBF/DFG Geotechnologien Programm, Projekt Nr. 03G0729A), Institute of Geodesy, University of Stuttgart, Germany (17.-18.9.)  
Project Meeting 1 of the project „Zukunftskonzepte für Schwerefeldsatellitenmissionen“ (BMBF/DFG Geotechnologien Programm, Projekt Nr. 03G0729A), SpaceTech Industries, Immenstaad-Kippenhausen, Germany (2.-3.12.)  
Requirements Review Meeting of the project „Assessment of a Next Generation Gravity Mission for Monitoring the Variations of Earth’s Gravity Field“ (ESA ITT AO/1-5914/09/NL/CT), ThalesAleniaSpace-I, Torino, Italy (19.11.)  
VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

#### SNEEUW N

Festkolloquium zur Emeritierung von Prof. K.-H. Ilk, Bonn (29.1.)  
European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)  
DFG-SPP1257 Workshop „Mass transport and mass distribution in system Earth“, Eitorf (29.6.-1.7.)  
VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)  
Geodätische Woche, Karlsruhe, Germany (22.-24.9.)  
GGOS/IGCP565-IAG-GEO-Workshop „Towards a Roadmap for Future Satellite Gravity Missions“, TU Graz, Austria (30.9.-2.10.)

#### TOURIAN M

European Geosciences Union (EGU), General Assembly 2008, Vienna, Austria (19.-24.4.)  
Direct Water Balance meeting, Stuttgart (6.8.)  
Direct Water Balance meeting, Stuttgart (2.9.)  
Direct Water Balance meeting München (16.11.)  
Direct Water Balance meeting Stuttgart (22.12.)

#### WEIGELT M

Geodätische Woche, Karlsruhe, Germany (22.-24.9.)  
VII Hotine-Marussi Symposium, Rome, Italy (6.-10.7.)

**University Service**

BAUR O

Member of the PR-Commission of the study course Geodesy &amp; Geoinformatics

GRAFAREND E

Member Faculty of Aerospace Engineering and Geodesy

Member Faculty of Civil- and Environmental Engineering

Member Faculty of Mathematics and Physics

KELLER W

Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart

KRUMM F

Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart

SNEEUW N

Associate Dean (Academic) Geodäsie &amp; Geoinformatik and GEOENGINE, Stuttgart

Member China Commission, International Affairs (IA)

Member Examining Board of the Faculty of Aerospace Engineering and Geodesy, Stuttgart

Member Search Committee Ingenieurgeodäsie und Geodätische Messtechnik, Stuttgart

Member Senate Committee for Structural Development, Stuttgart

Vice-Chair Examining Board of the Faculty of Aerospace Engineering and Geodesy, Stuttgart

**Professional Service (National)**

CAI J

Member Deutscher Verein für Vermessungswesen

GRAFAREND E

Emeritus Member German Geodetic Commission (DGK)

SNEEUW N

Member Scientific Board of the Deutsche Geodätische Kommission (DGK)

Member Scientific Advisory Committee of DGFI

Chair DGK section „Erdmessung“

Chair AK7 (Working Group 7), „Experimentelle, Angewandte und Theoretische Geodäsie“, within DVW (Gesellschaft für Geodäsie, GeoInformation und LandManagement)

Full Member Deutsche Geodätische Kommission (DGK)

Member DGK-working group „Neue Satellitenmissionen“

**Professional Service (International)**

CAI J

Luoja Professor at School of Geodesy and Geomatics, Wuhan University, China

Member of the Institute of Navigation (ION, USA)  
Member of European Geosciences Union (EGU)

#### GRAFAREND E

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

#### KELLER W

Society of Industrial and Applied Mathematics (SIAM)

#### SNEEUW N

Member IAG Working Group „GGOS Satellite Mission“  
Präsident IAG InterCommission Committee on Theory (ICCT)  
Member Editorial board of Studia Geophysica et Geodaetica  
Member Editorial board of Journal of Geodesy  
Fellow International Association of Geodesy (IAG)

#### WEIGELT M

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

### Courses - Lecture/Lab/Seminar

Adjustment I (Krumm, Baur)	4/2/0
Advanced Mathematics (Keller, Weigelt, Devaraju)	3/2/0
Analytic Orbit Computation of Artificial Satellites (Sneeuw, Baur)	2/1/0
Coordinates and Reference Systems (Krumm, Reubelt)	1/1/0
Dynamic Satellite Geodesy (Keller)	1/1/0
Foundations of Satellite Geodesy (Keller)	1/1/0
Geodesy and Geodynamics (Sneeuw, Reubelt)	2/1/0
Geodetic Reference Systems (ICRS-ITRS) for Satellite Geodesy and Aerospace (Weigelt, Reubelt)	2/1/0
Geodetic Seminar I, II (Krumm, Sneeuw)	0/0/4
Geometric Data Processing (Keller)	1/1/0
Gravity Field Modeling (Keller, Baur)	2/1/0
Integrated Field Work Geodesy and Geoinformatics (Keller, Sneeuw)	10 days
Introduction Geodesy and Geoinformatics (Sneeuw)	0.5/0.5/0
Map Projections and Geodetic Coordinate Systems (Krumm)	2/1/0
Map Projections (Krumm)	1/1/0
Mathematical Geodesy (Krumm)	2/1/0

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Measurement Techniques of Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Modeling and Data Analysis in the Field of Physical Geodesy (Baur, Reubelt)	2/1/0
Observation Techniques and Evaluation Procedures of Satellite Geodesy (Keller, Weigelt)	1/1/0
Official Surveying and Real Estate Regulation (Schönherr)	2/0/0
Orbit Determination and Analysis of Artificial Satellites (Baur, Reubelt)	2/1/0
Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Real-Estate/Property Valuation I, II (Haug)	2/1/0
Satellite Geodesy Observation Techniques (Weigelt)	2/1/0
Satellite Geodesy (Keller)	2/1/0
Statistical Inference (Krumm, Baur)	2/1/0





## Institute of Navigation

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 homepage: <http://www.nav.uni-stuttgart.de>

### Head of Institute

Prof. Dr.-Ing. A. Kleusberg

Deputy: Dr.-Ing. Aloysius Wehr  
 Secretary: Helga Mehrbrodt  
 Emeritus: Prof. em. Dr.-Ing. Ph. Hartl

### Staff

Dipl.-Ing. Doris Becker	Navigation Systems
Dipl.-Ing. Xu Fang	Navigation Systems
Dipl.-Ing. Michael Gaeb	Navigation Systems
Dipl.-Geogr. Thomas Gauger	GIS Modelling and Mapping
Dipl.-Ing. René Pasternak	Remote Sensing
Dipl.-Ing. Bernhardt Schäfer	Navigation Systems
Dipl.-Ing. Wolfgang Schöller	Education/Navigation Systems
Dipl.-Ing. Alexandra Seifert	Navigation Systems
M. Sc. Hendy Sushandri	Navigation Systems
Dipl.-Ing. (FH) Martin Thomas	Laser Systems
Dr.-Ing. Aloysius Wehr	Laser Systems
Dipl.-Ing. Xue Wei	Inertial Navigation
Dr. Ing. Franziska Wild-Pfeiffer	Navigation Systems

### EDP and Networking

Regine Schlothan

## Laboratory and Technical Shop (ZLW)

Dr.-Ing. Aloysius W e h r (Head of ZLW)  
Technician Peter S e l i g - E d e r  
Electrician Sebastian S c h n e i d e r  
Mechanician Master Michael P f e i f f e r

## External teaching staff

Hon. Prof. Dr.-Ing. Volker L i e b i g - Directorate ESA  
Hon. Prof. Dr.-Ing. B r a u n - RST Raumfahrt Systemtechnik AG, St.Gallen

# Research Projects

## Improving the GNSS Observation through coupling with the MEMS-acceleration measurements

This topic is a part of the UniTAS IV project described in the last annual report. The task of the institute of navigation is to build-up an tightly couple inertial navigation system. The aim of the system is to support the GNSS tracking loop with the MEMS (Micro Electro-Mechanical Systems)-acceleration in order to improve the GNSS observations.

The performance of the GNSS tracking loop was tested. These tests showed the sensitivity of the GNSS tracking loop in relation to dynamic stress and signal quality. A following postprocessing analysis revealed the improving of the GNSS observation by coupling with the MEMS-acceleration measurement. The developed algorithm is not suitable for real-time measurement and is not using the satellite geometry. Therefore the development of the algorithm will continue in the following year.

The MEMS sensors need to be calibrated before the application in order to minimize the bias. For that reason a methodology to calibrate a MEMS sensor was developed in the last year.

## Project Motion Pattern

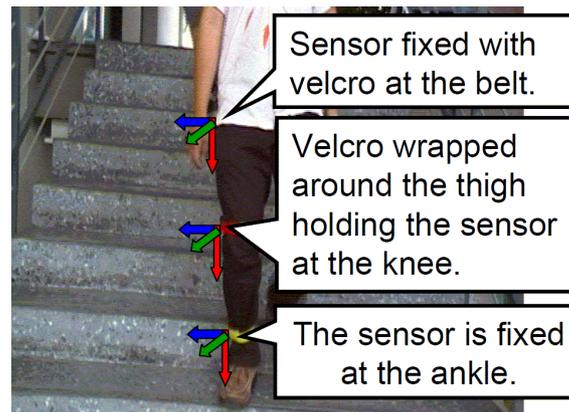
The aim of Project Motion Pattern (PMP) is to show the feasibility of detecting physical activity with low-cost micro-electro-mechanical systems (MEMS) accelerometers. In medicine and sports science the physical activity (PA) is an important parameter, which is often retrieved by questionnaires or telephone interviews and nowadays also with accelerometers. The PMP was created at the Institute of Navigation (INS) to investigate the framework of a system for PA detection using MEMS accelerometers.

For the tests with three probands, a wireless sensors platform was chosen comprising the triaxial MEMS accelerometer Freescale MMA7456L. The main features of the sensor platforms, the small size (35mm diameter, 10mm thickness) and light weight (20 g) combined with the wireless radio communication, allow the usage of these sensor platforms attached to the body of the probands without restrain their natural behaviors and movements.

So the probands, without being connected by any cable, were able to move freely and perform test series, where they were asked to walk, run, climb stairs, sit, stand and lie down. The specific force was measured by three accelerometers attached to the probands at the ankle, above the knee at the thigh and at the belt.

All data was recorded with a laptop that received the measurements by a ZigBee compliant protocol. Based on the measurements, MATLAB functions were developed to recognize the performed motion pattern in a post-processing analysis.

The motion pattern, with a detection rate between 74% and 98%, are given in a high time resolution and provide the PA of the probands in a very good quality.

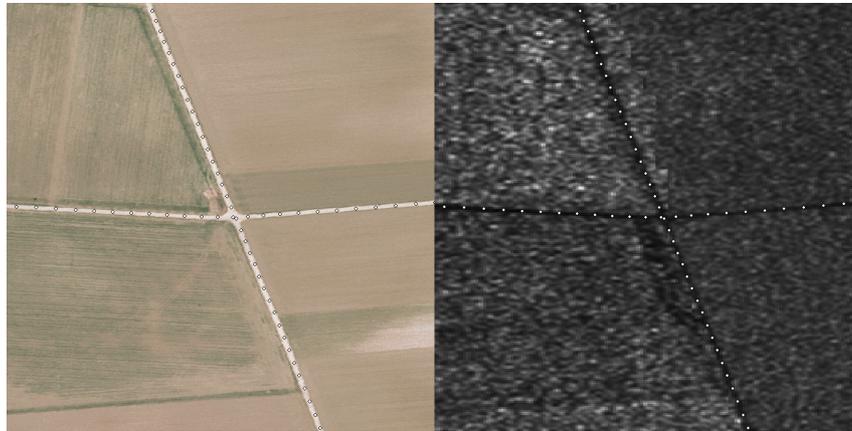


*Fig. 1: Three accelerometers are attached to the proband to detect the physical activity and the motion pattern.*

## Eplus

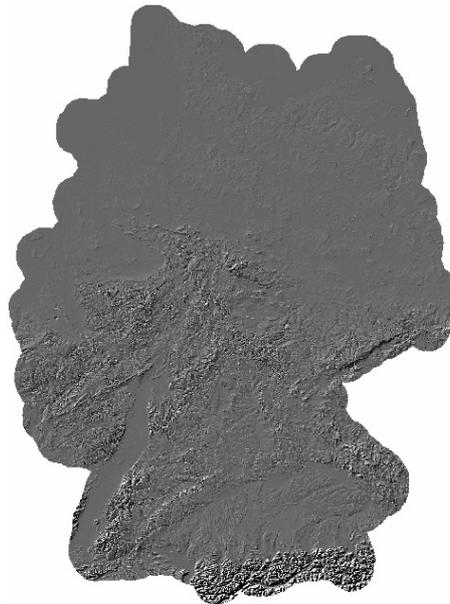
In 2009 the quality investigation of the DTM from Intermap Technologies for E-Plus Mobilfunk GmbH reached a final step and will be finished in spring 2010. The results within 2009 caused Intermap to recalculate the delivered DTM. Even though 1% of the area is affected the results were in evidence along the working units in a positive way.

Investigating the horizontal accuracy of the DTM a test run was done with the Applanix POS LV420 near Stuttgart. In Fig. 2 you can see the waypoints of the test run underlayed with the unprojected ORI-Image delivered by Intermap Tec. The waypoints fit the centerline of the tracks very well.



*Fig. 2: Waypoints of a test run underlayed with an unprojected DOP (left) and an the unprojected ORI-Image (right)*

The acquired DTM encompasses the whole countryside of Germany and a 30km buffer. For the buffer the vertical accuracy for 3 test sides was analyzed. The result is that the DTM observes the product specification valid for bare areas with a slope  $<10^\circ$  within these test sides.



*Fig. 3: Hillshade of the whole DTM*

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

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

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

The joint project is elaborated in close co-operation between the Netherlands Organization for Applied Scientific Research (TNO, Dept. Air Quality and Climate), Utrecht, The Netherlands, the working group on Tropospheric Research of the Institute for Meteorology 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](http://www.mapesi.de)

on the methods applied: <http://www.icpmapping.org/htm/manual/manual.htm>

on previous projects: [http://www.nav.uni-stuttgart.de/navigation/forschung/critical\\_loads](http://www.nav.uni-stuttgart.de/navigation/forschung/critical_loads)

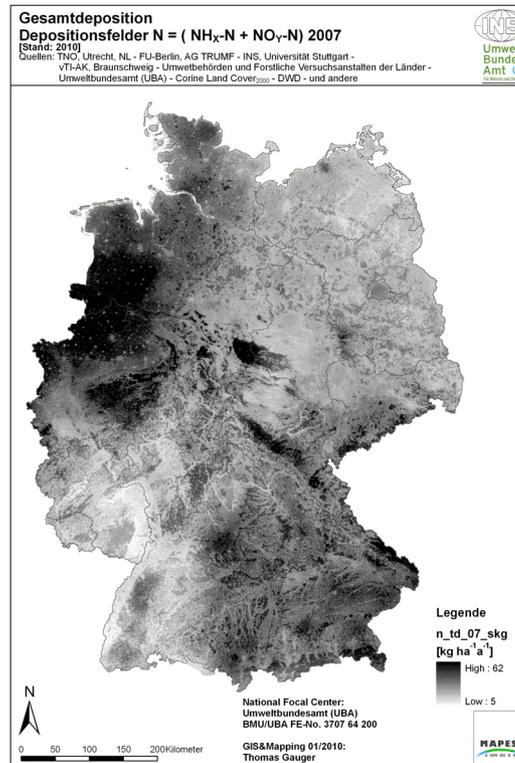


Fig. 4: Total deposition fields of nitrogen in Germany 2007

## Publications and Presentations

- Kleusberg A., Schäfer B., Xue W., Fang X.: „Aktivitätserfassung und Navigation“, Körperlich-sportliche Aktivitäten erfassen: Ambulantes Assessment in der Sportwissenschaft, Symposium, Institut für Sportwissenschaften, Universität Stuttgart, 14.10.2009
- Wehr, A.: „LIDAR Systems and Calibration“, Topographic Laser Ranging and Scanning: Principles and Processing, Jie Shan & Charles K. Toth (eds), Taylor & Francis Group, Boca Raton FL, 2009, pp. 129-172.
- Wehr, A., Petrescu, E., Duzelovic, H., Punz, Chr.: „Automatic Break Line Detection out of High Resolution Airborne Laser Scanner Data“, Conference: Optical 3-D Measurement Techniques IX, Vol II, Vienna, July 1-3, 2009, pp. 72-78.

- A. Wehr, H. Duzelovic: „Bruchkantendetektion mit hochauflösten Laserscannerdaten“, Österreichische Zeitschrift für Vermessung & Geoinformation (vgj), 97. Jahrg., Heft 4/2009, pp. 408-415.
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## Study Thesis

- Gao, Shangjin: „Stand der Technik für die automatische Generierung von Bruchkanten aus hochauflösenden Laserscanner-Daten“; Studienarbeit, Institut für Navigation; Universität Stuttgart; September 2009; (Wehr).
- Wang, Kan: „Modellierung der Dopplerfrequenz aus GPS- und MEMS-Messungen“; Studienarbeit, Institut für Navigation; Universität Stuttgart; April 2009; (Wehr).
- Locher, Marcus: „Galileo Aktueller Stand des Systems und der Signale“; Studienarbeit, Institut für Navigation; Universität Stuttgart; März 2009; (Wehr).
- Hu, Xiao: „Was ist MEMS?“; Studienarbeit, Institut für Navigation; Universität Stuttgart; April 2009; (Wild-Pfeiffer).
- Cobalás, Carmen: „Entwicklung eines internetbasierten Lernmoduls „Navigation“ als ergänzendes Lern- und Lehrmittel“; Studienarbeit, Institut für Navigation; Universität Stuttgart; März 2009; (Wild-Pfeiffer).
- Ming Deng: „Stabilitätsuntersuchungen an MEMS-Beschleunigungssensoren“; Studienarbeit, Institut für Navigation; Universität Stuttgart; 2009; (Wehr).
- Rosca, Alexandra: „Darstellung von importierten GPS-Tracks und von Echtzeitpositionen in Google Earth“; Studienarbeit, Institut für Navigation; Universität Stuttgart; Dezember 2009; (Schöllner).

## Diploma Thesis

- Shufang, Wang: Untersuchung zum Informationsgehalt von „Full Waveform Laserdaten“; 2009 (Wehr).
- Emilia Petrescu, Emilia: „Automatische Bruchkantendetektion aus hochauflösenden Laserscanner-Messungen“; 2009 (Wehr).
- Zimmermann, Naomi: „Positionsbestimmung für Bodenradarsysteme“; 2009 (Braun, Wehr).
- Locher, Marcus: „Umsetzung eines Kantendetektionsalgorithmus für zusammengesetzte Rasterdatensätze in ArcObjects“; 2009 (Pasternak).

## Participation in Conferences, Meetings and Workshops

Wild-Pfeiffer, F.

Gyro Symposium, Karlsruhe, 22.-23.09.2009

Geodetic Week, Bremen, 22.09.-24.09.2009

Meeting „Frauen im DVW“, Intergeo Karlsruhe, 23.09.2009

Schäfer B.

DGON Navigationskonvent, Berlin, 09-10.07.2009

Geodetic Week, Karlsruhe, 22-24.09.2009

Körperlich-sportliche Aktivitäten erfassen: Ambulantes Assessment in der Sportwissenschaft, Symposium, Stuttgart, 14.10.2009

## 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

## Honors/Awards

Wild-Pfeiffer, F.

IAG Young Authors Award 2008

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

Navigation and Remote Sensing (Kleusberg, Schäfer)	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 in Dynamic Systems (Kleusberg)	2/1/0/0
Navigation I (Kleusberg)	2/2/0/0
Inertial Navigation (Kleusberg)	2/2/0/0
Remote Sensing I (Wild-Pfeiffer)	2/2/0/0
Remote Sensing II (Smiatek)	1/1/0/0
Satellite Programs in Remote Sensing, Communication and Navigation I (Liebig)	2/0/0/0
Satellite Programs in Remote Sensing, Communication and Navigation II (Liebig)	2/0/0/0
Radar Measurement Methods I (Braun)	2/0/0/0
Radar Measurement Methods II (Braun)	2/1/0/0
Navigation II (Kleusberg)	2/2/0/0

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Integrated Positioning and Navigation (Kleusberg)	2/1/0/0
Interplanetary Trajectories (Becker)	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
Introduction to Geodesy and Informatics (BSc) (Kleusberg, Schäfer) WiSe 09/10,	2/2/0/0
Integrated Fieldwork (Schäfer) (SoSe 2009)	





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#### Geoinformatics

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

#### Photogrammetry and Remote Sensing

Head: Dr.-Ing. Michael Cramer	Digital Airborne Sensors
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Dipl.-Ing.(FH) Markus English	Sensor Laboratory
M.Sc.Eng. Mohammed Othman	Image Orientation
Dipl.-Ing.(FH) Werner Schneider	Digital Photogrammetry Laboratory
M.Sc.Eng. Rongfu Tang	Bundle Block Adjustment Extension

#### Terrestrial Positioning Systems and Computer Vision

Head: Dr.-Ing. Jan Böhm	Spatial Segmentation and Object Recognition
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# Research Projects

## Geoinformatics

### Automatic Interpretation of Map Objects with Kohonen Feature Maps

Different map objects have typical geometrical appearances depending on their object type. For example, houses have typically rectangular structures, rivers are normally represented with smooth lines and streets are often represented with straight lines. Some objects have a very typical unique appearance, like football stadiums or churches. In order to interpret the object type, the objects can be classified with a neural network. Kohonen Feature Maps (or self-organizing maps) are a special type of neuronal networks. A Kohonen Feature Map consists of an input layer and an output layer. Objects, that should be classified, are represented with a feature vector which describes the object characteristics. This feature vector is the input for the Kohonen Feature Map. The output is a classification of the objects into different object classes.

In the following, the practical use of Kohonen Feature Maps for the classification of map objects is shown by an example. The objects are represented in the scale of 1:10,000 and the different object classes that should be classified are: Buildings, highways, major roads, side roads, roundabouts, stadiums and rail tracks. First, the object characteristics of the different object classes have to be defined with a vector consisting of 0 and 1 values. Altogether ten object characteristics are used which result in an input vector with the dimension ten. In the next step, the numbers of neurons of the Kohonen Feature Map have to be defined. The number of neurons of the input layer corresponds to the number of different object characteristics. The optimum number of neurons of the output layer was estimated by testing. Based on an evaluation of different configurations, we use 30\*30 neurons in the output layer.

We tested this classification approach using two test areas (one rural and one urban area). The classification result of the urban area is shown in Figure 1. The recognition rate in the rural area is 94.6% and in the urban area 79.7%. The reason for the lower recognition rate in urban areas is that object characteristics in urban areas have a higher variability as in rural areas. However, these are only first results and it can be expected that the recognition rate can be further improved.

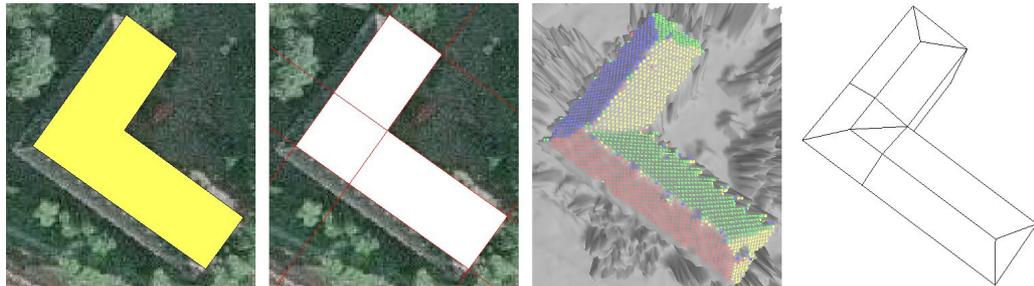


Figure 1: Classification example.

### 3D Building Reconstruction from LiDAR

The reconstruction of 3D city models has matured in recent years from a research topic and niche market to commercial products and services. In addition to the companies operating digital earth viewers, many cities are building up their own data sets as a basis for decision making tools for urban planning, marketing, and resale. When constructing models on a large scale, it is inevitable to have reconstruction tools available that offer a high level of automation and reliably produce valid models within the required accuracy.

In cooperation with Virtual City Systems GmbH, the Institute for Photogrammetry developed a 3D building reconstruction approach, which produces LOD2 models (as defined in the OGC standard CityGML) from existing ground plans and airborne LiDAR data. As well-formed roof structures are of high priority for our projects, the approach constructs models by assembling building blocks from a library of parameterized standard shapes. As a reference, the whole process is exemplarily depicted in Figure 2.



*Figure 2: The reconstruction algorithm decomposes a given building footprint (1) into mostly quadrilateral cells (2), classifies the LiDAR points according to their local regression planes (3) and gives the cells the best fitting roof shapes (4).*

It is assumed that the majority of residential houses have either one main section or multiple connected sections with additional smaller extensions and that a partition thereof can be properly derived from the building's footprint. An integral part of this work lies therefore on the method to decompose a 2D building footprint into a set of nonintersecting cells. However, the difficulty to generate correct facade and roof shapes from a partition increases with the number, shape and arrangement of its elements. We therefore generate only a small set of non-overlapping, mostly quadrilateral shaped polygons that together approximate the original footprint. Although the result is only an approximation, it is still accurate enough for reconstruction purposes. The benefit is, that the sections are separated nicely, especially for residential houses with gabled or hipped roofs. It sometimes happens that the ground shapes are not quadrilateral. As not all roof shapes produce a valid solid in that case, these cells are then restricted to only bear certain roof shapes.

Once such a footprint partition is found, a general geometrical description of the roof can be constructed by assigning a parameterized standard shape to each section. The shape of each cell is determined from the LiDAR points with regard to the neighbour cells to better fit adjacent cells. After identifying the points inside a cell, the normal vectors from the local regression planes of the points are tested against all possible roof shapes. Here, only the orientation is used to speed up the comparison process against the high number of shapes we support. The shape that best fits the points is then chosen and its parameters estimated from the 3D LiDAR point coordinates.

Cells whose neighbour configurations suggest corner-, t- and cross-junctions are examined again and replaced if a junction shape can be fitted according to the neighbour shapes and parameters.

After the cell shapes have been determined, the cells are glued together to form the final geometry of the model. Next, the resulting building models are textured from oblique aerial images. Any lack of geometric detail that is due to our rather restricting model oriented approach is then hardly noticeable in the result.

Many large-scale projects have already been processed with the implemented software, e.g. Berlin, Cologne, Frankfurt am Main, Chemnitz (all in Germany), and Gent (Belgium). For the 3D city model of Berlin (see Figure 3), approximately 470,000 buildings were reconstructed from LiDAR points with a mean point density of 4 points/m<sup>2</sup>. An overall automation rate in the order of 80-85% has been quantified, which gets worse in inner city areas with complex roof structures and better in residential areas. The rest of the reconstructed buildings fail the automatic or visual inspection and must be manually corrected. The model of Berlin was fully textured from approximately 100.000 oblique aerial images.



Figure 3: 3D city model of Berlin textured from oblique aerial images (provided by virtualcitySYSTEMS).

## Privacy in 3D City Models

Within the NEXUS project, spatial world models are used to build a framework for context-aware applications. To achieve this goal, different scientific disciplines work together in joint work. These are for example computer scientists and photogrammetrists, but also researchers from the economic sciences as well as technical philosophers.

Emerging from this interdisciplinary research, privacy concerns in geospatial data systems, like Google StreetView and photorealistic 3D building models were discussed in joint work with the Institute of Philosophy. In two publications the term privacy, its different dimensions as well as its importance to society were explained. Furthermore, privacy issues which may occur in basic geospatial data systems were pointed out and discussed. While geospatial data as such is only object-related data and therefore not initially subject to data protection laws, it may become personal data. This is the case, if it can be located by coordinates and thus easily matched to its owner or residents or if the data is - to put it more generally - able to describe personal or factual affairs. To overcome these privacy issues, a basic list of abstraction and obfuscation methods was compiled. These methods range from the removal of people in texture images by multi-image fusion to texture abstraction and generalization. As the main intrusion in 3D city models can be expected to be coming from the windows, approaches which are usable to hide the window contents were presented. Furthermore, even stronger abstraction techniques like the geometric abstraction of building models or building blocks were discussed as well as using generalization techniques like typification to hide buildings that are at risk concerning their security.

The compiled and presented approaches are merely an overview of methods initially designed for other purposes and used here to counteract privacy issues. Therefore, the research in the field of privacy in geospatial data systems is ongoing.



Figure 4: Left to right: Photo-realistic building model, texture abstraction, texture and geometry abstraction, hidden window contents.

## Quality inspection and quality improvement of road network data

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

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

At first, the edges of the datasets are matched. To consider the topological differences between the two datasets, we extended the matching model „Buffer Growing“ in order that not only matchings between edges but also between edges and nodes are possible. Then, the form of each matching pair is determined by a network algorithm and corresponding nodes are matched.

Data quality is calculated based on similarity measurement on different levels of granularity. High similarity is an indicator for high relative quality. On the dataset level, a global geometric quality measure based on the evaluation of adjacency matrices is proposed. Furthermore, completeness and topologic similarity are measured. On the matching pair level, geometric modeling, geometric similarity and attribute similarity are analyzed.

The last step is the quality improvement by conflation of the datasets. The conflation is subdivided into two steps: conflation of unmatched objects and conflation of matched objects. Depending on the form of the matching pairs, different methods are applied. Due to topological differences, not every matching pair can be merged simply by calculating the middle line. Therefore, all matching pairs with different topologies are allocated into a cluster and conflated by a transformation of this cluster. The attributes and semantic relationships of the matched objects can be transferred from one dataset into the other dataset. The unmatched objects of each dataset are allocated in additional clusters and transferred into the final dataset using a geometrical transformation.

Figure 5 shows the conflation process on two examples. The TeleAtlas edges are represented in green color and the OpenStreetMap edges in blue color. The edges after data fusion are represented in red color.

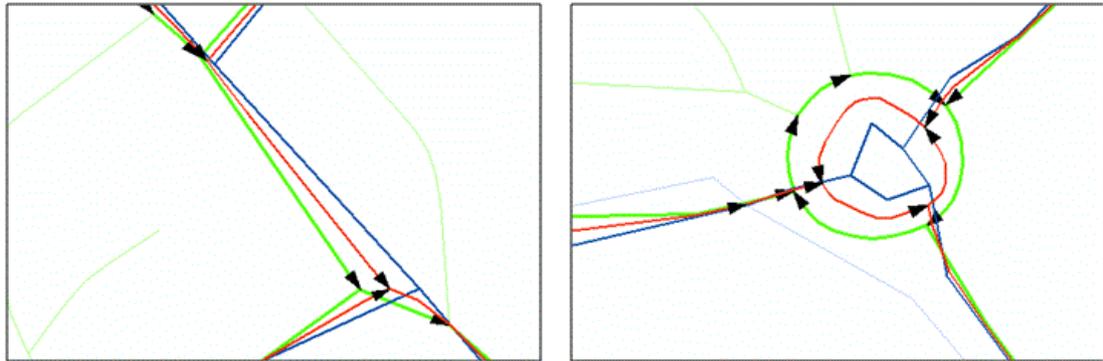


Figure 5: Conflation of matched objects.

### Quality evaluation of cartographic generalization of ground plans

Even though the generation of maps has considerably changed with the technological transition from paper to digital media, the transformation of spatial data from larger to smaller scale still remains very challenging. If the information density of a map is too high, the important aspects are hard to perceive. Instead of being helpful, the map becomes confusing and useless. Thus, the cartographic generalization aims to avoid information overloading by means of reducing the amount of presented details.

This work is dedicated to the quality analysis of cartographic generalization of ground plans. Because there exist many different generalization approaches which are driven by different priorities, many different solutions for the same data are possible. Therefore, one of the most important tasks of quality evaluation of generalization is to enable the comparison of alternative solutions.

Different quality parameters are defined to evaluate the generalization quality. Trueness of ground plan is a boundary-based quality measure that can be expressed by the largest deviation between the contour of the original and generalized ground plan calculated with the Hausdorff distance. Another quality parameter is the percentage of the original outline that remains after generalization, either exactly or within a pre-defined tolerance. Trueness of extension identifies the area distribution of an object in space. The extensional difference between two ground plans can be expressed by the area difference or, in other words, by the difference of intrusions and extrusions measured relative to the original ground plan.

In order to show the validity of the quality measures, they were tested on an example data set consisting of 196 ground plans that were provided by the City Surveying Office of Stuttgart. The ground plans were simplified with a generalization algorithm that has a strong focus on generating a simplified topology, but which does not explicitly generate coordinates that are true to the original

ground plan. In order to have a second data set, the generalized ground plans were additionally adjusted with an approach that tries to best fit the generalized ground plans to the original one. The generalized and the adjusted ground plans were compared with the original ground plans.

It can be seen in Figure 6 that the contours of the ground plans were improved by the adjustment process whereas the area difference becomes worse by the adjustment process (Figure 7). The given examples prove that the introduced quality measures work as they supposed to. Also, they reflect different quality aspects which cannot be improved at the same time.

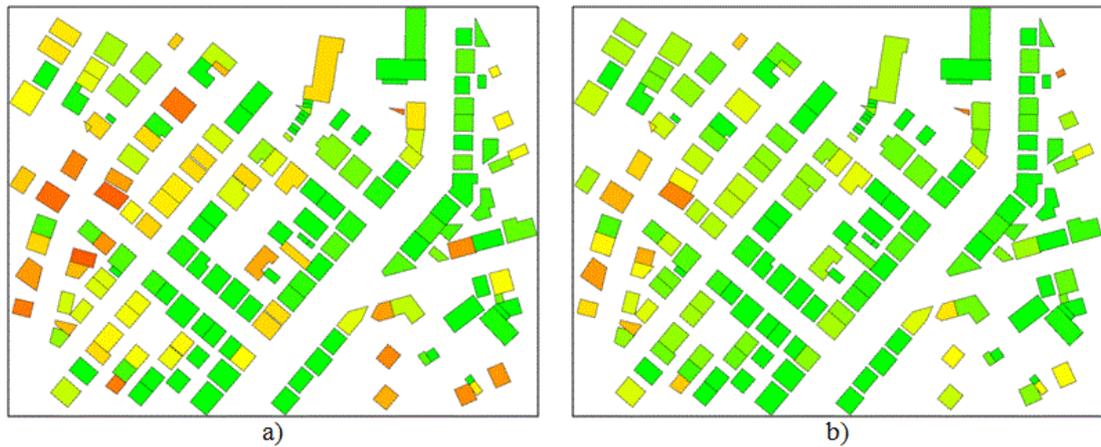


Figure 6: Trueness of generalized (a) and adjusted (b) ground plans.

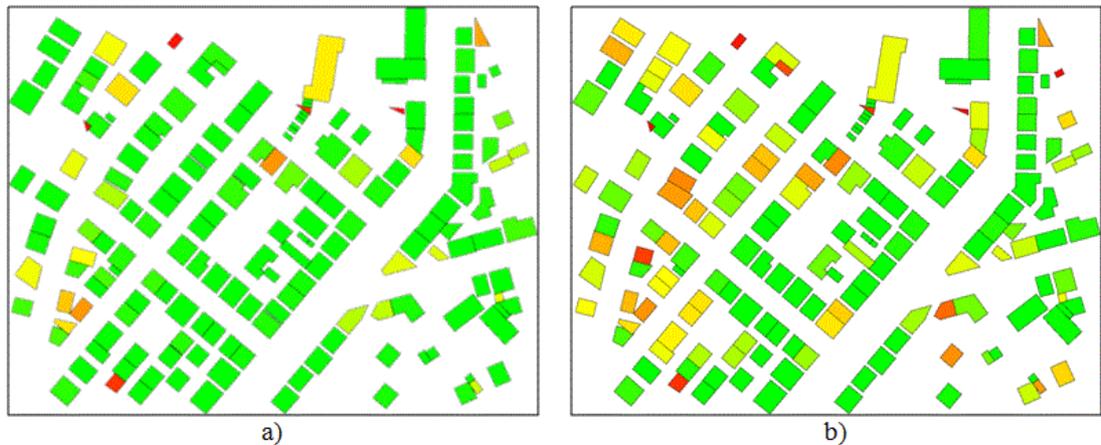


Figure 7: Area difference of the generalized (a) and adjusted (b) ground plans.

## Photogrammetry and Remote Sensing

### Quality dependent reconstruction of building facades

Modelling and visualization of 3D urban landscapes has been a topic of major interest in the last years. A number of tools for the production of virtual city models were developed, which are usually based on 3D measurements from airborne stereo imagery or LiDAR. In addition to this area covering airborne data collection, which mainly provides the outline and roof shape of buildings, terrestrial laser scanning is frequently used, especially if a more accurate and detailed 3D mapping of man-made structures is required. Beside measurements from fixed viewpoints, these scanners are often mounted on moving platforms. Such mobile mapping systems are usually also equipped with multiple video or digital cameras and allow for the rapid and cost effective capturing of 3D data for larger areas. However, considering 3D point clouds, differences in accuracy, coverage and density will occur due to variations in viewpoint and distance to the object of interest. Such differences in data quality will become even more evident when terrestrial data is collected by non-experts using low-cost sensors. Thus, reconstruction techniques will be required which are much more flexible towards different data quality and incomplete sensor data. In this respect, our grammar based approach for the quality sensitive reconstruction of 3D facade structures has been further enhanced enabling the generation of realistic facade structures for large areas even when only few sensor data of sufficient quality is available.

Figure 8 shows an example where a number of buildings in Stuttgart's historic center have been synthesized applying a grammar which has been automatically derived from facade structures of a single facade. In addition to the good visual quality, which could be realized for all of our reconstructed 3D models, several other applications using the resulting building structures will need a decent quality assessment of the results. Therefore, strategies and metrics for the quality evaluation of facade models have been proposed.

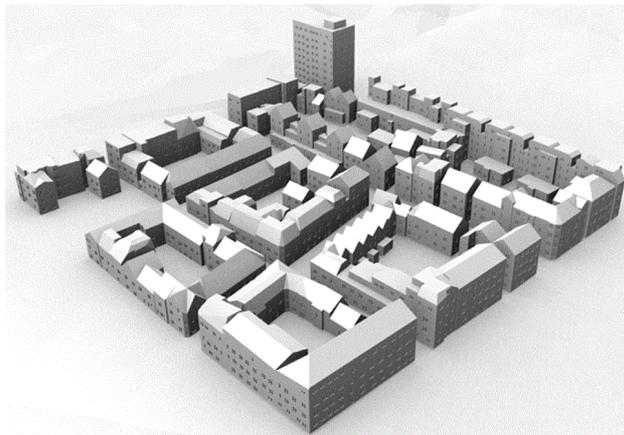


Figure 8: Synthesized facade structures for an exemplary block of buildings in Stuttgart.

## Digital Airborne Imaging - State of the Art

Digital airborne imaging has become widely fully operational. Large format sensor systems like the Intergraph/ZI DMC, Vexcel Imaging Ultracam and Leica Geosystems ADS products have matured. Other systems based on medium format frame sensors, often arranged in multi-head configurations (like IGI Quattro DigiCAM or Trimble (former Rolleimetric) AIC-x4) are competing with the above mentioned former large-format systems and may even exceed them in terms of image size. Besides that other systems are around, some of them following quite new imaging concepts like the panorama-like VisionMap A<sup>3</sup> sensor. As it can be seen today's world in digital airborne imaging is quite heterogeneous and challenging.

Triggered by this dynamic development in digital airborne imaging the testing and independent evaluation of these new systems is an ongoing issue and was also one of the major activities at the Institute for Photogrammetry during the past years. Such tests help to gain a knowledge base in digital camera performance which is then for example used for decision-making when changing from analogue to digital sensor flights. Despite the fact, that some European countries like Finland already decided to completely switch to digital image recording and abandon the old analogue cameras and film development equipment, comprehensive testing of the latest generation digital sensor systems including the quality analysis of sensor products (i.e. covering the whole process line) was typically not considered so far. This was the motivation of the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF) to define a test bed to comprehensively analyse the performance of photogrammetric digital airborne camera systems and work flow. All these tests were done under the project coordination of the Institute for Photogrammetry.

Focus was laid on airborne and large format photogrammetric sensor systems. The test was not limited to sensor performance but also investigates the software processing chain which is another important component when photogrammetric products are of interest. This is different to most of the tests carried out before. In order to allow for a comprehensive analysis, the data was collected in similar test flight conditions and controlled environments. Thus the flight campaigns were realized in summer/fall 2008 using the Vaihingen/Enz photogrammetric test site. The year 2009 was used to finish the comprehensive analysis of the complex data sets, exemplarily results for the geometric performance and the performance of photogrammetric DSM generation are given in the following.

### Quality of object point determination from aerial triangulation

Figures 9 - 11 exemplarily depict the absolute accuracy from check point analysis for three of the systems, namely analogue RMK-Top15 (for comparison) and the frame based multi-head sensors DMC and Quattro DigiCAM. Results are obtained from image blocks flown with 8cm ground sampling distance (GSD). Notice, that the individual block geometries were slightly different, since the area covered by each of the sensors is different due to the individual camera geometry. Thus results may not directly be compared, at least the differences in block geometry and environmental changes during data recording have to be considered.

Processing of data was done at four different institutions independently, namely University of Hannover (UH), Technical University Vienna (TUV), Technical University Graz (TUG) and University of Stuttgart (US). The differences in the RMS values also reflect the variability of results based on the different image point measurements and dependencies on different applied models and block configurations during processing. In some of the variants the cross strips have not been considered (cr0: no use of images from cross strips). Regarding distribution of ground control points operational layouts have been chosen, mainly using only 4 GCPs in the corner of the blocks, at least when directly observed camera positions and attitudes from integrated GPS/inertial systems have been used in processing (nDS: no direct sensor orientation, no use of GPS/inertial data; GPS: only use of perspective centre coordinates, ISO = integrated sensor orientation, i.e. use of positions and attitudes from GPS/inertial as weighted observations for exterior orientation elements).

If one compares the different results from different systems obtained RMS values are very consistent and in almost all cases in the range of 5cm and better. This is well within the sub-pixel range (GSD 8cm). This accuracy is only obtained with the use of appropriate parameter models for self-calibration. More traditional models like the 44 parameter model by Grün (apG44), the 12 parameter model by Ebner (apE16 but here extended with 2 radial and 2 tangential distortion parameter), the physical parameter model by Brown (apBRs, but here only subset with 5 parameters used), a combined model like the Bluh 12 parameter model (apB12) or the extended Bluh 20 parameter model (apB20) have been investigated. Even though the applied models are quite different, the finally obtained accuracy is close, showing that obviously different models allow for efficient compensation of systematic errors in the image data.

The Quattro DigiCAM data set has to be considered in some more detail (see figure 11). The Quattro DigiCAM is one representative of the medium format based multi-head camera systems, as already explained above. Even though the principle design concept is not too much different to the large format frame based multi-head systems like DMC - both using 4 tilted camera heads to obtain larger terrain coverage -, the Quattro DigiCAM images only used the four images per station as separate images. There was no stitching process applied, as this is the case for the DMC virtual images and most of the other remaining frame based multi-head sensors. Obviously, with such configuration the use of GPS/inertial data is helpful for block adjustment. The variants from UH have been processed without the use of directly observed GPS/inertial exterior orientation elements and they show less accurate results, even though a higher number of control points was used. Accuracy could be increased when using a more sophisticated model for self-calibration (Bluh 12 parameter model vs. the extended 20 parameter model). Still, results obtained from integrated sensor orientation (US and TUG variants) are of better quality, which underlines the positive effect on block geometry when high quality GPS/inertial data is introduced. Notice that integrated GPS/inertial systems are inherent part of the Quattro DigiCAM installation. Stitched large format virtual images are also possible for the latest generation of the Quattro DigiCAM system, but have not been considered in this test.

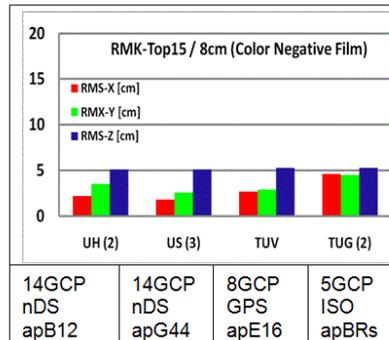


Figure 9: RMS values from check point analysis RMK-TOP15 (cross strips used).

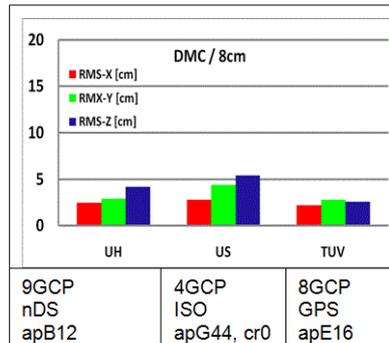


Figure 10: RMS values from check point analysis DMC (cross strips used except processing done by University of Stuttgart (US)).

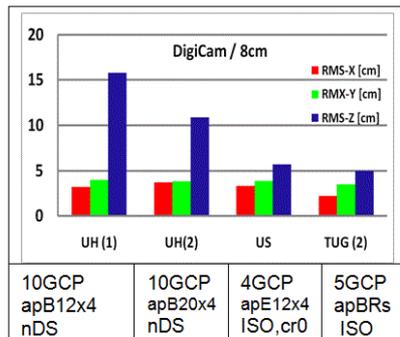


Figure 11: RMS values from check point analysis Quattro DigiCAM (cross strips used except processing done by University of Stuttgart (US)).

## Performance of Digital Surface Model (DSM) generation using image matching

Despite the fact that tools for automatic stereo image matching are available for more than two decades, the collection of high resolution, high accuracy elevation data was mainly dominated by the application of airborne LiDAR systems. However, digital airborne cameras meanwhile enable the area covering acquisition of high dynamic image data with good signal-to-noise ratio. The wide availability of this data also triggered the revival of elevation data collection based on image matching. This trend is currently supported by the development of improved software tools which for example extend traditional stereo- to multi-image matching.

The accuracy, reliability and density of elevation data as generated from automatic image matching is influenced by a number of factors. Important factors are the quality of the available image data and the sophistication of the used matching algorithms, but also the geometric complexity of the respective object surfaces. Image quality again depends on the accuracy of image geometry which is affected by the geometric configuration of the image block, the geometric stability of the camera and the accuracy and reliability of the camera model. Further on, it depends on the signal-to-noise-ratio of the digitized image signal, which is again influenced by the quality of the sensor system but also by the respective illumination and texture of the depicted surface patches. Another considerable impact to the final result results from the subsequent data processing, where the employed software usually consists of different modules for automatic point transfer as well as surface interpolation and filtering. The wide range of interacting factors which mutually influence the quality of the generated elevation data complicates the analysis of the complete process. However, the data as it is available from the DGPF test provides a suitable scenario to discuss a number of aspects.

The overall accuracy of DSM generation can be obtained from comparison of DSM heights to known heights from terrestrial GPS reference point measurements. For the investigations DSM grids of 0.2m raster width were generated from the 8cm GSD imagery using the software MATCH-T DSM. As a reference a 0.2m raster DSM was derived from the ALS 50 LiDAR point cloud. In order to allow for a first evaluation of the resulting DSM qualities, differences between the respective raster surfaces and the available reference points were computed. The results for the respective camera systems DMC, Ultracam-X, Quattro DigiCAM and RMK-Top15 and the LiDAR reference measurement are summarized in Table 1. About 145 reference points have been considered for this accuracy check.

The resulting RMS value for the LiDAR DSM measured by the ALS 50 sensor is 3.4cm, which is almost in the order of the vertical accuracy of the used check points. Compared to this accuracy, the RMS values of the DSMs for the DMC, Ultracam-X and DigiCAM are only slightly larger and rather similar for the different camera systems. The results of these highly overlapping blocks also correspond very well to the vertical component of the preceding block adjustment which also gave a sub-pixel accuracy. For interpretation of these results, it still has to be mentioned, that all above used reference points were typically installed at paved areas like small roads or parking lots. If not occluded, such flat neighborhoods are beneficial for the filtering and interpolation process during

generation of the DSM raster in that area. Thus above accuracy numbers might be too optimistic. For this reason differences between respective DSMs can be computed to allow for a more area covering analysis in addition to the singular elevation values at the available reference points.

*Table 1: Differences between DSM and all reference points (8cm GSD flights) after elimination of gross errors.*

	Sensor	RMS [cm]	Mean [cm]	Δ Max/Min [cm]		Elim. Points
LiDAR- reference	ALS 50	3.4	-1.1	6.4	-11.0	3
GSD 8cm	DMC	3.9	-0.8	21.1	-0.9	2
	Ultracam-X	4.2	-1.4	11.7	-10.8	0
Raster 0.2m	DigiCAM	5.3	-1.1	15.5	-15.7	1
	RMK-Top15	5.2	2.4	15.6	-19.9	2

With that the advances of digital airborne camera systems compared to scanned analog images for matching become much more obvious, as it is demonstrated in Figure 12. The bottom left picture shows a shaded DSM from image matching based on the DMC 8cm GSD block. The corresponding result for the scanned RMK data is depicted on the bottom right. These two examples of the test are especially interesting, since both image blocks were captured simultaneously at identical atmospheric and illumination conditions by using a double-hole aircraft. Both depicted DSM grids of 0.2m raster width were generated from the 8cm GSD imagery using the software MATCH-T DSM. For comparison, the top left image of Figure 12 additionally shows the corresponding ortho image, additionally the shaded DSM derived from the ALS 50 LiDAR point cloud is depicted in the top right.

Obviously, the higher radiometric quality of digital images allows for much better matching while scanned analogue imagery is not suitable for the automatic derivation of high accurate surface models. This supremacy was verified for all investigated digital camera systems of the DGPF test. Thus, recent developments in sensor and software technology facilitate the automatic image based generation of elevation data at a quality, which in the past was only feasible by LiDAR measurements. The results clearly indicate, that a considerable number of applications will be feasible based on height data from image matching, if digital airborne cameras are used.



Figure 12: Comparison of shaded DSM from different data sets.

### Towards automatic reconstructing 3D geometry from low-resolution multiple images

The reconstruction of 3D information from multiple images of a scene has long been an active issue still open in computer vision, graphics and photogrammetry, and it has inspired a wide variety of different approach and algorithms. The demand of 3D models is increasing in several fields,

such as Cultural Heritage, Computer Graphics, Robotics and many others. The reconstructed 3D object and its features are highly dependent on the use of the model. Results may differ in terms of accuracy and time needed for their generation. The key issue is to develop a fully automatic data processing pipeline for accurate, efficient and fast dense reconstruction from a small set of low-resolution multiple images of a complex scene taken by a hand-held digital camera. For that the following cascade is developed:

- ▷ (1) wide-baseline matching
- ▷ (2) structure and motion recovery
- ▷ (3) dense matching
- ▷ (4) 3D model reconstruction

In particular, highly discriminative features are first detected in all images. This is accomplished using the operators SIFT or SURF for detection and description of local point features. Correspondences are then found in all image pairs by wide-baseline stereo matching and traced across images (Figure 13). This data then is used in a scene structure and camera reconstruction step that can cope with occlusion and outliers. The matching quality is improved by applying a double direction matching (DDM).

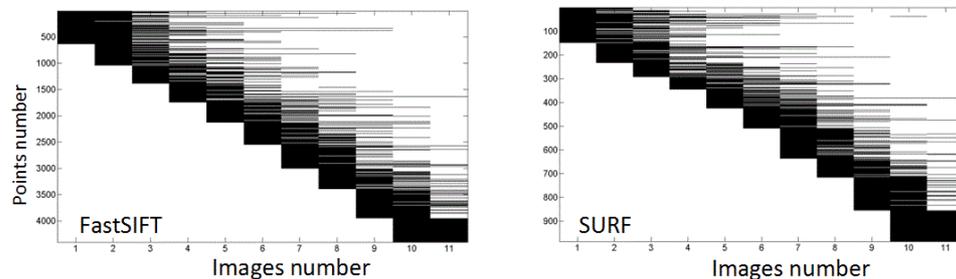
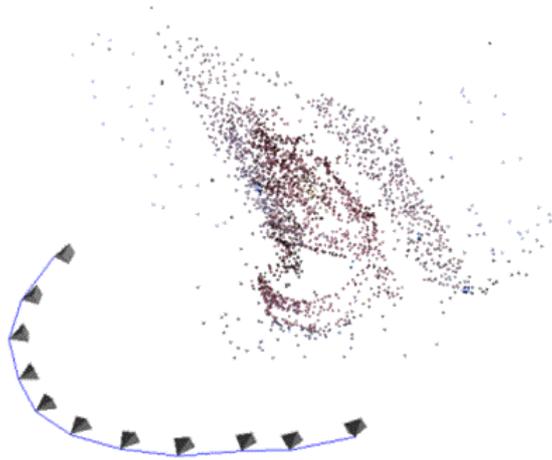


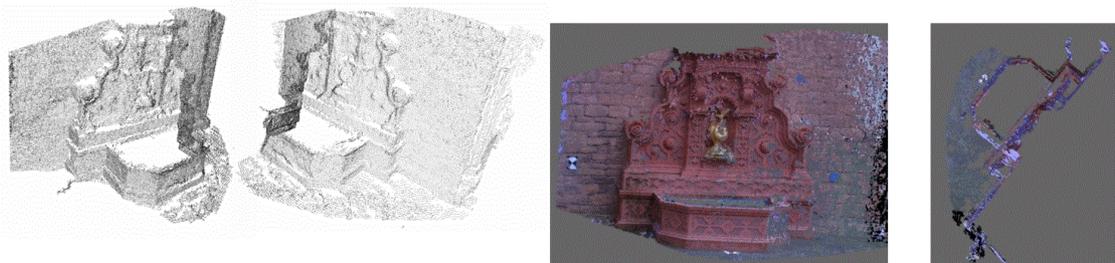
Figure 13: FastSIFT (left) and SURF results (right).

Structure from motion (sfm) is the second stage of the pipeline; it is made up of state-of-the-art algorithms. It follows an incremental greedy approach that entails to start from a seed reconstruction, made up of two calibrated views and the relative 3D points in Euclidean frame. sfm takes the set of tracks and estimate the position of each view as well as the 3D location of the tracks (Figure 14). The extrinsic parameters of two given views are obtained by factorizing the essential matrix. The corresponding points are triangulated, given an initial set of 3D points. Then a Sparse Bundle adjustment (SBA) is performed to eventually improve the reconstruction. After that additional camera stations are added. We not only add the camera that has the highest number of matches to the existing 3D points but also add any camera that has more than 70% of this number of matches. Adding multiple cameras in one step results in less number of iterations of bundle adjustment and thus improves efficiency.



*Figure 14: Camera and scene geometry.*

For the dense matching and 3D model reconstruction (Figure 15) an approach is used, which is implemented as a match, expand, and filter procedure. It starts from a sparse set of matched keypoints and repeatedly expanding these to nearby pixel correspondence before using visibility constraints to filter away false matches (PMVS program by Furukawa).



*Figure 15: Reconstruction results (left) dense 3D point cloud (right) textured 3D model.*

## Terrestrial Positioning Systems and Computer Vision

### Automated 3D Reconstruction of Interiors from Point Clouds

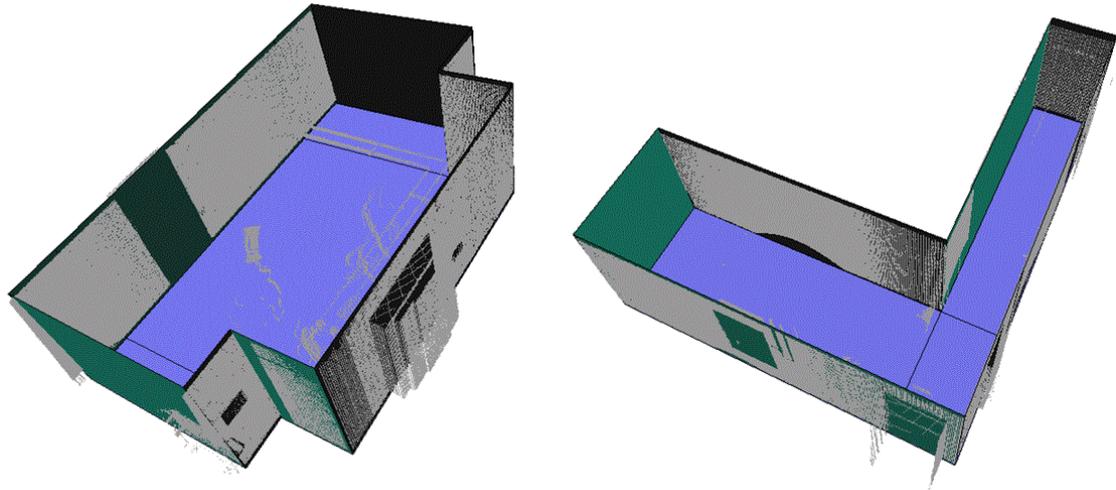
Building models in urban environments are currently classified through the formal specification in CityGML. This open data model supports five different LODs that provide a hierarchical description of building entities, both exterior and interior. The goal of our reconstruction process is to automatically achieve an indoor model that is consistent with the degree of resolution typical for a model at LOD4, the highest representation level of building features in terms of details. So far, realistic models of interiors have always been designed manually with the help of dedicated software packages. However, the demand for indoor models for different purposes has recently increased, thus a higher automation could better satisfy different applications and speed up the processes by improving the efficiency in the project pipeline.

We developed a new technique for the fully automated 3D modelling of indoor environments from a point cloud. The procedure we propose in order to extract the model uses a 3D point cloud as an input for the algorithm. After the data acquisition, the main steps of the algorithm are segmentation (based on a plane sweep technique) and ground plan extraction (using half-space modelling). The basic approach to data segmentation is plane sweeping based on a hypothesis-and-test strategy. From the segmentation results, the ground plan is created through cell decomposition by trimming the two-dimensional ground space using half-space primitives. An extension in height of the ground contours makes the generation of the 3D model possible. The generated indoor model is stored in CAD format for analysis and further applications or, simply, as a record of the interior geometry.

Referring to the field of computer vision, segmentation is an image processing operation that partitions a digital image by grouping sets of pixels with relevant common characteristics. In this way, objects of interest are isolated from the rest of the image, which becomes more meaningful and easier to analyze. 2D segmentation of images shares the same goal of our segmentation, which, although it is applied to 3D points and not to intensity pixels, aims to make different structures distinguishable within the input data set. The distances of such structures from the origin of the coordinates, together with their orientations (angles) in the reference system determine the type of planar region identified (floor, ceiling, walls . . .). To be precise, a plane sweep algorithm is used to collect and separate points describing the walls and the two horizontal faces, namely floor and ceiling. The approach is based on a hypothesis-and-test strategy. A hypothesis is made about the position of a plane, referred to as the sweeping plane, along its normal vector. The criterion for testing this hypothesis is a threshold on the number of points in the neighbourhoods of the sweeping plane. The plane is accepted when the number of points exceeds the threshold.

The second part of the algorithm extracts the ground plan through a half space modelling technique. According to this paradigm, the two-dimensional space is partitioned and shaped by repeatedly splitting it up into two half-spaces using straight lines. In order to recover the ground plan contours, the lines that are used to trim the ground space are those determined by the traces of

the walls on the floor. As a result, a set of ground cells is found. As we mentioned above, the algorithm is able to estimate the geometry of the ground plan automatically without requiring any a priori information about its shape. This is a considerable advantage since the ground plan of buildings is not always available. In our case, we make the basic assumptions that the floor and the ceiling are horizontal, the walls are vertical and they are either perpendicular or parallel to each other. Results of our approach are displayed in Figure 16.



*Figure 16: Two examples of our approach for automated reconstruction. The point cloud is displayed in grey. The reconstructed model is displayed in blue (floor) and green (wall).*

## **RoboMAP**

RoboMAP is a project funded by the Bundesministerium für Bildung und Forschung aiming at the development of a robot guided optical inspection system for the measurement of cylinder heads in the automotive industry. In this project we cooperate with partners from science as well as industry. In order to measure all significant features of a cylinder head, a combination of different measurement techniques has to be applied. A triangulating system and an interferometer are combined to a multi sensor which is capable of measuring outer geometry as well as inner geometry, applying a specialized measuring strategy. This strategy is named Coarse-to-Fine-Strategy and can be roughly described as a stepwise improvement of measuring accuracy and sensor positioning accuracy at the same time. As an initial step, to further increase the system's flexibility, the cylinder head is to be detected using an external, statically mounted camera. This object recognition task and the calibration of the overall system depict the main topics the Institute for Photogrammetry is entrusted with.



Figure 17: Image of the multi sensor taken during a demonstration run in October 2009.

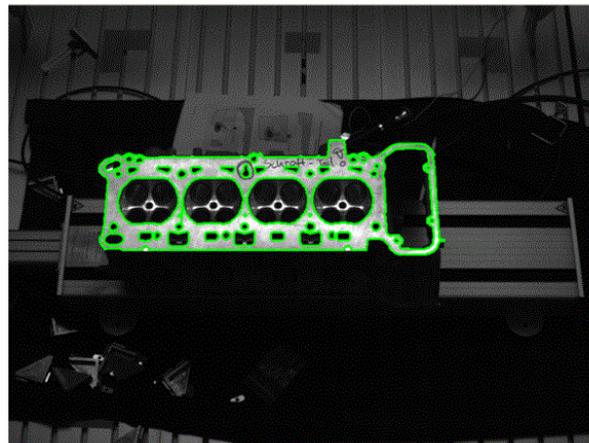
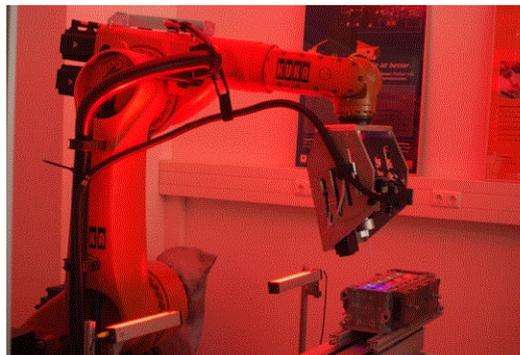


Figure 18: Image taken by the object recognition camera; the recognition's result is used to project the CAD model of the combustion chamber back into the image in order to demonstrate its correctness.

In a first test phase a view based object recognition approach, which uses the known object geometry provided via a CAD model, was applied to a simple test object. The experience gained this way helped determining the parts of the data useful for recognition and transferring the algorithm successfully to the cylinder head. The results could be improved in their accuracy from about 5mm to about 1.5mm concerning the determined object position. An adequate planning of the whole configuration was crucial for this development. This includes not only the choice of the camera position but also the creation of a special lighting solution. We use high power LEDs and a large reflecting surface to create a very diffuse indirect lighting of the combustion chamber. This way we are able to exploit its reflectivity, which usually is seen as a disadvantage, by highlighting the combustion chamber in an image that is otherwise very dark. This coincides with the fact that we solely use the combustion chamber for the purpose of recognition as this surface is the most distinct surface of the cylinder head.

Calibration of the over-all system was the second focus of our work in 2009. The task is to determine the relations between the coordinate systems of all partitioning components. This includes the static as well as the dynamic robot coordinate systems, the coordinate system of the object recognition camera and the coordinate systems of the two robot guided sensors. Especially merging those two sensors to a single multi sensor and determining this multi sensor's relation to the coordinate system of the robot hand demands the development of new calibration strategies including the creation of a specialized calibration body. This body provides special features for each sensor, whose measurement is to yield the complete 6DOF information for the sensors with respect to the calibration body's coordinate system.

In addition implementation issues, such as the integration of our software into the robot control system, will be addressed. All of our work is influenced by general project constraints, e. g. robot workspace design, cycle time of the cylinder head production and the demand for easy maintenance of the system.



*Figure 19: Image taken during a demonstration run, showing the RoboMAP system while measuring a calotte using the triangulation system.*



*Figure 20: Image of the calibration body for the multi sensor calibration; the four spheres yield the triangulation sensor's position; the cylindrical bore hole with its additional features in the inner part of the body yield the interferometers position.*

### **Reconstruction of the Hirsau Abbey**

In a long-term and ongoing effort we are working on the full reconstruction of the remains of the Hirsau Abbey. There were a series of monasteries in the Hirsau valley which date back as far as the 8th century. The structures we see today are commonly referred to as St. Peter & Paul and date to the 11th century. With the support of the „Freunde Kloster Hirsau e. V.“ a society devoted to the promotion and preservation of the abbey and the „Landesamt für Denkmalpflege“ the public authority for preservation, we have started to model the main structures of the abbey. We use both terrestrial laser scanning and close range photogrammetry, to collect dense point clouds and high-resolution textures. For the acquisition of the point cloud we use our Leica HDS 3000 laser scanner. We acquire a point density of about 20-30 mm point spacing. Each section contains about 10 Million points.

In three Master's Theses students of the Institute for Photogrammetry have derived detailed three-dimensional models of the hunting lodge, the cloister and the Lady chapel, which are shown in Figure 21. The results are made available to interested partners and to the public via internet services, such as Google's 3D warehouse. For example, you can access a model of the hunting lodge at:

<http://tinyurl.com/ycqfmd4>

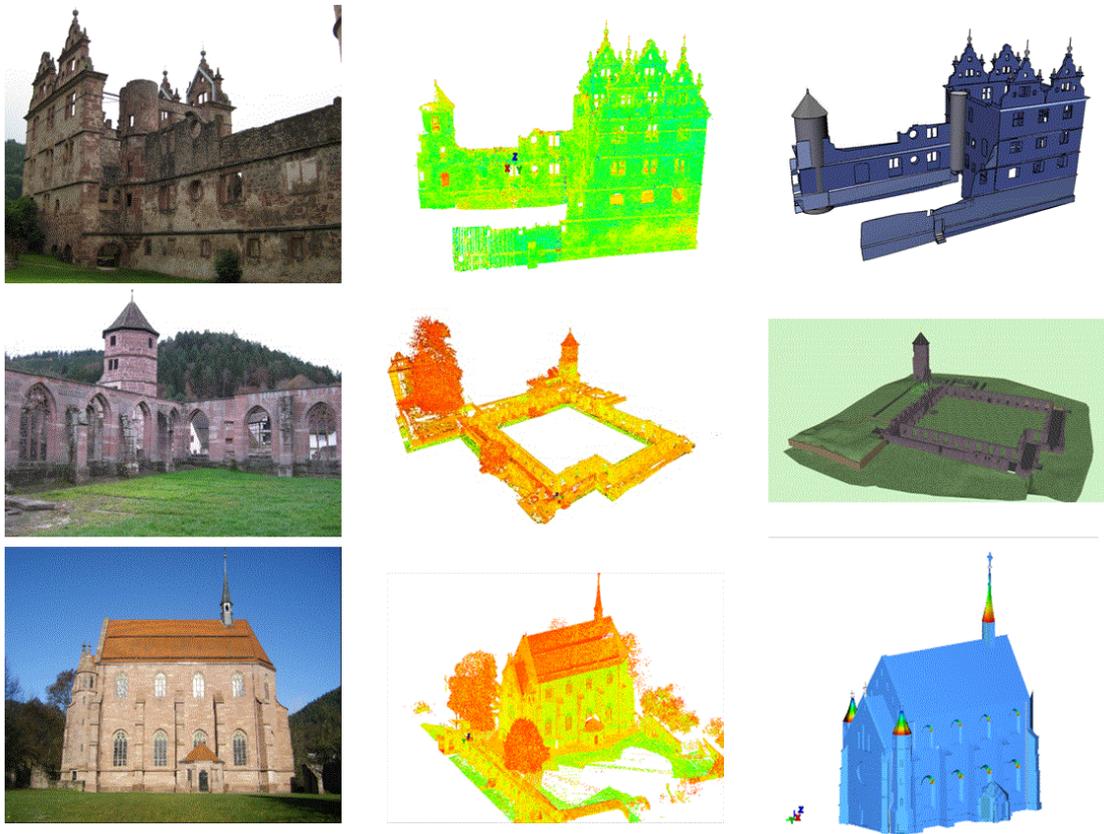


Figure 21: The three sections of the Hirsau abbey that were captured so far: the hunting lodge (top), the cloister (middle) and the Lady chapel (bottom). Each row shows an image of the particular site, a rendering of the point cloud and the three-dimensional model, respectively.

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- Blumrich, F.: Optische korrelationsbasierte Messtechnik mittels zufälliger Punktemuster. Forschungsbericht 2009-10, Deutsches Zentrum für Luft- und Raumfahrt. Supervisor Prof. D. Fritsch, Co-Supervisor: Prof. A. Dilmann.

## Diploma Theses / Master Theses

- Tao, J.: Generierung von 3D-Oberflächenmodellen aus stark überlappenden Bildsequenzen eines Weitwinkel-Kamerasystems. Supervisors: Kurz, F. (DLR), d'Angelo, P. (DLR), Haala, N.
- Filippovska, Y.: Qualitätsuntersuchung von formvereinfachten Gebäudegrundrissen. Supervisor: Walter, V.
- Zhang, L.: Lokalisierung eines mobilen Roboters mittels einer externen statischen Kamera. Supervisors: Gräfenstein, J. (Robert Bosch GmbH), Haala, N.
- Singh, J.: Information Extraction for the Classification of TerraSAR-X Images. Supervisor: Fritsch, D.
- Fuchs, T.: Einsatz einer Highspeed-Kamera für die PROPAC-Messtechnik. Supervisors: Blumrich, F. (DLR Göttingen), Haala, N.
- Jarzabek, M.: Segmentation and presentation of multiple 3D point clouds. Supervisor: Haala, N.

- Tao, T.: Entwicklung und Bewertung von LiDAR-Auswertemodulen für die Aufnahme von Freileitungstrassen. Supervisors: Haala, N., Dörr, I. (GA Energieanlagenbau Süd GmbH), Balsen, H. (GA Energieanlagenbau Süd GmbH), Walter, A. (GA Energieanlagenbau Süd GmbH).
- Zheng, B.: Optimierung der Prüfung intrinsischer Kameraparameter und Evaluierung verschiedener Messkonzepte. Supervisors: Haala, N., Apel, U. (Robert Bosch GmbH), Weber, S. (Robert Bosch GmbH).
- Dan, L.: Erstellung eines WebGIF (WebGIS) aus Basis .Net Web ADF und Erweiterung um Druckfunktionalität. Supervisors: Walter, V., Helm, M. (Intend Geoinformatik GmbH).
- Moussa, W.: Digital Preservation of the Hirsau Abbey by Means of Static LiDAR & HD Close Range Photogrammetry. Supervisors: Fritsch, D., Böhm, J., Kolbe, T. (Th Berlin).

## Study Theses

- Zhou, D.: Radiometrische Einschätzung von digitalen Luftbildkameras. Supervisors: Cramer, M., v. Schönermark, M. (IRS).
- Konrad W.: Genauigkeitsanalyse automatischer Höhenmodelle für Daten verschiedener Luftbildkamera. Supervisor: Haala, N.
- Körner, M.: Realisierung einer Strahlformungsoptik für die Substratvorbelichtung. Supervisors: Pruss, C. (ITO, Stuttgart), Haala, N.
- Schmid, S.: Untersuchungen zum geometrischen Auflösungsvermögen von digitalen Luftbildkameras. Supervisor: Cramer, M.
- Tao, J.: Robuste Zuordnung von Merkmalspunkten in Aufnahmen ebener Objekte. Supervisor: Böhm, J.
- Zhang, L.: Bestimmung der äußeren Orientierungsaus der projektiven Beziehung mehrerer Bilder. Supervisor: Böhm, J.
- Rau, D.: Optimierung der Auswertesoftware für die Reflected Pattern Correlation (REPAC). Supervisor: Haala, N., Blumrich, F. (DLR).

## Activities in National and International Organizations

- Böhm, J.:  
Co-Chair ISPRS Working Group V/4 - Image-based and range-based 3D modelling  
Mitglied im VDI/VDE GMA Fachausschuss 3.32 Optische 3D-Meßtechnik - Gemeinschaftlicher Ausschuss des VDI und der DGPF
- Cramer, M.:  
President EuroSDR Technical Commission I - Sensors, primary data acquisition and georeferencing

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

Fritsch, D.:

Member D21 Advisory Board

Member Board of Trustees German University in Cairo (GUC)

Member Apple's University Education Forum (UEF)

Member Advisory Board Finnish Geodetic Institute

Chairman Board of Trustees 'The ISPRS Foundation'

Chairman Scientific Advisory Board 'Baden-Württemberg International'

Member Advisory Board ISPRS

Vice-President Research EuroSDR

Haala, N.:

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

Vorsitz DGPF Arbeitskreis Sensorik und Plattformen

Walter, V.:

Nationaler Berichterstatter für die ISPRS Kommission IV

## Education - Lectures/Exercises/Training/Seminars

### Bachelor Geodäsie und Geoinformatik

Introduction into Geodesy and Geoinformatics (Cramer, Fritsch, Sneeuw, Keller, Kleusberg)	4/2/0/0
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### Diplomstudiengang Geodäsie und Geoinformatik

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 (Dvorak)	1/0/0/0
Pattern Recognition and Image Based Geodata Collection (Haala)	2/1/0/0
Photogrammetry and GIS (Cramer)	2/1/0/0
Animation and Visualisation of Geodata (Haala, Kada)	1/1/0/0
Cartography (Urbanke)	1/0/0/0

### **Master Course Geoengine**

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, Kada)	2/1/0/0

### **Master Courses „Infrastructure Planning“ and „Water Resource Management“**

Advanced GIS (Walter)	2/0/0/0
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### **Diplomstudiengang Geographie (Stuttgart und Tübingen)**

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**

Introduction into Photogrammetry (Cramer)	2/0/0/0
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### **Honors/Awards**

Cramer, M.  
Carl Pulfrich Award 2009