The Department of Geodesy and Geoinformatics

Stuttgart University

2005

Preface

Dear friends and colleagues, we are pleased to report some of the highlights of the Department of Geodesy and Geoinformatics in the year 2005. As in the previous years this little brochure aims at an information of our friends, colleagues and students about the achievements and changes both in research and education. We consider our work done in 2005 as a contribution to the development of satellite- and mathematical geodesy, navigation, land surveying, engineering surveys, telematics, photogrammetry, remote sensing, optical inspection, geographic information systems and location based services.

The year 2005 brought a change in the position of the head of the Geodetic Institute: After 25 years of successful research and teaching Prof. E.W. Grafarend retired and Prof. Nico Sneeuw took over his position. Prof. Sneeuw is not only continuing the work of Prof Grafarend, he will also sharpen the research profile of the Geodetic Institute in the direction of dedicated satellite gravity-field missions and formation-flying.

All four institutes are involved in a number of curricula at the Universität Stuttgart and run also their own curriculum. The attractiveness of this curriculum is demonstrated by the growing number of German and foreign students, which matriculate in studies of Geodesy and Geoinformatics. After a long lasting preparation time the international Master-program Geomatic Engineering (GEO-ENGINE) is now ready to be launched in 2006.

As in the years before, this report is also on the WEB, to allow for colored figures and further services: downloads of papers, videos, lecture notes etc. Please visit our website:

http://www.ifp.uni-stuttgart.de/jahresberichte/jahresbericht.html

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Wolfgang Möhlenbrink   Nico Sneeuw   Detlef Wolf

Institute for Applications of Geodesy to Engineering

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Head of Institute

Prof. Dr.-Ing. Wolfgang Möhlenbrink
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Scientific Staff

Dr.-Ing. Renate Czommer	Map matching
Dipl.-Geogr. Wolfgang Fürst	Networks for Mobility
Dipl.-Ing. Andreas Gläser	Sensor Integration
Dipl.-Geogr. Thilo Kaufmann	Geodata and GIS applications
Dipl.-Ing. Ralf Laufer	Information quality
Dipl.-Ing. Katrin Ramm	Kinematic positioning
Dipl.-Ing. Ralf Schollmeyer	Vehicle positioning
PD Dr.-Ing. Volker Schwieger	Engineering geodesy
Dr.-Ing. Thomas Wiltschko	Traffic information techniques

Technical Staff

Niklaus Enz
Martin Knihs
Lars Plate
Doris Reichert

External teaching staff

Dr.-Ing. Max Mayer - Landesamt für Flurneuordnung

General View

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

This report shows several research activities which refer to projects supported by public funds. Therefore a new chapter 4 is included into this report characterizing these projects and their environment by short descriptions.

Research Work

The institute's research work can be characterized by the main topic 'Positioning and controlling of moving objects in the digital representation of space'. The institute's current research and development work focuses on the following main fields:

▷ engineering geodesy and metrology

▷ traffic information techniques

▷ eLearning

Engineering geodesy and metrology

Within this working area the IAGB is active in designing, developing and applying multi senor systems for static and kinematic positioning. Evaluation of the measurement data, modelling as well as guidance and control of moving objects in different frequency scales are parts of the working area.

Modular Positioning System

The institute deals with positioning tasks related to quite different quality levels due to the different applications such as car navigation systems, location based services and driver assistance systems. To avoid individual developments and implementations of positioning systems for different tasks, a flexible Modular Positioning System (MOPSY) is developed at the institute. For example MOPSY can be installed at the measurement vehicle of the IAGB and can also be configured for rail applications. It comprises various sensors such as (D)GPS, odometer, gyroscope or non-contact optical speed sensor as well as the respective event-based data acquisition. For this task the software LabView® in combination with measurement computers of National Instruments® is used. By this means synchronisation of the individual sensors can be realized within some nsec. Evaluation is effected by using a loosely-coupled Kalman-filter algorithm, which is the optimal solution regarding a modular system. MOPSY encompasses a MySQL®-based data management system and is continuously upgraded by further acquisition modules and sensors.

Modelling of moving objects

Models with increasing complexity are necessary to correctly measure and analyse moving objects like vehicles. A Kalman-filter algorithm basing on non-accelerated circular movements is applied at the IAGB for modelling trajectories.

Inter-epochal correlations of GPS measurements are taken into account by integration of a shaping filter into the existing approach. Functional modelling of the correlation length is derived from empiric GPS time series and leads to an autocorrelation function of the bell-shaped curve type.

Analyses for the improvement regarding automated realtime error detection are performed in close connection with the introduction of a variable standard deviation for the GPS measurements. Further research will be done to consider the uncertainties and variabilities within modelling of the correlation length by an adaptive shaping filter augmentation.

Modular System for Guidance and Control of Construction Machines (PoGuide)

Within the field of guidance and control of construction machines, especially in road construction, more and more wireless control systems are used besides classical infrastructure controlled systems. Hereby machine position is provided by three-dimensional positioning sensors, such as tachymeters or differential GPS. For spatial orientation further inertial sensors on board of the machine are necessary.

As the market shows many different machines and sensors for different applications the guidance and control systems up to now always represent very special realisations. Adaptations to other machines or other applications always require extreme developing work.
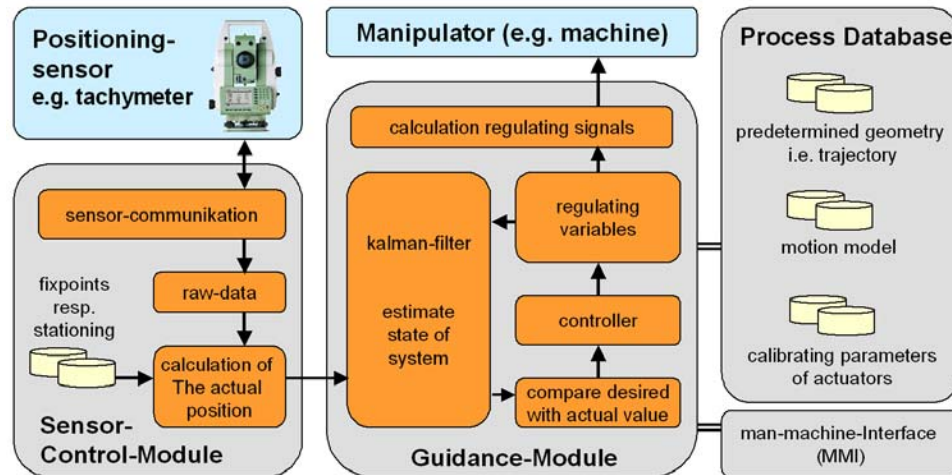
Fig. 1: System design of PoGuide-System with its main components.

A modular system for guidance and control of construction machines (PoGuide) was developed at the institute in an archetypal realisation using LabView® software. The system design is shown in figure 2. As the system is modular it can be used for various applications, such as automatic machine guidance along a defined trajectory, or for machine control towards a defined position. The individual modules shown at the system design can be transformed into other modules due to standardised interfaces, thus integrating different functionalities into the guidance and control system. All modules as a whole represent a toolbox, the so-called PoGuide-Toolbox.

For developing the PoGuide-Toolbox varying applications from the field of construction machine control were defined in a generic approach. With respect to the functions necessary to fulfil the task, the analysis of these applications comprises more than 60 individual functions.

Aim of future research and development is to completely build up these functions within the PoGuide-Toolbox for realisation of all application possibilities of this system.

Positioning by mobile phones

In the project Do-iT (data optimisation for integrated telematic) methods for positioning within the GSM network are analysed. Single positions or sequences of positions of anonymous mobile phones whose users are involved in road traffic are matched to the road. The resulting trajectories can be used for traffic state acquisition and forecasting.

The data acquisition within the GSM network is network-based and can be analysed by using different geometries.
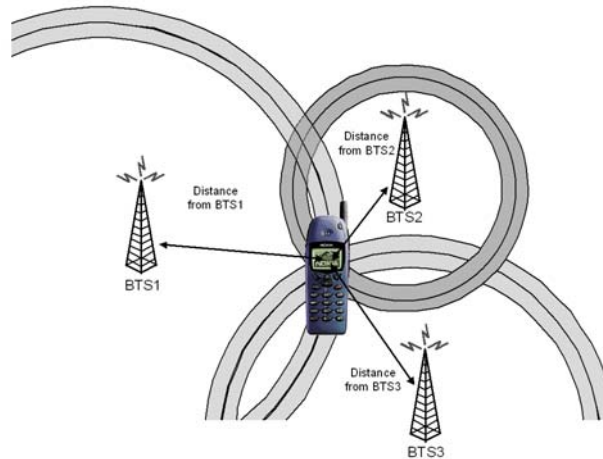
Fig. 2: Position of a mobile phone via arc section.

Figure 3 exemplarily shows the use of distance data (from signal power or timing advance values between a mobile phone and multiple base transceiver stations, BTS) for analysis of an arc section: the so-called time of arrival method (TOA).

Sequences of positions are fed into a filter algorithm and map matching methods are used to relate them to a road element. This research is currently done within a simulation. The analysis with real data from the T-Mobile network is planned for the ongoing year.

Variance-based sensitivity analysis

In general, the sensitivity analysis deals with the relation among input and output quantities of a model. One important task of surveying engineering is the analysis of measurement values within application-oriented models. Frequently these models are non-linear or even non-additive, and the methods of local and linear sensitivity analysis can not be applied. But the global variance-based sensitivity analysis is an effective tool for these cases. The method is based on Monte-Carlo simulation and allows information of qualitative and quantitative correct sensitivity measures. These measures are independent of the model characteristics like linearity.

Last year the method was applied to evaluate a kinematic deformation model for monitoring heights at a church where sensitive measurement points were detected. In another application sensitivity of measurement quantities of a Kalman-filter for the kinematic modelling of vehicle movement was determined.

Fig. 4 shows the results of a simulation for a curve movement with different radii and different movement scenarios for the state variable „orientation of the vehicle". The essential share of the GPS measurements is shown as well as the fact that the simulated radii have no influence on the results of the sensitivity analysis. The single sub-columns show the share of each measurement quantity on the total variance. The different movement scenarios are indicated by character-digit-combinations.
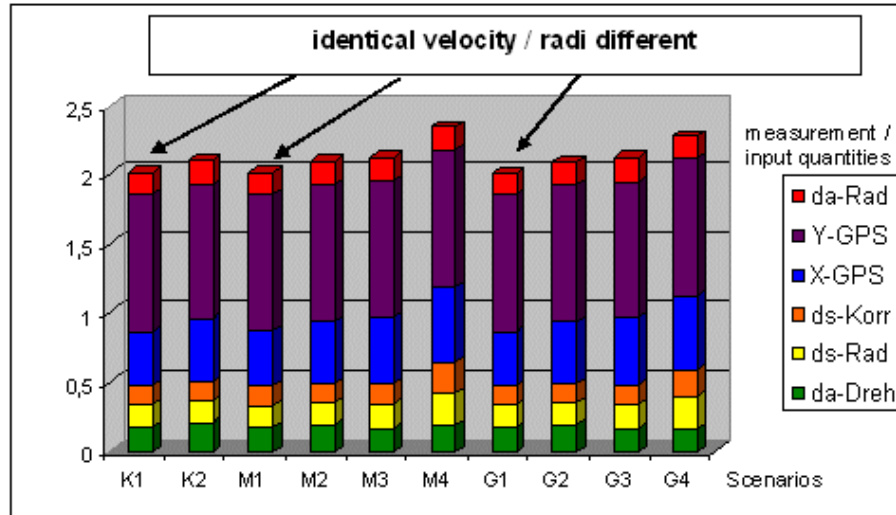

Fig. 3: Influence of the measurement variances on the variance of the vehicle orientation.

Traffic Information Techniques

Within the interdisciplinary field of traffic telematics, the IAGB is contributing with the traditional geodetic work of position determination, modelling in a digital map, as well as reliability of data acquisition and data processing. A variety of activities is focussed on the development of future mobility services and driver assistance systems. One main topic is, beside others, the preparation and analysis of the complete information chain from source data to the end user, thus disposing data of a quality and safety standard required by the application.

Evaluation methods for geodata quality

Quality of geodata and their description wins more and more importance due to the extended applications. Hereby the special challenge is how to practicably determine the quality. Therefore a quality model was developed in the project EuroRoadS with the aim to describe each quality characteristic (e.g.: completeness) by a parameter (e.g. rate of omission) and to quantify it with

the corresponding quality parameter value (e.g.: 2%). For determination of quality parameter values appropriate evaluation methods were specified, classified in „indirect", „direct internal" and „direct external". With „indirect evaluation" methods quality information can be derived from expert knowledge or investigations (e.g. known accuracy values for GPS or digitising). Those methods are summarised as „direct internal", which use only data from the dataset itself. One example are consistency checks by which data are compared with their data specification. And finally there are direct external evaluation methods, by which a complex comparison with reference data and/or field study is necessary.
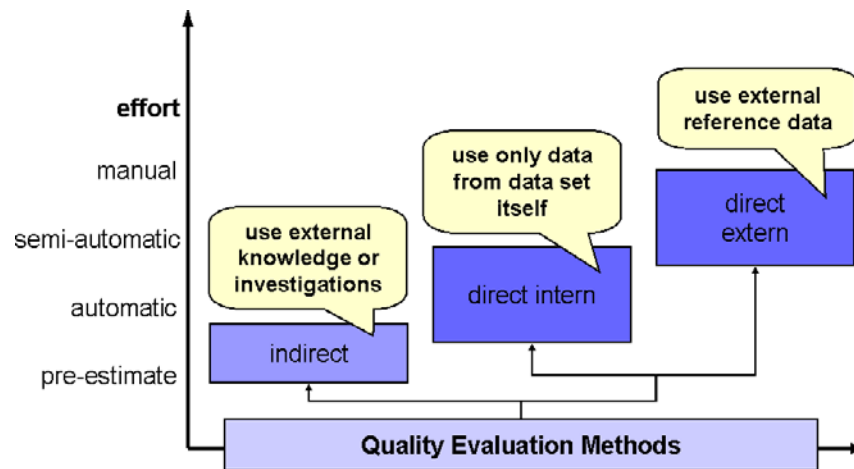

Fig.4: Evaluation methods for geodata quality.

A catalogue of evaluation methods was provided as well as a proceeding in form of a quality inspection scheme for sampling inspection. The specified evaluation methods are tested in a demonstrator on their applicability in close cooperation with the EuroRoadS project partners PTV AG and Bavarian Board of Building for acquisition and processing of road data.

Metadata Catalogue

In the field of geodata infrastructure (GDI), metadata are used in order to ensure a transparent description of spatial data. For issues of official road databases an ISO 19115-conformal metadata catalogue was provided at the IAGB in the context of the EU-project EuroRoadS. The description of data content and quality is an important part. In order to define the extent of the metadata catalogue for its fitness in practice, a multi-level expert questioning of surveying and mapping agencies and service providers was accomplished within the consortium. Thus the UML-modelled metadata catalogue contains core elements as well as other important elements from the extensive

metadata standard ISO 19115. Furthermore the catalogue contains extended elements, being important for road databases, their quality description, and their international application.

The metadata catalogue is integrated into a GML-based exchange format by the Swedish Road Admininstration Vägverket, so that the metadata can be transferred within the whole information chain and edited if necessary. Furthermore parts of the metadata catalogue are implemented into the EuroRoadS metadata server by the project partner DDS/PTV AG. By using this server a customer can be informed on offers of official road data, thus making possible a specific search.
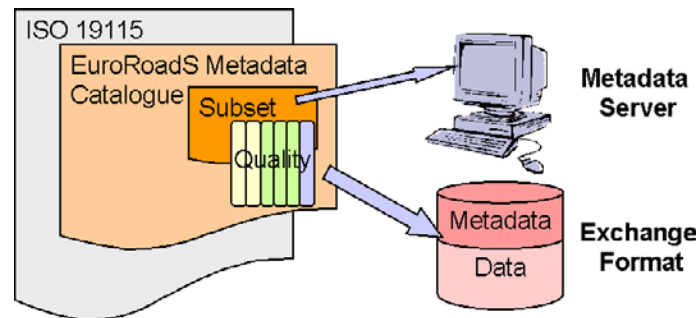

Fig.5: Structure and usage of EuroRoadS metadata catalogue.

Quality model for traffic information

Regarding the development of the last few years, describing and measuring data quality has become one of the essential skills of the IAGB. By using and advancing these skills, a quality model for the Do-iT research project is designed which mainly deals with various kinds of traffic information. The idea is to describe and evaluate quality beginning with the raw data (e.g. Floating Car Data - FCD) via the data processes up to the generated traffic information for end users by a fixed set of inherent quality characteristics. Unlike these characteristics the corresponding quality parameters are not clearly defined from the beginning. So the first aim was to search for adequate parameters by discussing the topic with all project partners. This was necessary to allow for the great variety of different data types occurring within the processing chain.

The second aim is to enrich supply of traffic data for end-users with a useable kind of quality description. We therefore developed an inquiry concept to learn, which quality parameters are of interest especially for rating of traffic information. This inquiry is to be done within the next months. Development of an analytical method for evaluating the quality of different kinds of data is the next step.

Localisation network for mobile phone positioning

In the project DoiT a data base allows calculation of Floating Phone Data (FPD). Base stations and other information from mobile phone network are used as fixed points. To increase position accuracy, road net data resulting from map matching technologies are applied. For identification of active drivers further information, such as Points of Interest (POI) and data from public transport, are used. Special data models and data structures were developed to combine the different data types. During the first phase of the project modelling of these data was analysed and integrated into a combined data model. To evaluate the current traffic status within FPD, the localisation network will be used in real time. Rapid access and rapid data extraction are essential optimisation aims. These requirements were applied to the data model. According to these requirements specifications and first imports of data were completed.

Virtual Demonstrator for FPD

Aim of the so-called „Virtual Demonstrator" is to generate cell phone data in laboratory and verify the algorithms developed. Based on a digital road map and choice of the routing behaviour of simulated subscribers the trajectory including coordinates will be generated. Within these reference data the algorithm for positioning, identification, and referencing to digital road maps will be carried out. Result of this calculation, the current trajectory (geometric route and time information) will be compared to the input data for simulation. Status of the present activity is to work out the structure of simulator and data interfaces.

Geodata in Public Transport

Flexible service of public transportation „RudyBus"

Within the project RUDY a nine months testing (March to December 2005) has been carried out according to the demands arising at stop points. The technical specifications were finished and equipment of four demonstration vehicles was successfully established in time. Passengers in the surrounding area of Ulm could receive the current schedule or book a RudyBus via internet, or call a call-centre in the phase of testing. Due to a predefined schedule with only a few fixed stop points booking by passengers takes influence in the route. In a fully automated booking system the route will be newly calculated as each passenger books individually. In the test phase of RudyBus the essential booking time until departure was evidenced with only 5 minutes.
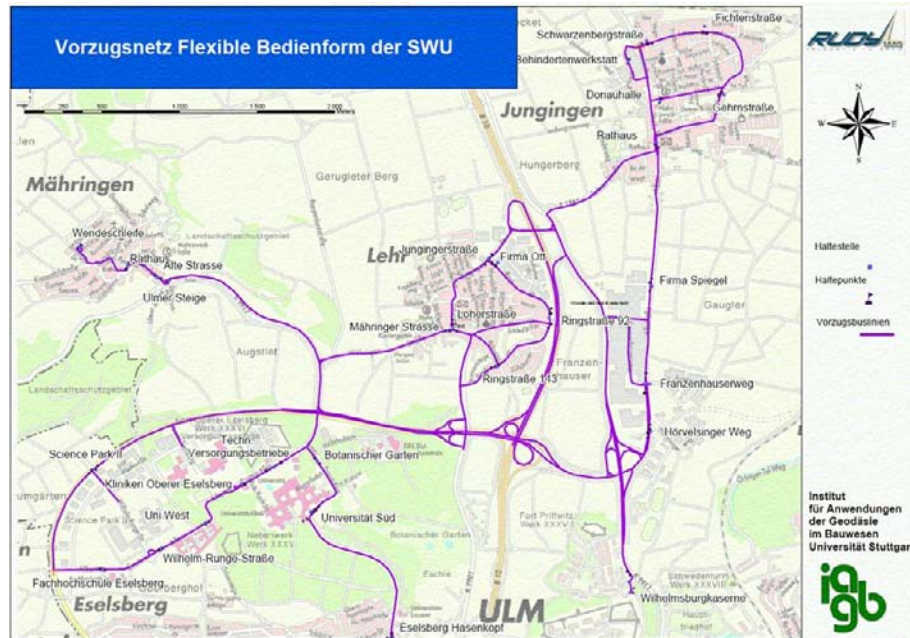
Fig. 6: RudyBus - Section of digital road map of flexible service.

Driving time matrix

The driving time matrix stores all connecting times between stops in the service area. This matrix is the data base for information purposes and for booking the flexible service RudyBus. It also contains the fully geometric data of a route between the individual stop points. For this purpose a special calculating method based on ArcGIS was developed. This algorithm calculates the optimal connection between stops. It is necessary to adjust average speed of the road elements to speeds of public transport vehicles. For the first time an adequate approximation was found by using values of schedules, and the speeds of a digital road map for passenger cars. By analysing RudyBus protocols a better version of the road map was established.

Guiding system

Especially the destination guiding by using a navigation system assists the driver in flexible service. When the route is changed on tour the driver always gets the best route and guiding for safe departure und arrival times. This additional activity within the project RUDY has the impact that the driver gets assistance to concentrate on traffic and increase safety. Accepting and claim for such systems were affirmed by several public transport companies and public authorities.

New Media in physical teaching

Based on the e-learning-platform developed within the project GIMOLUS and completed successfully in 2003, new e-learning modules are developed continuously. The focus is mainly on contents generated for neighbouring disciplines like „civil engineering", „architecture", „geography" and „technique and economy of real estate". Within 2005 the following e-learning modules could be completed:

▷ coordinate transformations,

▷ coordinate systems and projections,

▷ cartographic animations (active map).

Within the scope of the e-learning competition „self-study-online" at the Universität Stuttgart in July 2005 the module „active map" won the second price. The main reason for the award was the combination of e-learning and physical exercises. For example the exercises of „thematic cartography" are combined with several modules. Application was accompanied by evaluation of the target group, the single modules and the e-learning platform itself. At start of the exercises 80 students of the courses „geography" and „geodesy and geoinformatics" were interviewed about their experiences and expectations regarding e-learning. The main result of this target group evaluation is that computer and internet usage is self-evident, but the experiences regarding e-learning are very low. Evaluation of the single modules regarding learning success and understandability of structure and content was positive. Based on additional notes of the students the current modules were enhanced. At the end of the exercises the whole e-learning-platform was evaluated. The results were positive too.
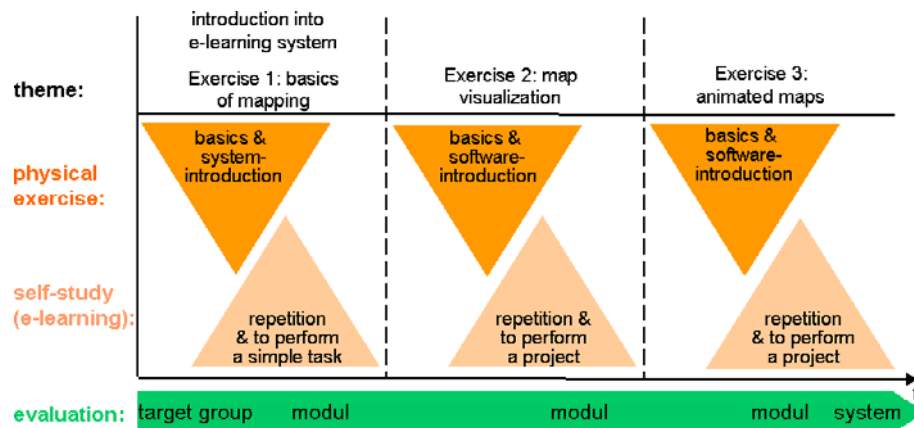

Fig. 8: Integration of physical teaching and e-learning as well as evaluation for the exercises on thematic cartography.

Projects - short descriptions

EuroRoadS - Pan-European Road Data Solution

EuroRoadS is a project funded by the European Commission starting in March 2004 with a duration of 30 months. Aim of the project is the development of a platform for delivering public road data. By a harmonised data exchange access will be simplified.

Focus of IAGB are development and implementation of a quality management concept for road data. Therefore a quality model was developed to be applied within the entire information chain and being part of the specified metadata catalogue. Feasible evaluation methods allow measuring of the actually reached data quality and are an essential part to deliver quality assured road data. The approach will be realised and verified in a demonstrator in 2006.
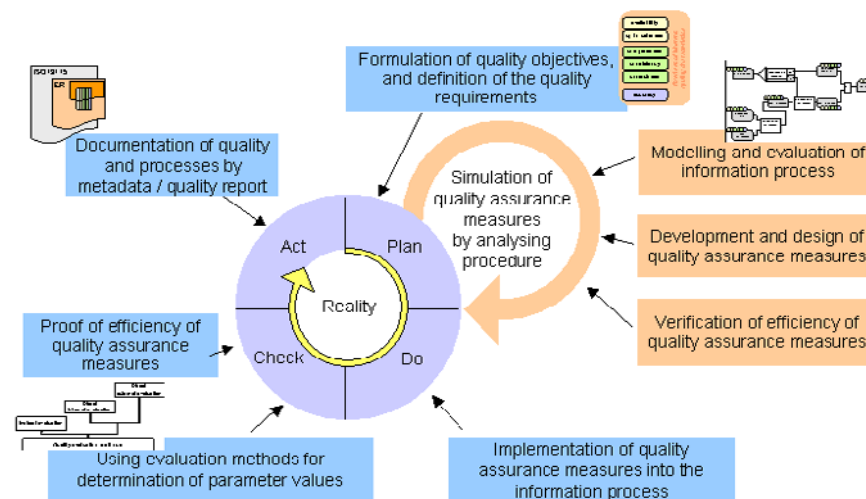
Project website: www.euroroads.org

Fig.9: Tasks for quality management of road data processing according the PDCA-cycle.

Do-iT - Data optimisation for integrated Telematics

Do-iT deals with acquisition of traffic data using mobile phone data, and the application of the so-called floating phone data (FPD) for traffic planning and traffic control will be investigated. The project is funded by the German Federal Ministry of Education and Research (BMBF) within the research initiative „Verkehrsmanagement 2010". Duration is from April 2005 to June 2008. The main activities of the IAGB are as follows:

▷ Localisation with mobile phone data

▷ Generation of routes using map-matching technologies

▷ Identification of active road users

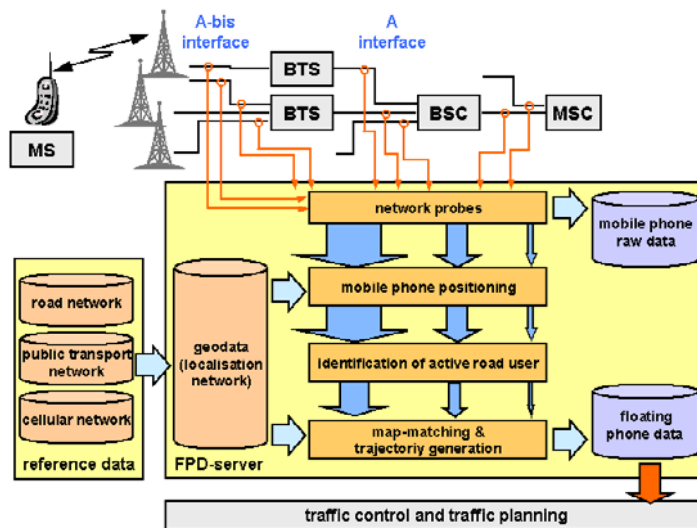▷ Accompanying quality management

Project website: www.vm2010.de

Fig. 10: System architecture and information flow for generation of floating phone data.

RUDY - Regional dynamic networking of information, operational and planning systems in public transport

With the project RUDY public transport in rural regions will be improved by integration of telematics technologies. By means of practical demonstrations within the region of Ulm, Germany, company spanning assurance of connections, route flexible incident management, and different kinds of route flexible and demand-oriented transport supplies were developed. The project started in October 2001 and was finalized in December 2005, funded by the German Federal Ministry of Education and Research (BMBF)

The IAGB was involved in development of a geo-data based intermodal transport control system (GeoITCS), specification and capturing of the necessary and application specific data base, as well as realisation of a driver information system based on a commercial navigation system.
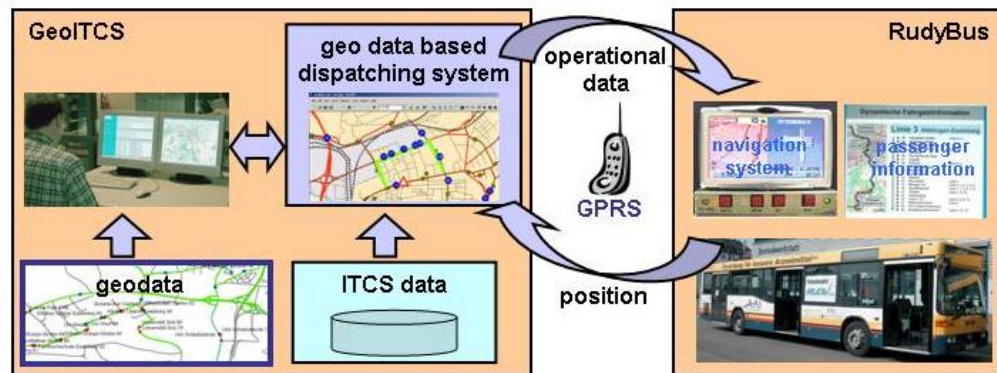
Project website: www.rudyulm.de

Fig. 11: System architecture of GeoITCS for flexible operation of public transport.

Activities of Prof. Dr.-Ing. Dr.sc.techn.h.c. Dr.h.c. K. Linkwitz

The lectures „Analytic Formfinding of Lightweight Structures" for students of the master course „Computational Mechanics of Materials and Structures" (COMMAS) were held in English language. The appertaining practical computer exercises have been performed on windows-NT-computers.

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 „Geometric methods for computer-aided design" were held.

Publications

Eichhorn, A.: Ein Beitrag zur Identifikation von dynamischen Strukturmodellen mit Methoden der adaptiven KALMAN-Filterung. Deutsche Geodätische Kommission, Reihe C, Heft 585, 2005.

Gläser, A.: A Modular System for Guidance and Control Applications for Construction Machines. In: Grün, Kahmen (Eds.): 7th Conference on Optical 3-D Measurement Techniques, Volume I, pp. 307-316, Vienna, 2005.

Linkwitz, K.: Refining Formfinding and Analysis of Prestressed Surface Structures by Using Least Square Method. 5th International Conference on Shell and Spatial Structures, IASS and IACM, Salzburg, 2005

Möhlenbrink, W. und Wiltschko, T.: Safe information for telematic applications. Proceedings on 5th European Congress and Exhibition on Intelligent Transport Systems and Services. Hannover, 1-3 June 2005.

Schwieger, V.: Quality of Low-Cost GPS for Geodetic and Navigation Applications. GIS@development Middle East, Heft Nr. 5, September - Oktober, 2005.

Schwieger, V., Schollmeyer, R., Ramm, K.: Integrated Positioning by MOPSY. Proceedings on 5th European Congress and Exhibition on Intelligent Transport Systems and Services, Hannover, 01.-03.06. 2005.

Schwieger, V.: Nicht-lineare Sensitivitätsanalyse, gezeigt an Beispielen zu bewegten Objekten. Deutsche Geodätische Kommission, Reihe C, Heft 581, 2005.

Schwieger, V, Gläser, A.: Possibilities of Low Cost GPS Technology for Precise Geodetic Applications. Proceedings on FIG Working Week 2005, Kairo, Ägypten, 16.-21.04. 2005.

Schwieger, V., Kaufmann, T.: Teaching Geodata Acquisition - E-Learning Experiences and Visions. Proceedings on FIG Working Week 2005, Kairo, Ägypten, 16.-21.04. 2005.

Stark, M.: Modellgestützte Kostenprognose für den Aufbau qualitätsgesicherter Geodatenbestände. Deutsche Geodätische Kommission, Reihe C, Heft 590.

Wiltschko, T., Kaufmann, T. (2005): A quality model for quality assurance of road information. - In: 5th European Congress and Exhibition intelligent transport systems and services ITS 2005.

Wiltschko, T., Kaufmann, T. (2005): Modellierung und Bewertung der Qualität in Prozessen der Geodatenverarbeitung am Beispiel von Straßendaten. - In: Strobl, J. et al (Hrsg.): Angewandte Geoinformatik. XVII Beiträge zum AGIT-Symposium 2005, Wichmann Verlag, Heidelberg.

Wiltschko, T. und Möhlenbrink, W. (2005): Bordautonome Ortung von Schienenfahrzeugen mit Map-Matching-Technologie. ZEVrail 129, Heft 6/7. Ort: Verlag, 2005. S. 268-274.

Wiltschko, T. und Kaufmann, T. (2005): Quality assured road information for ITS-applications - the quality concept of EuroRoadS. Proceedings on 12th World Congress and Exhibition on Intelligent Transport Systems and Services. San Francisco, 6-10 November 2005.

Diploma Thesis

Christine Holst: Statische Deformationsanalyse der Parabolantenne 7m XY MBA

Katharina Bulach: Entwicklung eines Kalman-Filters zur Positionsschätzung mittels der zur Erhebung der LKW-Maut genutzter Sensorik

Ralf Laufer: Untersuchungen des T-Scan-Systems von Leica-Geosystems hinsichtlich Funktionssicherheit und Genauigkeit

Master Thesis

Yong Cui: Implementation of the optimisation theory for user oriented automatic dispatching systems in railway transport.

Maxeen Hammouda: Integrated transportation land use modelling application in GIS & TPS: case study Verband Region Stuttgart

Masum Bin Majid: Quality management for acquisition and processing of road data - specification measures and measuring methods for quality parameters.

Study works

Thomas Döring: Gleitende Approximation von Polygonen zur Generierung glatter Trajektorien

Fen Luo: Untersuchung der GIS-Erfassungsgeräte GS 20

Feng Mai: Erstellung eines interaktiven internet-basierten Lernmoduls zu Koordinatensystemen und Projektionen

Daniel Wilhelm: Ein Beitrag zur Validierung zweier Modellierungsansätze für bewegte Fahrzeuge unter Nutzung der varianz-basierten Sensivitätsanalyse

Tong Zhou: Untersuchungen zur Basisilinienbestimmung mit Gramin eTrex Vista GPS-Empfängern

Education

Surveying I, II for Civil Engineers (Möhlenbrink, Schollmeyer, Laufer)	3/1/2/0
Surveying for Architects (Möhlenbrink, Kaufmann)	2/0/1/0
Acquisition and Management of Planning Data (Möhlenbrink, Kaufmann)	3/1/0/0
Geodetic Measurement Techniques I, II (Wiltschko, Ramm)	4/2/0/0
Surveying (Möhlenbrink, Ramm)	2/1/0/0
Statistics and Error Theory I, II (Schwieger, Schollmeyer, Ramm)	2/2/0/0
Basic Geodetic Field Work (Ramm, Laufer)	5 days
Integrated Field Work (Gläser, Schwieger, Laufer)	10 days
Surveying Engineering I (Schwieger, Czommer)	2/1/0/0
Surveying Engineering II, III (Schwieger, Gläser, Laufer)	4/2/0/0
Surveying Engineering IV (Möhlenbrink, Czommer, Laufer)	2/1/0/0
Analysis of Networks for Surveying Engineering (Schwieger, Laufer)	2/1/0/0
Multisensor Systems for Terrestrial Data Acquisition (Schwieger, Schollmeyer)	1/1/0/0
Causes and Impacts of Deformations in Structures (Hangleiter)	2/0/0/0
Thematic Cartography (Möhlenbrink, Kaufmann)	1/1/0/0
Traffic Telematics (Wiltschko, Czommer)	2/1/0/0
Analytical Formfinding of Lightweight Structures (Linkwitz)	2/0/0/0
Geodetic Seminar I, II	
(Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink, Wolf)	0/0/0/4
Reorganisation of Rural Regions (Mayer)	1/0/0/0

Institute of Geodesy

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Head of Institute

GRAFAREND Erik W, em. Prof. Dr.-Ing. habil. Dr.tech.h.c.mult. Dr.-Ing.E.h.mult. (until 31.3.)
SNEEUW Nico, Prof. Dr.-Ing. (since 1.8.)

Academic Staff

FINN Gunter, Dipl.-Ing.	Geoid determination
KELLER Wolfgang, Prof. Dr. sc. techn.	Satellite Geodesy, Wavelets
KRUMM Friedrich, Dr.-Ing.	Mathematical Geodesy, Map Projections
REUBELT Tilo, Dipl.-Ing.	Gravity Field Modeling CHAMP
WOLF Detlef, Prof. Dr. rer. nat. habil.	Geodetic System Theory and Modeling

Research Associates

AUSTEN Gerrit, Dipl.-Ing.	Geoid modeling
BAUR Oliver, Dipl.-Ing.	Satellite Gravity Gradiometry
CAI Jianqing, Dipl.-Ing. M.Sc.	Deformation Analysis, Mathematical Statistics
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KUBIK K, Prof. Dr., Brisbane/Australia, 1.1.-2.2.
KUHN M, Dr., Perth/Australia, 2.1.-21.1.
MORITZ H, Prof. Dr., Graz/Austria, 17.2.-4.3., 17.-27.5.
SJÖBERG L, Prof., Stockholm/Sweden, 9.5.-30.5.
VANÍCEK P, Prof. Dr., Fredericton/Canada, 3.5.-27.5.
VARGA P, Prof. Dr., Budapest/Hungary, 15.6.-15.7.

Additional Lecturers

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RICHTER B, Dr., Deutsches Geodätisches Forschungsinstitut, München
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Research

Gravity field recovery from kinematic CHAMP-orbits by means of the acceleration approach

Within the project CHAMP-DACH (part of the geotechnology-programme which is financed by the BMBF) an acceleration approach for the determination of the Earth's gravitational field from CHAMP-data was tested and applied successfully for the analysis of real satellite data.

In the acceleration approach, the satellite's accelerations are computed from the kinematic orbit, which had been transformed into the quasi-inertial reference frame before. This is realized by means of numerical differentiation of second order, where the application of Newton-interpolation turned out to be suitable. Normally numerical differentiation leads to an increase of noise, but if the noise is correlated, the effect of noise can be diminished. In our case, since the noise of kinematic orbits is correlated, numerical differentiation can be classified as unproblematic in our case. In the

next step, the obtained accelerations are reduced from disturbing gravitative and non-gravitative effects. By means of Newton's Law of Motion, these reduced accelerations are balanced by the gradient of the gravitational potential. The gravitational potential is represented by means of a spherical harmonics series expansion, where the spherical harmonic coefficients appear linear in the system of equations. By means of regularisation, for instance Kaula's rule, the system of equations can be stabilized and the noise of the coefficients of higher degree can be damped.

A major problem is the handling of the large amount of data. For a resolution up to degree 90 from a two years' kinematic orbit data set 8278 parameters have to be estimated out of 6 millions of observations. In order to solve systems of equations of such a dimension the algorithm has to be implemented on a supercomputer or an iterative solution has to be applied, which can manage with the limited storage of a PC. An appropriate technique is the method of conjugate gradients, since, on the one hand, the memory-demanding and time-consuming computation of the normal matrix is avoided and on the other hand the design-matrix doesn't have to be stored but is computed and evaluated line-by-line. The stable convergence of the procedure can be accelerated by preconditioning. This can be done by assumption of an ideal orbit, which leads to a block-diagonal approximation of the normal matrix, which can be applied as a preconditioner. Thus convergence can be achieved within 5-10 iterations for simulated data, for real data the convergence is a little bit slower within 10-15 iterations due to bigger deviations from an ideal orbit.

From kinematic CHAMP-orbit data sets of the epoch March 2002 - March 2004, which were computed and provided by the IAPG (TU Munich) various gravity field solutions were estimated. Models with a resolution up to degree and order $l_{max} = 90$ were computed, whereas a comparison with preliminary GRACE-models of higher resolution and accuracy, especially EIGEN-GRACE02S, in terms of degree-RMS shows that gravity field coefficients up to degree 80 could be determined significantly. Furthermore the improvement of up to one order of magnitude in comparison to the best pre-CHAMP state-of-the-art gravity field model EGM96 up to degree 65 indicates the high quality of CHAMP-data.

The reduction of non-conservative disturbing accelerations by means of the accelerometer observations led to a deterioration of the results compared to estimated gravity fields where the accelerometer data and thus the non-conservative disturbing accelerations were neglected. This may be caused by the accelerometer calibration parameters, which were derived by GFZ Potsdam from older observations and thus may not be accurate enough anymore.

Due to bad constellations of the GPS-satellites or too little observable GPS-satellites kinematic orbits may contain outliers and jumps which affect the accuracy of gravity field recovery quite strongly. Thus data preprocessing and outlier elimination play an important role. In principle, outlier detection is possible on the level of the kinematic orbit itself and on the level of the determined accelerations. The following procedures were examined:

▷ filtering by means of orbit variances (→ GIS-CHAMP-var20): inaccurate positions of the kinematic orbit can be eliminated by means of the provided variance-covariance matrices

▷ a simple thresholding procedure (→ GIS-CHAMP-threshold): by comparison of the kinematic orbit with a smooth reduced-dynamic reference-orbit and by comparison of the determined accelerations with reference accelerations propagated from an existing gravity field model inaccurate data can be eliminated, which exceed a certain threshold value (e.g. 3σ)

▷ wavelet-filtering (→ GIS-CHAMP-wavelet): First the differences between the kinematic and the reduced dynamic reference orbit and the differences between the determined accelerations and the reference accelerations propagated from a gravity field model are generated. Finally outliers can be detected by means of the fast discrete wavelet transformation.

Alternative to outlier elimination procedures robust estimation was tested, where reference information isn't needed at all and where all observations are applied. In an iterative process the weights of the accelerations are determined from observation residuals, which, in turn, are applied in the next iteration step for data-weighting within the Gauss-Markoff-model. In the first iteration step the identity matrix is used for weighting. Applied in the acceleration approach, robust estimators converge within 2-3 iteration steps. The advantage of robust estimation compared to conventional least-squares-adjustment is based on a more realistic underlying probability distribution, which makes the estimation more stable against outliers. The advantage compared to outlier elimination can be seen in the fact that no reference information is needed and in the fact that all observations are applied and weighted iteratively according to their accuracy.

Figure 1 illustrates various GIS-CHAMP-models, which were estimated by means of different methods of data preprocessing and robust estimation respectively. Figure 2 compares the most accurate GIS-CHAMP-model to CHAMP-models, which were computed with the classical approach by GFZ Potsdam as well as to EGM96.

Figure 1 emphasizes the importance of data preprocessing: Compared to the least squares solution obtained from the unfiltered dataset - GIS-CHAMP-unfiltered - outlier elimination improves the accuracy significantly. Thereby wavelet-filtering and the simple thresholding procedure lead to almost equivalent results while the gravity field model estimated with outlier elimination by means of orbit variances is slightly worse. The reason for this is that not all outliers and inaccurate positions are identified by large variances. Robust estimation, in this case by means of the Huber-method (GIS-CHAMP-Huber), proved to be superior to the outlier elimination algorithms.

The comparison of GIS-CHAMP-Huber with the CHAMP-model EIGEN-3p and its final version EIGEN-CHAMP03S, which are both determined by means of the classical technique, indicates that the classical method as well as the acceleration approach lead to gravity field models of similar accuracy. The EIGEN-models are a little bit more accurate up to degree 40, for degrees between 50 and 80 GIS-CHAMP-Huber is slightly better. The fact that the degrees between 50 and 80 of the EIGEN-models have a lower accuracy despite a longer observation period can be explained by a previous measurement epoch of most of the data. At these previous epochs

the satellite was in a higher orbit and thus its measurements were less sensitive to the high frequency parts of the gravity field. The higher accuracy of the EIGEN-models for degrees > 80 in comparison with the GIS-CHAMP-models can be explained with the regularisation, which was abandoned at GIS-CHAMP-Huber.

Expressed in terms of geoid accuracy (resolution up to degree $l_{max} = 70$), GIS-CHAMP-Huber leads to a RMS of the geoid-difference related to EIGEN-GRACE02S of 18.9 cm, the classical CHAMP-model EIGEN-CHAMP03S leads to a RMS related to EIGEN-GRACE02S of 23,3 cm.
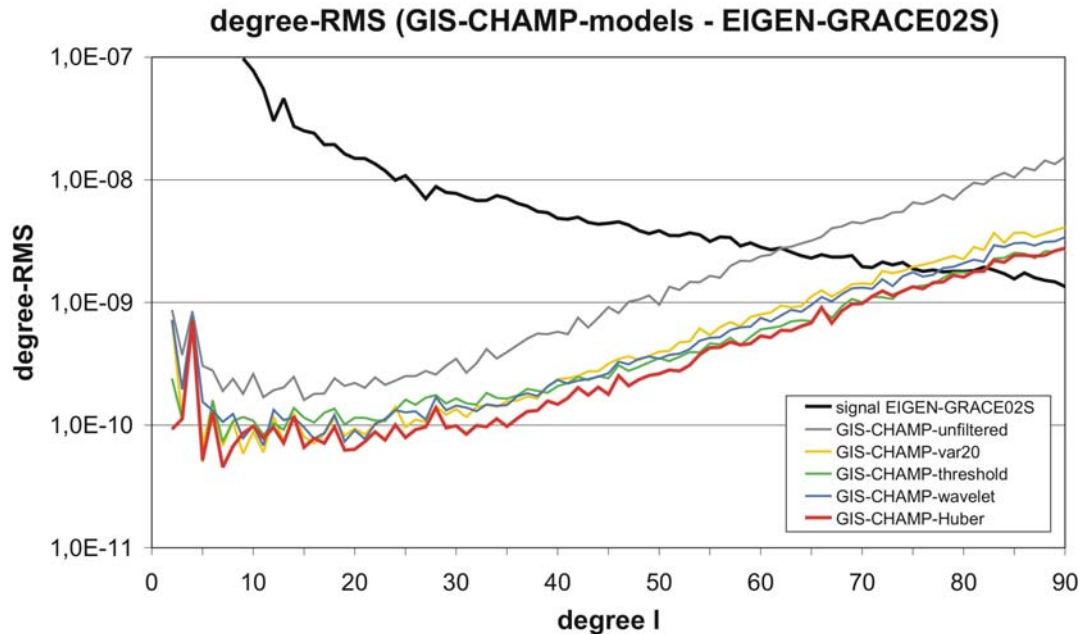

Fig. 1: Gain of accuracy by means of data preprocessing and robust estimation compared to the unfiltered least squares solution
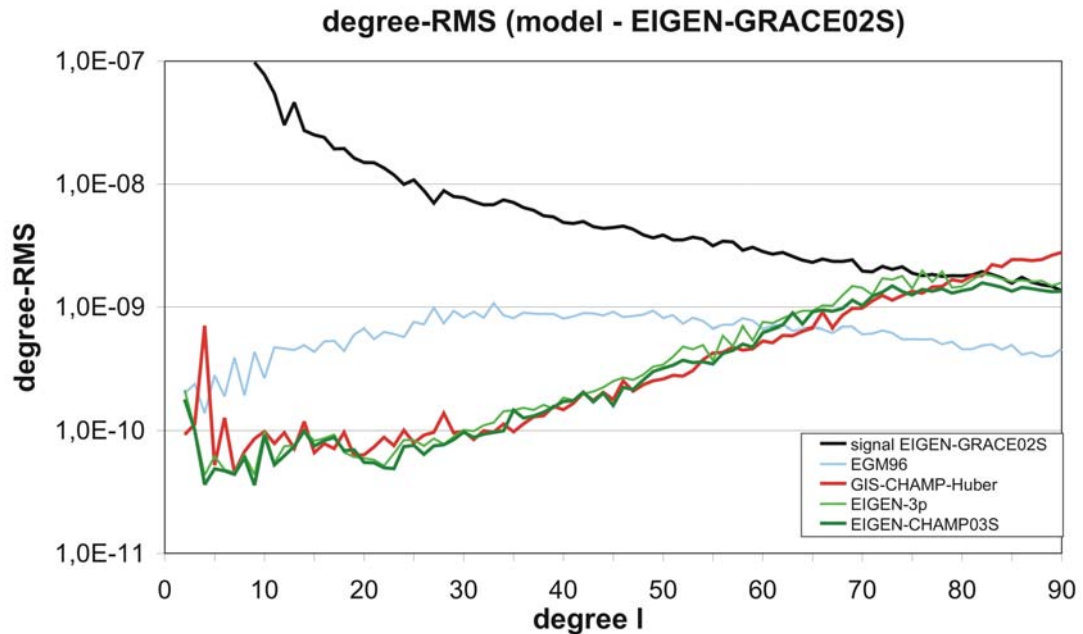
Fig. 2: GIS-CHAMP-Huber compared to EGM96 and CHAMP-models, which were estimated by means of the classical method (EIGEN-3p, EIGEN-CHAMP03S)

GOCE Gravity Field Recovery from Gravity Gradients Tensor Invariants

Dedicated to be launched in autumn of 2006, GOCE (Gravity field and steady-state Ocean Circulation Explorer) will be the first three-dimensional gradiometer mission in satellite geodesy history. The ambitious experiment is part of ESA's (European Space Agency) Living Planet Programme, namely its first so-called Earth Explorer Core Mission to be realized. The primary objective of GOCE Satellite Gravity Gradiometry (SGG) is constituted in modelling the short-wavelength part of the terrestrial gravity field with a spectral resolution of its harmonic series expansion up to degree and order 250-300. Expressed in a geometrical equivalence, the geoid accuracy of 1-2cm with a spatial resolution of about 140km is enforced. The tri-axial gradiometer instrument consists of six 3D accelerometers whose combined measurements allow setting up the so-called gravitational tensor. The coefficient matrix of that tensor is both symmetric and trace-free. Its individual elements are referred to as Gravitational Gradients (GG). They correspond to the second order derivatives of the gravitational potential (twice the application of the gradient operator).

The effective developments of the common project called GOCE-GRAND (GOCE GRavitationsfeldANalyse Deutschland) within the GEOTECHNOLOGIEN II programme „Observation of the

System Earth from Space" have been the basis for its further foundation on the part of the German Federal Ministry of Education and Research (BMBF). Hence, since autumn of 2005 the project GOCE-GRAND II has been in progress, namely a cooperative work of the Universities of Stuttgart, Munich, Bonn, Hanover and Hamburg as well as the GeoForschungsZentrum (GFZ) Potsdam and the Federal Agency for Cartography and Geodesy (BKG) in Frankfurt.

Amongst others the common project is concerned with the development of strategies for terrestrial gravity field research based on GOCE observation data. For that purpose the GIS (Geodätisches Institut Stuttgart) is involved to come up with appropriate analysis algorithms. One special approach is based on the rotational invariants of the gravitational tensor. Table 1 summarizes the advantages and disadvantages of that method compared to the classical proceeding, i.e. the analysis of GG. The scalar-valued pseudo-observations behave invariant with respect to orthogonal transformations. Thus, they are independent of both the orientation of the gradiometer instrument in space and its accuracy. On the other hand, this approach results in a non-linear functional model for gravity field parameter estimation since the invariants are composed of products between the GG.

Pros	Cons
▷ scalar-valued functionals of the gravitational field	▷ the full gravitational tensor (i.e. all its elements) has to be known
▷ independent of the gradiometer instrument orientation in space	▷ the components of the gravitational tensor should be provided with preferably the same level of accuracy
▷ independent of the gradiometer instrument orientation accuracy in space	▷ non-linear functional model, requiring an iterative parameter estimate
▷ independent of reference frame rotations / parameterisation	

Table 1: Pros and Cons of the gravity gradients tensor invariants approach

In terms of computational considerations GOCE data analysis involves an outstanding challenge for the practical application of the concepts which even is heightened for the invariants approach. Covering an operational observation period of twice six month and a sampling rate of 1s results in about 30millions measurement points. Further, according to Table 2, up to approximately $u = 90.000$ unknown parameters have to be resolved. Using least squares adjustment techniques for the inversion of the resulting normal equation system at least one triangle of the symmetric normal matrix **N** with dim(**N**) $= u * u$ has to be kept in the main memory.

Maximum Resolution L	Number of Unknowns u	Memory Requirement for **N** (MByte)
70	5038	101
100	10.198	416
200	40.398	6.528
250	62.998	15.875
300	90.598	32.833

Table 2: Main memory requirements for normal matrix storage

Obviously, standard personal computers (PC) can cover these requirements only for a moderate maximum degree of resolution in the range of $L = 100 - 150$. Additionally, the processing of millions of observation data combined with the parameter estimation in an iterative manner for the invariants approach is a huge task regarding runtime, which requires adequate solution techniques.

The key to come along with these challenges can be found in High Performance Computing (HPC), i.e. the use of multi-processor platforms. Especially SMP (Symmetric Multi-Processing) systems (Figure 3) are very suitable for that kind of problems since the CPUs (Central Processing Unit) have uniform access to all the storage elements (RAM) of the platform. Actually, the CPUs share the effort for normal equation system assembly and inversion. With optimal degree of parallelization runtime scales with the number of CPUs used simultaneously.
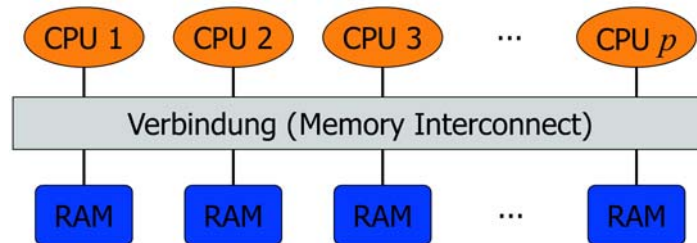

Fig. 3: Schematic structure of a SMP system

Within the scope of the research performed at the GIS mainly the multi-processor platforms of the High Performance Computing Centre Stuttgart (HLRS) are used for numerical calculations. Moreover, the participation at HPC-Europe, an EU funded project, allowed for the acquaintance and use of some computational resources of the Computing and Networking Services in Amsterdam (SARA).

The combination of innovative solution methods, its efficient implementation and its transfer to highly powerful computation platforms allows for modern terrestrial gravity field research. Particularly with regard to the GOCE satellite mission this is the base for forthcoming real data analysis.

A comparison of the satellite-to-satellite tracking formulations

CHAMP and GRACE as the Earth's gravity field dedicated missions have been collecting invaluable information on the geopotential. The knowledge on the field will be dramatically improved by the launch of the European mission, GOCE.

The recovery of the field using the space born data results in a huge linear system of equations with the shear number of unknown coefficients. The system cannot be easily solved in ordinary PCs. Coding on the sophisticated parallel platforms is an alternative which requires special programming skill as well as access to the expensive parallel machines.

As a viable alternative, some soft constraints can be imposed on the observations and the unseen properties of the spherical harmonic functions exploited to facilitate the recovery process. Having evenly-spaced observations on a sphere, for instance, is the minimum requirement for implementation of the Space-wise approach. In this approach, the huge linear system is split into smaller linear systems which can be easily inverted in ordinary PCs.

The GRACE observations, the realization of the satellite-to-satellite tracking in the low-low mode, are formulated in the space-wise approach. Since the observables are of the type non-invariant, two different iterative approaches are developed for the determination of the spherical harmonic coefficients. Both approaches are formulated and their performance is compared numerically.

Geoid modeling in the singularity-free gravity space formulation

At present two complementary theories for gravity field modeling and geoid computation exist: the geometry space and the gravity space formulation of the geodetic boundary value problem. Until now, geoid determination has been predominantly carried out in geometry space using gravity anomalies as boundary values. The gravity space approach, which is based on the singularity-free transformation of the geodetic boundary value problem from geometry into gravity space, features the advantage of using potential instead of gravity data as boundary values. Potential information is deduced from spirit levelling and gravity information from gravimetry campaigns. In general, spirit levelling lines are denser than gravimetric benchmarks. Moreover, potential data is smoother than gravity data. Therefore, incorporating topography and global gravity field models, gridded potential data can be derived with higher relative accuracy and higher resolution than gridded gravity data. Higher data density and higher smoothness of potential data make the gravity space approach from a numerical point of view very interesting. Furthermore, the gravity space approach exhibits, after linearization with respect to a spherical normal potential, the same mathematical structure than the linearized Molodenskij problem. Therefore all well-known numerical methods of the classical concept of geoid determination can be transferred to gravity space.

For the first time, numerical experiments should be conducted to verify the theoretical concepts of the gravity space approach first derived by F. Sansò in the 1970s and refined by W. Keller in the 1980s. For this purpose a closed-loop study (Figure 4) for a global simulation scenario had been

chosen to generate, based on known gravity field and topography models, the boundary surface and the corresponding boundary values. The subsequent analysis step aimed at the recovery of the primary gravity field parameters by means of the underlying methods of gravity space. A final comparison of recovered and true potential coefficients gave information about the applicability of the gravity space approach in geoid determination.
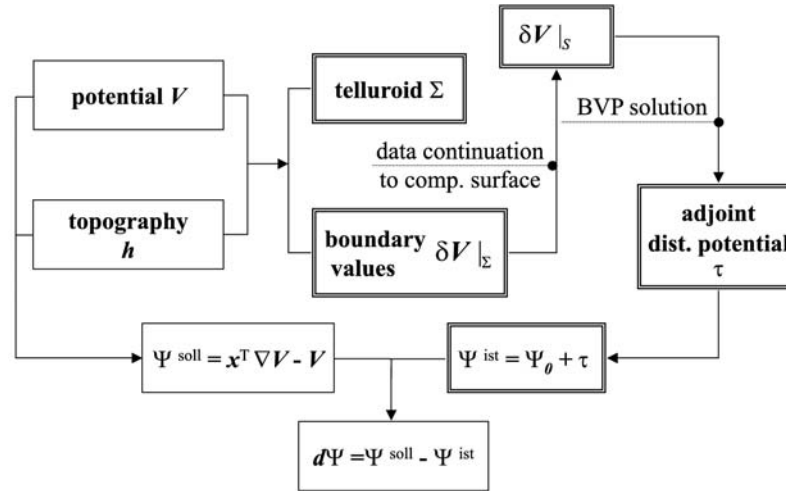

Fig. 4: Flowchart of the gravity space approach

In more detail, the following work steps were necessary for the global study. Based on the global gravity field model GPM98B from H.-G. Wenzel up to degree/order 1800 and the global topography model TUG87 from M. Wieser up to degree/order 180 the boundary surface, referred to as gravimetric telluroid, and the corresponding boundary values i.e. the potential disturbances were generated. In the framework of global analyses the so-called synthesis step was accomplished straightforward since, in accordance to the spherical harmonic series expansion of the geopotential, series representations for the gravimetric telluroid and the boundary values exist. Next, the boundary values were upward continued from the boundary surface to a mathematical computation surface, e.g. the Brillouin sphere. For this data continuation step a specifically tuned pointwise iterated collocation method using remove-computer-restore technique was applied. To setup the corresponding covariance function a high quality long-wavelength solution of the Earth's gravity field, e.g. EIGEN-GRACE 02S up to degree/order 150, and an approximation of the terrestrial gravity field, e.g. EGM96, with even higher resolution up to degree/order 360 were required. That followed, the harmonic analysis of the boundary values on the Brillouin sphere by means of Gauss-Legendre quadrature combined with FFT (Stokes solution in the frequency domain). Finally, the coefficients for the spherical harmonic series expansion of the adjoint disturbing po-

tential were derived from the coefficients of the Stokes solution by comparing coefficients. After backward transformation into geometry space the adjoint potential was compared to the original potential to judge the capability of the gravity space approach for geoid modeling.

First numerical experiments suggest that a global geoid accuracy of $\sim$ 3cm can be expected. Furthermore, it can be stated that the largest errors were introduced in the data continuation step. Thus, the gravity space approach was for the first time successfully used for practical geoid computation. By means of a second simulation study the potential of the gravity space approach for regional geoid determination, e.g. the area of Baden-Württemberg, was investigated. In detail, the particular work steps followed Figure 4. Again, the boundary values were generated on the basis of an adopted global geopotential model (e.g. EGM96 up to degree/order 360) and for the true topography of Baden-Württemberg. Regarding the boundary surface, its computation had to be adapted to the new conditions, i.e. the local gravimetric telluroid had to be determined pointwise in an iterative manner through Newton's method by equating the gradient of the normal potential at the gravimetric telluroid to the gradient of the true potential at the Earth's surface. In addition, due to the lack of knowledge of the local covariance behaviour of the gravity field the use of collocation for data continuation was substituted by a trivariate harmonic polynomial method. An average data continuation error of less than 1cm was achieved. As opposed to the aforementioned three-dimensional solution of the Stokes problem, computation of Stokes integral in planar approximation is envisioned for the regional study. This possibility is presently under investigation.

Astro-Gravimetric Geoid Determination

A broad range of geodetic, geophysical, oceanographic and precise engineering applications exist, rendering the need for precise geoid determination methods more pressing than ever. The more accurate the geoid is known, the more problems can be satisfactorily analysed. A new theory is developed for high-resolution geoid computation based on vertical deflections as well as gravity values. Its algorithmic version can be described as following: Remove the long wave component from the observations. This effect can be modelled using a reference gravity potential field of very high degree/order. An example for such a reference field is SEGEN (Internet: http://www.uni-stuttgart.de/gi/research/paper/coefficients/coefficients.zip) an ellipsoidal harmonic expansion up to degree/order 360/360. Remove the effect of the centrifugal potential at the point of measurement (POM), in particular GPS positioned. Remove the short wave component (terrain effect) from the residual observations. The influence of local density disturbance in the near zone of the POM is modelled with a digital elevation model. The area's size depends on the highest degree of the harmonic expansion. The remove steps aim at generating a harmonic gravitational field outside the International Reference Ellipsoid (IRE). The residual vertical deflections as well as the residual gravity disturbance are downward continued to the IRE by means of the inverse solution of the ellipsoidal horizontal / vertical boundary value problem based upon the modified ellipsoidal Abel-Poisson kernel. As a discretised integral equation of the first kind, downward continuation is

Tykhonov-Philipps regularised by an optimal choice of the regularisation factor. Restore the effect of short / long wave component at the point on the IRE which corresponds to the POM. Convert the restored disturbing gravitational potential on the IRE to geoidal undulations by means of the ellipsoidal Bruns formula. Validate the results using GPS levelling data. As a case study, the Finnish geoid was computed based on this algorithm. The results are in good agreement with the NKG 96 model.

Bistatic Radar GPS- Imaging

Navigation Satellites emit electro-magnetic signals, which continuously illuminate the Earth's surface (Figure 5). Due to their high orbit altitude, the reflected signals cannot be received by the same navigation satellites. Therefore, the bistatic radar principle has to be applied in order to generate an image of the Earths' surface from the reflected signal. In this bistatic configuration the navigation satellites still play the role of the signal sender but the receiver is an air- or space borne down-looking GPS antenna. Since the receiver is moving, the reflection areas simultaneous scan several stripes on the Earth's surface. Since the reflection is not specular, it is necessary to assign to each reflected signal component the location where the corresponding reflection has occurred.
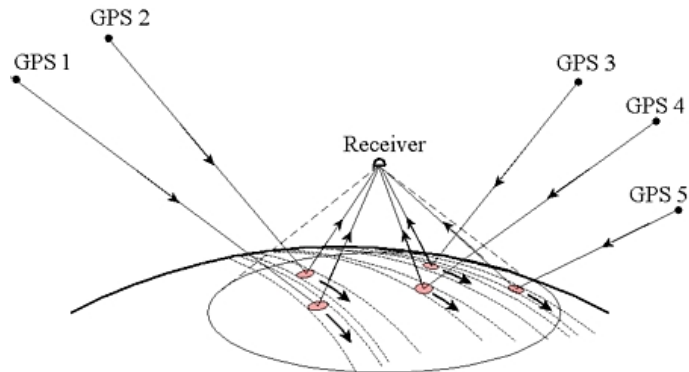

Fig. 5: Transmitter-Receiver Configuration

For this purpose signal travel time and signal Doppler-shift are used. All points, generating the same travel time of the reflected signal lie on a ring-shaped area (Figure 6a) while those points generating the same Doppler-shift in the reflected signal lie on a parabolic area (Figure 6b). If the received signals are ordered by travel time and Doppler-shift, an image of the reflecting area can be formed. In the research project first the resolution of the image as a function of height and speed of the receiver was investigated. To increase the resolution the synthetic aperture principle was carried over to th bistatic case. It could be demonstrated that for a flight altitude of 1500 feet objects with a diameter of 200-300m and a high reflectivity
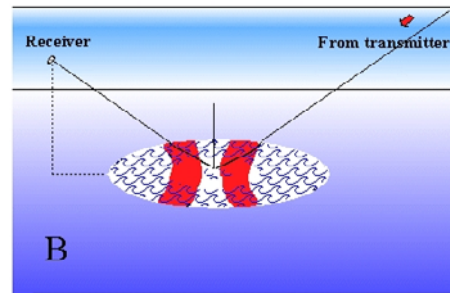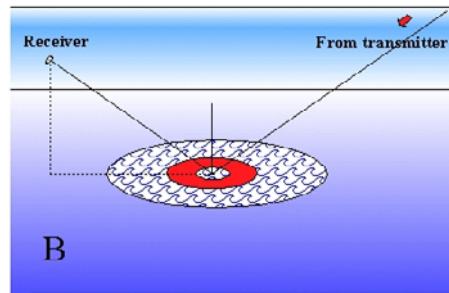
Fig. 6a: Points with the same travel time   *Fig. 6b: Points with the same doppler shift*
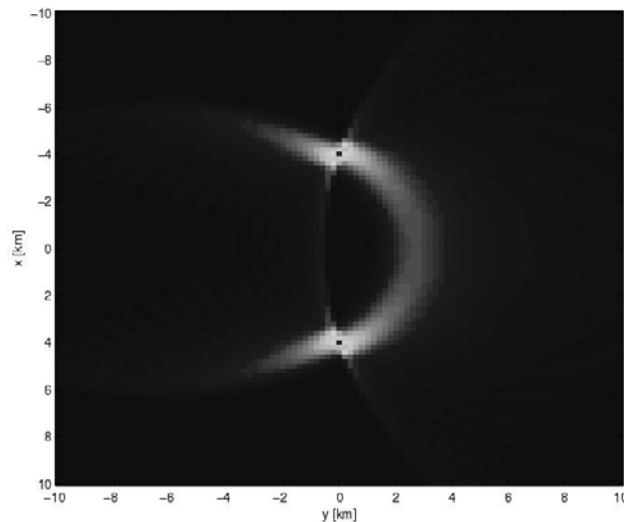
Fig. 7: SAR image of a single reflection point

The statistical analysis of the eigenspace components of strain rate tensors in Fennoscandia

In the deformation analysis in geosciences (geodesy, geophysics and geology), we are often confronted with the problem of a two-dimensional (or planar and horizontal), symmetric rank-two deformation tensor. Its eigenspace components (principal components, principal direction) play an important role in interpreting the geodetic phenomena like earthquakes (seismic deformations), plate motions and plate deformations among others. With the new space geodetic techniques, such as GPS, VLBI, SLR and DORIS, positions and change rates of network stations can be

accurately determined from the regular measurement campaign, which is acknowledged as an accurate and reliable source of information in Earth deformation studies. This fact suggests that the components of deformation measures (such as the stress or strain tensor, etc.) can be estimated from the highly accurate geodetic data and analyzed by means of the proper statistical testing procedures. While station velocity diagrams demonstrate relative motions among stations, strain rate diagrams show the in-situ strain concentration rate which is directly connected to local stress concentration rates and possibly also to seismic hazard potentials. Therefore, the strain analysis can be considered as a basis of a dynamic model whereas the classical deformation analysis is similar to a kinematic model. In a case study the strain rates tensors in Fennoscandia and the variance-covariances of their eigenspace components are derived (Figure 8). Further detailed analysis of the results is also performed with respect to geodynamical and statistical aspects.
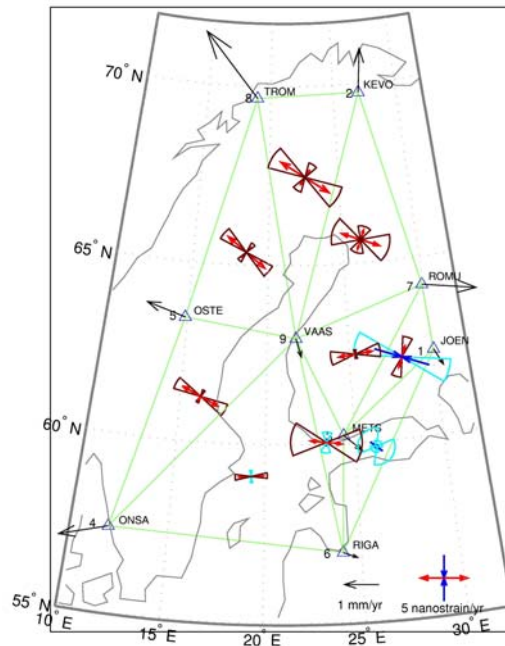

Fig. 8: Pattern of the principal strain rates with 2 σ formal errors of every triangle and the associated residual velocities of the selected 9 BIFROST sites in Fennoscandia. Extension is represented by symmetric arrows pointing out, contraction is represented by symmetric arrows pointing in and the residual velocity is represented by black arrow

Intrinsic Deformation Analysis Approach

The main purpose of this research is concerned with use of a geometrically formulation of recently formulated by shell theory capable to catch finite deformations. The Earth surface is assumed to has linear movement. Hence the shell formulation falls within the class of so called differential geometrically exact theories, where, on the one hand, all nonlinearities are of geometrical origin and where on the other hand the nonlinearities are taken into account without any simplifications. The surface of the Earth is given in the reference configuration (t=0) in a parameter representation with Gaussian parameters $\theta^\alpha(\alpha = 1, 2)$.Within static and dynamic problems we have to determine the deformed state at time t for the given velocities of the Earth's surface by permanents GPS stations. From there we get the interesting tensor fields, namely the kinematic variables such as surface strain tensor with related invariants (rotation tensor and dilatation) and changing of curvature tensor with related invariants (changing of Gaussian curvature and changing of mean curvature). The results of intrinsic deformation analysis approach on surface deformation across the Southern California based on Scripps Orbit and Permanent Array Centre (SOPAC) solutions were success to detect deformation signals. Comparison of the patterns with seismic map of the area suggested how well patterns were able to uncover geodynamical features across this region.

Postglacial sea-level indicators

The reconstruction of the sea-level height during the past 18,000 years constitutes and important tool for the determination of the post-glacial relaxation of the earth after the melting of the last Pleistocene ice sheets on the northern hemisphere. For the reconstruction serve fossil samples deposited near the former coast lines. After the determination of altitude and age, they form sea-level indicators (SLIs), which, first of all, may be used for the reconstruction of the relaxation curve for a particular region and, furthermore, may be inverted with respect to the viscosity distribution in the earth's mantle or the Pleistocene glaciation history. The data bank used for archiving the SLIs was continuously extended and at present contains details on about 14,000 SLIs. Divided according to regions (Figure 9), about 1,380 SLIs belong to Fennoscandia, about 1,050 SLIs to the British Isles (compilation by I. Shennan, University of Durham), about 600 SLIs to the Barents Sea, about 9,030 SLIs to North America (compilation by A. Dyke, Geological Survey of Canada), about 640 SLIs to the equatorial region (compilation by K. Fleming, GFZ) and about 540 SLIs to Antarctica and Patagonia. Besides the geographic coordinates, the altitude above the present-day sea level and the age, the data bank also contains details on the material and the deposition conditions of the SLIs according to the original publications, which may be selectively analysed by means of fuzzy logic. The essential feature of this analysis method is that it allows us an individual weighting of the SLIs according to the details stored in the data bank and, thus, an improved determination of the post-glacial relaxation of the earth. In particular, the method also permits us to take into account whether an SLI is a sample like shell, which suggests a lower bound on the former sea-level height, or whether an SLI is a sample like driftwood, which suggests an upper bound on the former sea-level height (Figure 10).
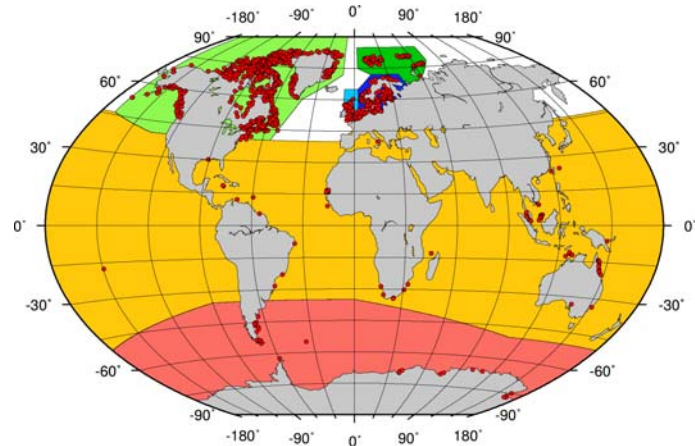
Fig. 9: Global distribution of sea-level indicators stored in data bank. The colours indicate the regions distinguished: Fennoscandia (dark blue), British Isles (light blue), Barents Sea (dark green), North America (light green), equatorial region (yellow) as well as Antarctica and Patagonia (pink)
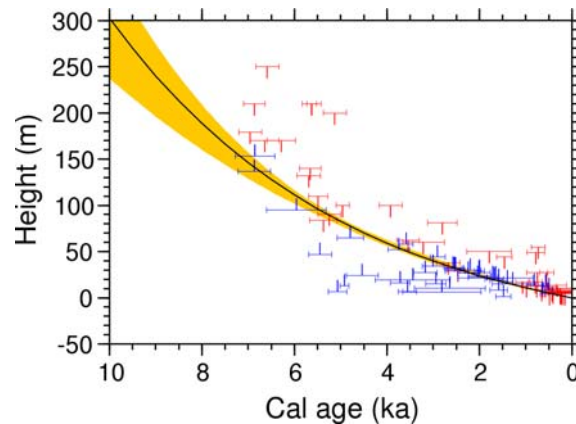
Fig. 10: Height of sea-level indicator with respect to present-day sea level as a function of its calibrated age for the region Churchill (Hudson Bay). Blue symbols denote samples like shell, which indicates a lower bound on the former sea level. Red symbols denote samples like driftwood, which indicates an upper bound on the former sea level. The solid line is the best-fitting post-glacial relaxation curve (exponential function) determined using fuzzy logic. The orange band shows the range of possible exponential functions within a predefined misfit.

Three-dimensional viscoelastic earth model

For modelling the gravito-viscoelastic relaxation of the earth in response to surface-load changes, the spectral finite-element method was further developed. The characteristic feature of this method is that the angular dependence of the field quantities is represented by spherical-harmonic functions, whereas their radial dependence is expressed in terms of finite elements. Furthermore, the field equations governing the problem are solved in the time domain, which facilitates the consideration of three-dimensional viscosity distributions. In addition, this simplifies the solution of the sea-level equation, which models the redistribution of water in the ice-ocean system. Similarly, the glacial-isostatically induced rotational response of the earth was formulated as a time integral of the Liouville equation and solved by means of the MacCullagh formulae, which connect the temporal changes of the inertia tensor with those of the gravity potential.

Mantle viscosity below Iceland

As a result of its exceptional location on the mid-Atlantic ridge, Iceland constitutes an attractive region for geodynamic studies. Due to the enhanced subsurface temperature, it is to be expected in particular that below Iceland the viscosity of the earth's mantle is diminished. A further characteristic of Iceland is the presence of several recent ice caps of which Vatnajökull with a radius of about 50 km is the largest. Owing to ice retreat since about 1900 as well as the reduced mantle viscosity, a land uplift is to be expected in the periphery of Vatnajökull, which may be inverted in terms of the viscosity value. For the determination of the uplift rate, up to four GPS campaigns were carried out under the direction of L. Sjöberg (Royal Institute of Technology, Stockholm) south-east of the ice cap (Figure 11). For the inversion of the observed uplift rates, a circular ice model (Figure 11) was assumed as well as a loading history simulating an ice loss of 2 km^3 per year during the past 100 years. The parameterization of the spherical earth model was based on PREM. As viscosity of the upper and lower mantle, $1*10^{20}$ Pa s and $1*10^{22}$ Pa s, respectively, was assumed. The lithosphere thickness, the asthenosphere thickness and the asthenosphere viscosity were free parameters. Nearly equally close fits resulted for 16-46 km and 129-384 km for the lithosphere thickness and asthenosphere thickness, respectively, and $1*10^{18}-1*10^{19}$ Pa s for the asthenosphere viscosity (Figure 12), which is an indication of the ambiguity of the inversion.
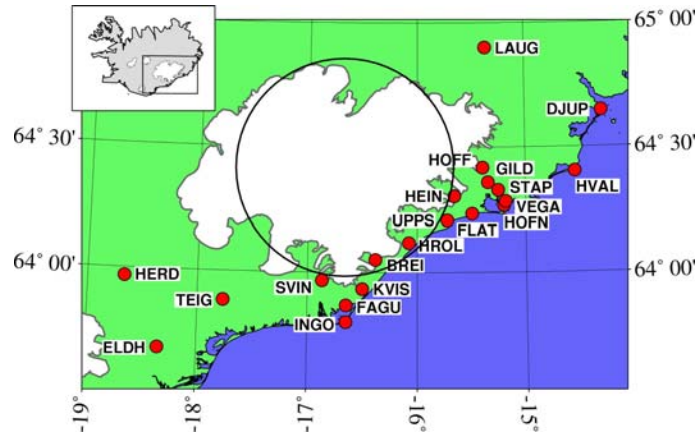
Fig. 11: Locations of GPS stations south-east of the Vatnajökull ice cap (Iceland) and outline of the circular ice model used for the inversion
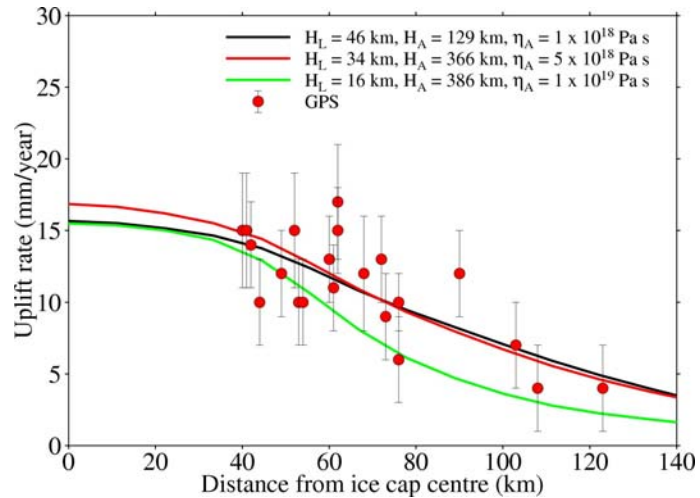
Fig. 12: Observed (red circles with error bars) and predicted uplift rates (coloured lines) as functions of the distance from the ice centre for the circular ice model and a loading history simulating an ice loss of 2 km³ per year during the past 100 years. The ranges of values for the lithosphere thickness, H_L, the asthenosphere thickness, H_A, and the asthenosphere viscosity, η_A, resulting in similarly close fits indicate the ambiguity of the inversion

List of Publications

AUSTEN G and O BAUR: High Performance Computing in Gravity Field Research. In: NAGEL WE, W JÄGER and M RESCH (Eds.): High Performance Computing in Science and Engineering'05, Springer-Verlag, Berlin Heidelberg, 2006

AUSTEN G, O BAUR and W KELLER: Use of High Performance Computing in gravity field research. In NAGEL WE, W JÄGER and M RESCH (Eds.): High Performance Computing in Science and Engineering'05, Springer-Verlag, Berlin Heidelberg, 2006

AWANGE J and E GRAFAREND: From space angles to point position using Sylvester resultant. Allgemeine Vermessungsnachrichten 7 (2005) 265-269

AWANGE J and E GRAFAREND: Solving algebraic computational problems in Geodesy and GeoInformatics, 326 pages, Springer 2005

AWANGE J, Y FUKUDA and E GRAFAREND: The application of commutative algebra to geodesy: two examples. Journal of Geodesy 79 (2005) 93-102

AWANGE J, Y FUKUDA, S TAKEMOTO and E GRAFAREND: Role of algebra in modern day Geodesy. In: SANSÒ F (ed.): Proceedings of the International Association of Geodesy (IAG) Symposia „A Window on the Future of Geodesy", June 30 - July 11, 2003, Sapporo, Japan, vol. 128, pages 524-529, Springer 2005

BAUR O and E GRAFAREND: High-Performance GOCE Gravity Field Recovery from Gravity Gradients Tensor Invariants and Kinematic Orbit Information. In: FLURY J, R RUMMEL, C REIGBER, M ROTHACHER, G BOEDECKER and U SCHREIBER (Eds.): Observation of the Earth System from Space, 239-253, Springer-Verlag, Berlin Heidelberg, 2006

BAUR O and E GRAFAREND: Orbital rotations of a satellite. Case study: GOCE. Artificial Satellites 40 (2005) 87-107

BÖLLING K and E GRAFAREND: Ellipsoidal spectral properties of the Earth's gravitational potential and its first and second derivatives. Journal of Geodesy 79 (2005) 300-330

BORKOWSKI A and W KELLER: Global and local methods for tracking the intersection curve between two surfaces. Journal of Geodesy 79 (2005) 1-10

CAI J and E GRAFAREND: The optimal Tykhonov-Phillips regularization parameter (?-weighted S-homBLE and via repro-BIQUUE), Geophysical Research Abstracts 7, 10075, 2005, European Geophysical Union 2005

CAI J and E GRAFAREND: The statistical analysis of geodetic deformation (velocity and strain rate) derived from the space geodetic measurements of BIFROST project in Fennoscandia. Geophysical Research Abstracts 7, 10089, 2005, European Geophysical Union 2005

CAI J, E GRAFAREND and B SCHAFFRIN: Statistical inference of the eigenspace components of a two-dimensional, symmetric rank-two random tensor. Journal of Geodesy 78 (2005) 426-437

FAN H: Geodätische Linie und Anfangswertaufgabe auf orthogonal parametrisierten Flächen (Geodesic and initial value problem on orthogonally parameterized surfaces). Study Work

FLEMING K, Z MARTINEC, J HAGEDOORN and D WOLF: Contemporary changes in the geoid about Greenland: predictions relevant to gravity space missions. In: REIGBER CH, H LÜHR, P SCHWINTZER and J WICKERT (eds.): Earth Observation with CHAMP: Results from Three Years in Orbit, Springer-Verlag, Berlin, Heidelberg, 217-222, 2005.

FU Q: Strainanalyse für Datumstransformation in Baden-Württemberg (Strain analysis for datum transformations in Baden-Württemberg). Study Work

GEBERT Ch: Bewertungsrelevante Aspekte bei Offenen Immobilienfonds (Valuation aspects of Open-Ended Real Estate Investment Funds). Diploma Thesis

GRAFAREND E: Harmonic Maps, Journal of Geodesy 78 (2005) 594-615

GRUBER C, D TSOULIS and N SNEEUW: CHAMP accelerometer calibration by means of the equation of motion and an a-priori gravity model. Zeitschrift für Vermessungswesen 130 (2005) 92-98

HAGEDOORN J: Glacial isostasy and recent sea-level change. Dissertation. Scientific Technical Reports (STR 05/13), GeoForschungsZentrum Potsdam

HAGEDOORN J, D WOLF and Z MARTINEC: Glacial-isostatic adjustment and present-day sea-level change: the impact of Pleistocene ice-sheet evolution on tide-gauge measurements. Joint Assembly of the IAG, IAPSO and IABO on Dynamic Planet 2005, Program and Abstract Book, pp. 261-262, 2005.

HINTZSCHE M: Vergleichswertverfahren, Lektion 4 zur Marktorientierten Immobilienbewertung. Euroforum Verlag, Düsseldorf 2005

ILK K-H, J FLURY, R RUMMEL, P SCHWINTZER, W BOSCH, C HAAS, J SCHRÖTER, D STAMMER, W ZAHEL, H MILLER, R DIETRICH, P HUYBRECHTS, H SCHMELING, D WOLF, HJ GÖTZE, J RIEGGER, A BARDOSSY, A GÜNTNER and TH GRUBER: Mass transport and mass distribution in the earth system: contribution of the new generation of satellite gravity and altimetry missions to geosciences, 2nd edition. Technical University Munich and GFZ Potsdam, 2005.

KELLER W and MA SHARIFI: Satellite gradiometry using a pair of satellites. Journal of Geodesy 78 (2005) 544-557

KLEMANN V and D WOLF: The eustatic reduction of shoreline diagrams: implications for the inference of relaxation-rate spectra and the viscosity stratification below Fennoscandia. Geophys. J. Int., 162 (2005) 249-256, doi:10.1111/j.1365-246X-2005.02637.x

KLEMANN V and D WOLF: Using fuzzy logic for the inference of the Holocene land uplift in the Hudson-Bay region based on sea-level indicators. EOS Trans. AGU, 86 (52), Fall Meeting Suppl. Abstract H51G-0447, 2005.

KUMAR P, R KIND, W HANKA, K WYLEGALLA, CH REIGBER, X YUAN, I WOELBERN, P SCHWINTZER, K FLEMING, T DAHL-JENSEN,TB LARSEN, J SCHWEITZER, K PRIEST-LEY, O GUDMUNDSSON and D WOLF: The lithosphere-asthenosphere boundary in the North-West Atlantic region. Earth Planet. Sci. Lett. 236 (2005) 249-257

KUROISHI Y and W KELLER: Wavelet approach to improvement of gravity field - geoid modeling for Japan. Journal of Geophysical Research 110: B03402, doi:10.1029/2004JB003371

MÄKINEN J, A ENGFELDT, BG HARSSON, H RUOTSALAINEN, G STRYKOWSKI, T OJA and D WOLF: The Fennoscandian land uplift gravity lines 1966-2003. In: JEKELI C, L BASTOS and J FERNANDES (Eds.): Gravity, Geoid and Space Missions, IAG Symposia, 129, Springer-Verlag, Berlin, 328-332, 2005.

MARTINEC Z and D WOLF: Inverting the Fennoscandian relaxation-time spectrum in terms of an axisymmetric viscosity distribution with a lithospheric root. J. Geodyn. 39 (2005) 143-163, doi:10.1016/j.jog.2004.08.007

NOVÁK P and E GRAFAREND: Ellipsoidal representation of the topographical potential and its vertical gradient. Journal of Geodesy 78 (2005) 691-706

NOVÁK P, G AUSTEN, MA SHARIFI and E GRAFAREND: Mapping Earth's gravitation using GRACE data. In FLURY J, R RUMMEL, C REIGBER, M ROTHACHER, G BOEDECKER and U SCHREIBER (Eds.): Observation of the Earth System from Space, Springer-Verlag, Berlin Heidelberg, 2006

SASGEN I, D WOLF, Z MARTINEC, V KLEMANN and J HAGEDOORN: Geodetic signatures of glacial changes in Antarctica: rates of geoid-height change and radial displacement due to present and past ice-mass variations. Scientific Technical Report, STR05/01, GFZ Potsdam, 2005.

SASGEN I, Z MARTINEC and D WOLF: Geoid-height change and vertical crustal motion due to present and past ice-mass variations in Antarctica. Geophys. Res. Abstracts, EGU General Assembly, 7, EGU05-A-00996, 2005.

SHARIFI MA and W KELLER: GRACE Gradiometer. In: JEKELI C, L BASTOS and J FERNANDES (Eds.): Gravity, Geoid and Space Missions, IAG Symposia, 129, Springer-Verlag, Berlin, 42-47, 2005

SNEEUW N, J FLURY and R RUMMEL: Science requirements on future missions and simulated mission scenarios. Earth, Moon and Planets 94 (2005) 113-142, DOI 10.1007/s11038-005-7605-7

TSOULIS D, CH GRUBER and N SNEEUW: A novel approach for the calibration of the CHAMP accelerometer using short data spans. Boll. di Geod. e Sci. Aff. 2 or 3 (2005)

WILHELM D: Application of Geodetic Techniques for Magnetic Resonance Imaging. Diploma Thesis

WOLF D, V KLEMANN, J WÜNSCH and F-P ZHANG: Geodetic and paleo-shoreline evidence of glacial-isostatic adjustment in the Churchill region, Canada: data reanalysis and inversion in terms of mantle viscosity. Joint Assembly of the IAG, IAPSO and IABO on Dynamic Planet 2005, Program and Abstract Book, p. 249, 2005.

WOLF D: Geodetic contributions to earth sciences. Joint Assembly of the IAG, IAPSO and IABO on Dynamic Planet 2005, Program and Abstract Book, p. 120, 2005.

WOLF D: Mantle viscosity, glacial changes and sea-level rise. Geophys. Res. Abstracts, EGU General Assembly, 7, EGU05-A-04639, 2005.

Doctoral Theses

ENGELS J: On the modelling of deformations caused by surface loads and of the induced polar wander

HAGEDOORN J: Glacial isostasy and recent sea level change

Guest Lectures and Lectures on special occasions

KUBIK K, Prof. Dr. (Department of Geographical Sciences and Planning, The University of Queensland, Australia): Über quadratische Ausgleichsprobleme (13.1.)

KUHN M, Dr. (Curtin University of Technology, Perth/Western Australia): Synthetische Erdschwerefeldmodelle entwickelt am Western Australian Centre for Geodesy (20.1.)

MORITZ H, Prof. Dr. (Universität Graz): Neuere Entwicklungen der Geodäsie, speziell der Physiaklischen Geodäsie (17.5., 19.5, 20.5, 23.5, 24.5., 25.5.)

SCHAFFRIN B, Prof. Dr. (Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University Columbus/USA): Generalizing the Total Least-Squares Estimator for Empirical Coordinate Transformations) (23.6.)

VOOSOGHI B, Dr. (Faculty of Geodesy and Geomatics Engineering, K.N. Toosi University, Tehran, Iran): GPS-derived Deformation Field and its Geodynamic Implications for Seismic Hazard in Iran (29.9.)

Lectures at other universities and at conferences

AUSTEN G and W KELLER: Duale Formulierungen des Geodätischen Randwertproblems. Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005

AUSTEN G and W KELLER: Numerical Implementation of Gravity-Space Approach - Proof of Concept. Gemeinsame Tagung der IAG, IAPSO und IABO, Cairns, 22.-26. August 2005

AUSTEN G, O BAUR and W KELLER: Use of High Performance Computing in Gravity Field Research. High Performance Computing in Science and Engineering - The 8th Result and Review Workshop of the HPC Center Stuttgart, Stuttgart, 13.-14. Oktober 2005

AUSTEN G: Gravitational Field Determination using GRACE - An approach based on acceleration differences. PSG Kolloquium der TU Delft, Delft, April 2005

BAUR O and N SNEEUW: WP 150: Das Problem der polaren Datenlücken: Lösungsstrategien und Einfluss auf die GOCE/GRACE Kombinationslösung, GOCE-GRAND II Kick-Off Meeting, Institut für Astronomische und Physikalische Geodäsie, TU München, 14. November 2005

BAUR O, E GRAFAREND AND N SNEEUW: GOCE Schwerefeldanalyse basierend auf den Fundamentalinvarianten des Beobachtungstensors, Geodätische Woche 2005, Düsseldorf, 5. Oktober 2005

BAUR O: GOCE activities in Stuttgart, PSG Kolloquium, TU Delft, 14. April 2005

CAI J and E GRAFAREND: Statistische Analyse der Datumstransformation, Geodätische Woche 2005, 4.-6. Oktober, Düsseldorf

CAI J and E GRAFAREND: The analysis of geodetic deformation (velocity and strain rate) in Fennoscandia, Geodätische Woche 2005, 4.-6. Oktober, Düsseldorf

CAI J and E GRAFAREND: The optimal Tykhonov-Phillips regularization parameter (?-weighted S-homBLE and via repro-BIQUUE), European Geophysical Union, Vienna, Austria, 24.-29. April 2005

CAI J and E GRAFAREND: The statistical analysis of geodetic deformation (velocity and strain rate) derived from the space geodetic measurements of BIFROST project in Fennoscandia, , European Geophysical Union, Vienna, Austria, 24.-29. April 2005

CAI J, E GRAFAREND and B SCHAFFRIN: Minimum MSE adjustment and the optimal Tykhonov-Phillips regularization parameter ?-weighted S-homBLE via A-optimal design and via repro-BIQUUE, Geodätische Woche 2005, 4.-6. Oktober, Düsseldorf

CAI J: Introduction of the Geodetic Study and Research in University Stuttgart, Wuhan University, China, Dezember 2005

CAI J: On the determination of the optimal Tykhonov-Phillips regularization parameter, Wuhan University, China, Dezember 2005

CAI J: Some new developments of theoretical Geodesy, Wuhan University, China, Dezember 2005

CAI J: The statistical analysis of geodetic deformation (velocity and strain rate) derived from the space geodetic measurements, Wuhan University, China, Dezember 2005

ENGELS J: Remarks to the Grain-of-Sand Problem. Abschiedskolloquiums E. Grafarend, 18. Februar 2005, Stuttgart

FINN G and E GRAFAREND: A Comparison of the New Finnish Geoid FINN2004 With Existing Models. EGU General Assembly, Vienna, Austria, 25. April 2005

FINN G and E GRAFAREND: Vergleich des neuen finnischen Geoidmodells FINN2004 mit existierenden Modellen. Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005

FINN G: GALILEO - Das Neue Satelliten-Navigationssystem. Kepler-Seminar, Heidehof Foundation, Stuttgart, 21.10.2005

FLURY J, R RUMMEL and N SNEEUW: Future Satellite Gravimetry: Mission Concepts and Benefit for Earth Sciences. Alfred-Wegner-Symposium, AWI, 30. Oktober-2. November 2005, Bremerhaven

GRAFAREND E, FINN G and A ARDALAN: Ellipsoidal Vertical Deflections and Ellipsoidal Gravity Disturbances: Case Studies. Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005

GRAFAREND E, J CAI and B SCHAFFRIN: On the determination of the optimal Tykhonov-Phillips regularization parameter (?-weighted S-homBLE via A-optimal design and via repro-BIQUUE), Workshop Inverse Problems, 24.-25. November 2005, Trippstadt

GRAFAREND E: Ellipsoidal Vertical Deflections and Ellipsoidal Gravity Disturbances: Case Studies. Geodätische Woche 2005, 4.-6. Oktober, Düsseldorf

HAGEDOORN J, D WOLF and Z MARTINEC: Glacial-isostatic adjustment and present-day sea-level change: the impact of Pleistocene ice-sheet evolution on tide-gauge measurements. (Poster). Joint Assembly of IAG, IAPSO and IABO on Dynamic Planet 2005, Cairns, Australia, 23. August 2005

HAGEDOORN J, Z MARTINEC, D WOLF and J KLEMANN: Glacial-isostatic adjustment and recent sea-level change: the influence of Pleistocene ice-sheet evolution on tide-gauge measurements. (Poster). ESF TOPO-EUROPE Workshop, Budapest, Hungary, 17.-18. März 2005

KELLER W: Target Detection from Reflected GPS-Signals. Workshop Inverse Problems, 24.-25. November 2005, Trippstadt

KLEMANN V and D WOLF: Using fuzzy logic for the analysis of sea-level indicators with respect to glacial-isostatic adjustment. Geodätische Woche, Düsseldorf, 4. Oktober 2005

KLEMANN V and D WOLF: Using fuzzy logic for the inference of the Holocene land uplift in the Hudson-Bay region based on sea-level indicators. (Poster). AGU Fall Meeting, 9. Dezember 2005

KLEMANN V, J HAGEDOORN and D WOLF: Using fuzzy-set classification for the analysis of sea-level indicators with respect to glacial-isostatic adjustment. Workshop on Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change, Lanzarote, Spain, 2. März 2005

MARTINEC Z, V KLEMANN and D WOLF: Three-dimensional viscoelastic earth model for surface-mass transport. Kolloquium zum DFG-Schwerpunktprogramm 1257 „Massentransporte und Massenverteilung im System Erde", GFZ Potsdam, 28. November 2005

REUBELT T, M GÖTZELMANN, E GRAFAREND and W KELLER: Methoden der Ausreißere-limination und neueste Ergebnisse in der Gravitationsfeldbestimmung aus kinematischen CHAMP-Bahnen mit dem Beschleunigungs-Ansatz: Datenvorverarbeitung versus Robuste Schätzung. Geodätische Woche 2005, 4.-6. Oktober, Düsseldorf

SASGEN I, Z MARTINEC and D WOLF: Geoid-height change and vertical crustal motion due to present and past ice-mass variations in Antarctica. (Poster). EGU General Assembly, Vienna, Austria, 26. April 2005

SASGEN I, Z MARTINEC and D WOLF: Seasonal mass variations in Antarctica from GRACE. PhD Day, GFZ Potsdam, 20. Dezember 2005

SNEEUW N: Aliasing problems in spaceborne gravimetry. CGU, May 2005, Banff TSOI R, N SNEEUW and E CANNON: GPS based navigation for future geopotential missions. CGU, May 2005, Banff

WOLF D, Klemann, V., Wünsch, J., Zhang, F.-P.: Geodetic and paleo-shoreline evidence of glacial-isostatic adjustment in the Churchill region, Canada: data reanalysis and inversion in terms of mantle viscosity. (Poster). Joint Assembly of IAG, IAPSO and IABO on Dynamic Planet 2005, Cairns, Australia, 23. August 2005

WOLF D: Isostasy: from statics to dynamics. Abschiedskolloquium E. Grafarend, 18. Februar 2005 , Stuttgart

WOLF D: Mantle viscosity, glacial changes and sea-level rise. EGU General Assembly, Vienna, Austria, 25. April 2005

WOLF D: Mantle viscosity, glacial changes and sea-level rise. Seminar at Seismological Obser-vatory, Geodetical and Geophysical Research Institute, Budapest, Hungary, 23. Mai 2005

WOLF D: Mantle viscosity, glacial changes and sea-level rise. Workshop on Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change, Lan-zarote, Spain, 2. März 2005

WOLF D: Mantle viscosity, glacial changes and sea-level rise: an introduction. Internal seminar, GFZ Potsdam, 24. Juni 2005

XU C, M WEIGELT M, N SNEEUW N and M SIDERIS: Gravity field recovery from a time-variable satellite ground track pattern. CGU, Mai 2005, Banff

Research Stays

AUSTEN G: DEOS, Delft University of Technology, Niederlande, 1.3.-31.5.2005

BAUR O: DEOS, Delft University of Technology, Niederlande, 1.3.-31.5.2005

GRAFAREND E W: Finnisches Geodätisches Institut, Masala, Finnland, 22.7.-11.9.2005

KELLER W: University of Queensland, Brisbane/Australien, Februar-April, Juli-Oktober 2005

KRUMM F: Geodetic and Geophysical Research Institute, Budapest, Ungarn, 2.-7.10.2005

Lecture Notes

ARDALAN AA: Measurement Techniques of Physical Geodesy, ca. 110 Seiten

GRAFAREND E: Adjustment Theory III, Part 1 (Hypothesis Testing), ca. 175 pages

HAUG G: Property Valuation I, ca. 30 pages
(http://www.uni-stuttgart.de/gi/education/Grundstu/VorlesungI.pdf)
Property Valuation II, ca. 11 pages
(http://www.uni-stuttgart.de/gi/education/Grundstu/Vorlesung_II.pdf)

KELLER W: Foundations of Satellite Geodesy, ca. 50 pages (http://gipc41.gis.uni-stuttgart.de/)
Observation Techniques and Evaluation Procedures of Satellite Geodesy, ca. 80 pages
(http://gipc41.gis.uni-stuttgart.de/)
Dynamic Satellite Geodesy, ca. 40 pages (http://gipc41.gis.uni-stuttgart.de/)
Coordinates and Reference Systems, ca. 90 pages (http://gipc41.gis.uni-stuttgart.de/)

KRUMM F: Map Projections, ca. 280 pages (plus 30 pages Attachments) Mathematical Geodesy,
ca. 190 pages

SCHÖNHERR H: Official Surveying and Real Estate Regulation, ca. 60 pages (http://www.uni-stuttgart.de/gi/edu-cation/Lieka/script_herbst2004.pdf)

WOLF D: Continuum Mechanics in Geophysics and Geodesy, ca. 100 pages (http://www.uni-stuttgart.de/gi/ research/schriftenreihe/report2003_2.pdf)

Participation in Conferences, Meetings and Workshops

AUSTEN G: Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005
High Performance Computing in Science and Engineering - The 8th Result and Review
Workshop of the HPC Center Stuttgart, Stuttgart, 13.-14. Oktober 2005

BAUR O: Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005
GOCE-GRAND II Koordinierungstreffen, Institut für Astronomische und Physikalische
Geodäsie, TU München, 14. Januar 2005
High Performance Computing in Science and Engineering - The 8th Results and Review
Workshop of the HPC Center Stuttgart, Höchstleistungsrechenzentrum Stuttgart, 13.-14.
Oktober 2005
GOCE-GRAND II Kick-Off Meeting, Institut für Astronomische und Physikalische
Geodäsie, TU München, 14. November 2005

CAI J: European Geophysical Union, Vienna, Austria, 24.-29. April 2005
Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005
Intergeo 2005, 4.-6. Oktober 2005, Düsseldorf
Workshop Inverse Problems, 24.-25. November 2005, Trippstadt

FINN G: EGU General Assembly, Vienna, Austria, 24.-29. April 2005
Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005

GRAFAREND E: European Geosciences Union (EGU) General Assembly, 24.-29. April 2005, Wien
INTERGEO, 4.-6. Oktober 2005, Düsseldorf
Geodätische Woche 2005, 4.-6. Oktober 2005, Düsseldorf
Jahrestagung Deutsche Geodätische Kommission (DGK), 2.-4. November 2005, München
Workshop TU Kaiserslautern, „Inverse Problems", 24.-25. November 2005, Trippstadt

KELLER W: Tagung der IAG, IAPSO und IABO, Cairns, 22.-26. August 2005
Geodätische Woche 2005, 4.-6. Oktober 2005, Düsseldorf

REUBELT T: Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005

SCHLESINGER R: Geodätische Woche 2005, Düsseldorf, 4.-6. Oktober 2005
BGI/ICET/IAG Summer School on Microgravimetric methods, Lanzarote, Casa de los Volcanes, 23.-28. Oktober 2005

SNEEUW N: INTERGEO, 4.-6. Oktober 2005, Düsseldorf
Geodätische Woche 2005, 4.-6. Oktober 2005, Düsseldorf
Jahrestagung Deutsche Geodätische Kommission (DGK), 2.-4. November 2005, München
Workshop TU Kaiserslautern, „Inverse Problems", 24.-25. November 2005, Trippstadt
DFG-Kolloquium zum Schwerpunktprogramm „Massenstransport und Massenverteilung im System Erde", 28.-29. November 2005, Potsdam

WOLF D: Workshop on Deformation and Gravity Change: Indicators of Isostasy, Tectonics, Volcanism and Climate Change, Lanzarote, Spain, 1.-4. März 2005
ESF TOPO-EUROPE Workshop, Budapest, Hungary, 17.-18. März 2005
EGU General Assembly, Vienna, Austria, 24.-29. April 2005
Geodätische Woche/Intergeo, Düsseldorf, 4.-6. Oktober 2005
IERS Workshop on Combination, GFZ Potsdam, 10.-11. Oktober 2005

Activities in National and International Organizations

FINN G: Member IAG Study Group Spatial and Temporal Gravity Field and Geoid Modeling
Member European Geosciences Union (EGU)
Member Board of the Faculty Aerospace Engineering and Geodesy
Member Administrating Board Studentenwerk Stuttgart A. d. ö. R.

GRAFAREND E: Member Fakultäten Luft- und Raumfahrt und Geodäsie, Mathematik und Physik (kooptiert), Bau- und Umweltingenieurwissenschaften (kooptiert) der Universität Stuttgart
Member Österreichische Geodätische Kommission
Member des Wissenschaftlichen Beirats der Deutschen Geodätischen Kommission (DGK)
Member Deutsche Geodätischen Kommission bei der Bayerischen Akademie der Wissenschaften (retired)
Member Royal Astronomical Society
Member Flat Earth Society

HINTZSCHE M: Member Deutscher Verein für Vermessungswesen (DVW)
Member Gesellschaft für Immobilienwirtschaftliche Forschung (gif)
Member Research Group Bewertungsvergleiche und -standards
Vice President Gutachterausschuss für die Ermittlung von Grundstückswerten in der Landeshauptstadt Stuttgart
Member Verband Deutscher Städtestatistiker (VDSt)
Member Ingenieurkammer Baden-Württemberg

KELLER W: Member Society of Industrial and Applied Mathematics
Member Deutscher Mathematiker Vereins
Member Promotionsausschuss der Universität Stuttgart.
Member erweiterter Fakultätsrats der Fakultät für Bauingenieur- und Vermessungswesen an der Universität Stuttgart
Member Studienkommission Geodäsie und Geoinformatik an der Universität Stuttgart

KRUMM F: Member Studienkommission Geodäsie und Geoinformatik an der Universität Stuttgart

SNEEUW N: Member Deutsche Geodätische Kommission (DGK)
Chairman Working Group DVW-AK 7 „Experimentelle, Angewandte und Theoretische Geodäsie" (Gesellschaft für Geodäsie, GeoInformation und LandManagement), Experimentelle, Angewandte und Theoretische Geodäsie
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Member Studienkommission Geodäsie und Geoinformatik, Universität Stuttgart
Member Berufungskommission „Flugzeugastronomie und Extraterrestrische Raumfahrtmissionen", Fakultät Luft- und Raumfahrttechnik und Geodäsie, Universität Stuttgart
Chairman IAG Inter-Commission Committee for Theory (ICCT) Working Group „Satellite Gravity Theory"
Fellow International Association of Geodesy
Member American Geophysical Union
Member Canadian Geophysical Union

WOLF D: Chairman IAG Inter-Commission Committee for Theory (ICCT) Working Group „Dynamic Theories of Deformation and Gravity Fields"
Member American Geophysical Union
Member Canadian Geophysical Union
Member European Geosciences Union
Fellow International Association of Geodesy
Member Deutsche Geophysikalischen Gesellschaft

Courses - Lecture/Lab/Seminar

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

Institute of Navigation

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Dipl.-Phys. Manfred R e i c h	Interferometry
Dipl.-Ing. Oliver S c h i e l e	Navigation Systems
Dipl.-Ing. Wolfgang S c h ö l l e r	Education/Navigation Systems
Dipl.-Ing. Alexandra S e i f e r t	Navigation Systems
Dr.-Ing. Aloysius W e h r	Laser Systems
Dipl.-Ing. (FH) Martin T h o m a s	Laser Systems

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Regine S c h l o t h a n

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

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Dr.-Ing. Volker L i e b i g - Programme Directorate DLR-GE
Dr.-Ing. B r a u n - RST Raumfahrt Systemtechnik AG, St.Gallen

Research Projects

Modular RF front end for acquiring real-time data of GPS/GNSS signals

Since 2004 we have participated the DLR (Deutsches Zentrum für Luft- und Raumfahrt) funded project UniTas III. Under this project we have in 2005 conducted a research work on the development of a modular RF front end, by which the analysis of the signal processing in GPS/GNSS receiver is made feasible.

Figure 1 presents this RF front end developed in the Institute of Navigation, University of Stuttgart. The design follows the modular concept and takes both GPS and GALILEO signals into account. In other words, the RF front end, though at current primarily used for acquiring GPS L1 signals, can without effort be adapted to acquire incoming E1-E2 BOC signals, too. From the point of view of performance, components like antenna feeder, amplifiers, mixers, bandpass filters as well as lowpass filters are key ones. They are individually tested and optimized. Briefly the data flow is described in the following.

Figure 1: Modular RF front for acquiring real-time data of GPS/GNSS signals - front end with 2 local Oscillator (left) and Modular Components right

The input of the RF front end is the signal filtered and amplified through the antenna. In this project a Trimble antenna is chosen for our task. After being fed in through the antenna feeder, the signal of a frequency of 1575.42 MHz is firstly executed with a three-stage amplification, whose output is a signal of 0 dB average power. Further on, this signal is carried out with a twostage down conversion. At the output of the first down conversion a signal of a frequency of round 200 MHz is delivered, while at the output of the second down conversion holds the signal an intermediate frequency of about 2 MHz, which is adjustable with the use of different low pass filters. Those signals are all analog. They are then sampled and digitized by an ADC converter. Of our great interest is the use of down sampling technique in the signal processing. According to the Nyquist-Shannon theorem the sampling frequency must be higher than or at least equal to twice the signal bandwidth, it is therefore possible to use a low sampling frequency to acquiring GPS/GNSS signals of relatively high frequencies with no damage to the information. It has been found that a negative frequency can take place after the signal being down sampled. This negative frequency is normally paid no attention, however it is very important for a correct setting, otherwise the synchronization process in GPS receiver turns out to be broken. To declare this problem a lot of measurements have been taken, and detailed analysis has been done.

Scanning Laser Altimeter

In this year the electronic angular measurement system of the scanning mirror of the airborne laser scanner ScaLARS was redesigned in hard- and software. Due to this redesign it was possible to increase the rotation rate of the scanning mirror up to 25 Hz and to make use of the high angular resolution of 1024/360 deg of the angular encoder without additional interpolation. Also the PC for data recording was replaced by a robust industrial PC compatible computer. The new PC and all remaining control units were integrated in a new smaller rack (Figure 1). The overhauled ScaLARS was first used during a flying campaign in Poland over outskirts of Wroclaw. Under contract of the Department of Geodesy and Photogrammetry of Agricultural University of Wroclaw an area of 50 km^2 was surveyed, which may be overwhelmed by the river Oder. The project´s scientific objectives are the development of processing algorithms for laser scanning data at the Department of Geodesy and Photogrammetry. The Survey was carried out by an Antonov AN2 (Figure 2), which offers the advantage of a very low flying speed. Due to the high scanning rate an average point density on ground of about 2 per square meter was achieved. First results show (Figure 3) that very high resolved laser intensity images were sampled. A cut through the flight paths (Figure 4) makes clear the high accuracy in elevation which is about 10 cm and the achieved precision of register of the different flying paths after georeferencing. A tilt and displacement between the flying paths cannot be recognized. This proofs the optimal calibration of ScaLARS.

Figure 1: New rack

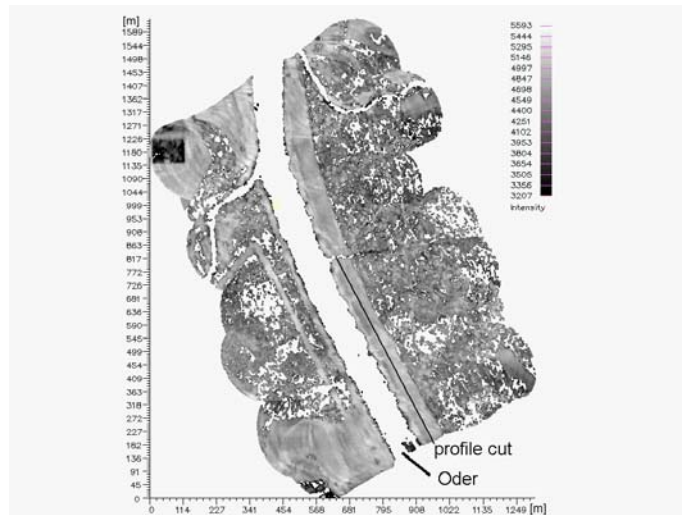*Figure 2: Surveying airplane Antonov AN2*

Figure 3: Intensity laser scanner image of a part of the surveyed area along river Oder
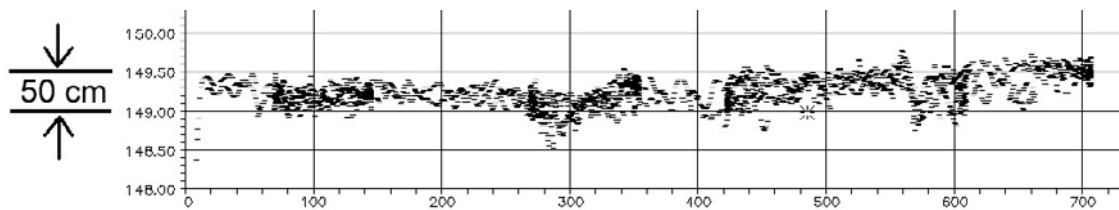

Figure 4: Elevation cut through four flight lines (see Figure 3)

Navigation with integrated micro electromechanical systems (IMEMS[R]) and micromagnetic integrated circuits

In 2004 the Institute of Navigation bought several MEMS sensors (accelerometers, gyroscopes) and micromagnetic integrated circuits. By means of a self developed circuit the sensors were integrated into a complete Inertial Mesurement Unit (IMU). This prototype IMU consists of printed boards and two of them contains one two axial accelerometer, three of them a gyro and one magnetometer. Therefore we have a threedimensional measurement unit for acceleration, rotation, and for the magnetic earth field.

First the calibration of the several sensors was started. Multiple static measurements were done in a climatic exposure test cabinet. The temperature of the test cabinet was stepwise increased from $0°C$ up to $40°C$ and afterwards lowered to $0°C$. The measurements delivered the coefficients of a compensative function for each sensor. On the basis of further measurements also the correlation between the sensor outputs and the magnitude of the power supply could be ascertained and analysed.

Subsequent to these tests in 2005 additional sensor errors - such as biases, scalefactors and non-orthogonalities - had to be determined. For these purposes first a mathematical model (with a total of 9 errors) for the acceleration sensors was developed which works on the basis of a least squares adjustment. This adjustment procedure was implemented in MATLAB™ and firstly tested with simulated accurate data series. After successful results with these undisturbed data we falsified the simulated data with normally dispersed errors in a varied order of magnitude.

Remote sensing - PROJECTS ERLEN-E AND MONAT-X

The TerraSAR-X Satellite, developed in Germany, will be available in 2006. TerraSAR-X will provide high resolution radar remote sensing data that allow an accurate determination of landuse using automatic remote sensing methods. The geometric resolution up to 1 m and the 11 day repetition rate together with the data acquisition independent from weather conditions and cloud coverage allow the TerraSAR sensor to be an ideal tool for the monitoring of the earth surface.

The Institute of Navigation has performed first investigations of the potential of the future TerraSAR-X data in cooperation with the remote sensing company ILV (Ingenieurbüro für Luftbildauswertung und Vermessung) in the framework of a project called ERLEN-E (Demonstrationsbeispiele für die **ER**fassung von **L**andschafts **E**lementen und **N**utzungsstrukturen auf der Basis von X - und L - Band SAR Daten - Extension).

A multi-layer hierarchical classification process was developed by INS. We applied segment based classifiers (eCognition 3.0 software) for the classification. A statistical analysis of the radar features was performed for all different land cover types to define qualified customised channels together with suitable class membership functions for the classification hierarchy. Classification accuracies of more than 98% could be achieved for the separation of forest and open land. Coniferous forest and deciduous forest were identified with 90% accuracy. The agricultural fields could be separated from the grassland with 90% accuracy.

The accuracies achieved are sufficient for many applications. The results of the ERLEN-E project have been presented to a large number of interested users in the framework of a discussion forum for TerraSAR-users held at Berlin [1].

The Landesvermessungsamt Baden-Württemberg (LV-BaWü), responsible for the ATKIS topographic information system of Baden Württemberg has shown great interest for the development of a cost effective method for the ATKIS-updating based on TerraSAR remote sensing data. The INS in close cooperation with LV and ILV has therefore submitted the proposal of a project named

MONAT-X (High accurate **Mon**itoring of Land Use and Updating of the **A**TKIS Topographic and Cartographic Information System using TerraSAR-**X** Data) to DLR. MONAT-X suggests an innovative method for updating of the ATKIS topographic and cartographic information system. The methods used for the ATKIS data acquisition so far (aerial Photogrammetry) are very expensive due to the required manpower. The LV-BaWü is therefore interested in modern computer based methods using radar remote sensing data, if these could provide the required information more cost effective.

The ATKIS-update is foreseen to be performed in two steps. The first step is the monitoring of ATKIS object classes and the detection of possible changes of object classes: The comparison of TerraSAR data taken at the same vegetation time period of two consecutive years will be used to detect those areas, where a change of ATKIS classes is likely to have taken place in between. The second step is the updating of the existing ATKIS-database with the classification results of a segment based classification using multi-temporal high resolution TerraSAR Spotlight products. This step is foreseen to be performed only for those areas, where a change of ATKIS classes has been detected in the initial monitoring step.

The MONAT-X Proposal has been accepted by DLR in December 2005. DLR will provide a total number of 40 TerraSAR image products for an area of 100 km * 150 km size located in Baden Württemberg. The acquisition of these data is foreseen to take place during the main vegetation periods of 2007 and 2008.
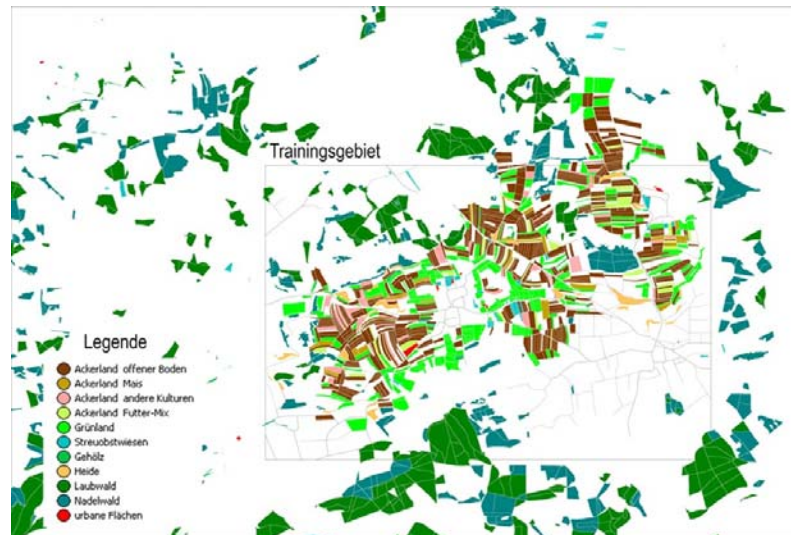
LAND USE GROUND TRUTH DATA
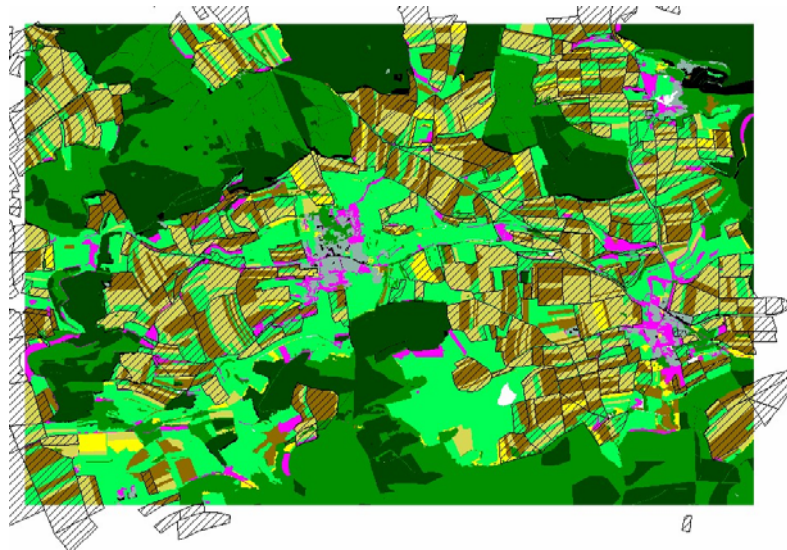
THEMATIC CLASSIFICATION of LANDUSE AND ATKIS VECTOR OVERLAY

Publications and Presentations

[1] Kleusberg, A.: „Zur Einführung von Bachelor- und Master-Studiengängen in Deutschland - Teil 1", zfv Heft 1/2005, DVW-nachrichten 55. Jahrgang, pp. n-14 - n-15.

[2] Kleusberg, A.: „Zur Einführung von Bachelor- und Master-Studiengängen in Deutschland - Teil 2", zfv Heft 2/2005, DVW-nachrichten 55. Jahrgang, pp. n-30 - n-32.

[3] Reich, M.: „Neue Möglichkeiten zur Beschaffung von Geoinformationen." Anwender-Forum TerraSAR, Umwelt Bundesamt Berlin am 25. Februar 2005.

[4] Thomas, M., Wehr, A.: „Possibilities of Multi-Spectral Laserscanners" Proceedings Optical 3-D Measurement Techniques VII Vol II, Oct. 2005, Wien.

[5] Ioannides, M., Wehr, A., Thomas, M.: „An Efficient Algorithm for the Real-Time Digitization and Reconstruction of 3D Contours/Objects", Proceedings Optical 3-D Measurement Techniques VII Vol II, Oct. 2005, Wien.

[6] Schiele, O., Wehr, A., Kleusberg, A.: „Operational Calibration of Airborne Laserscanners by Using LASCAL", Proceedings Optical 3-D Measurement Techniques VII Vol II, Oct. 2005, Wien.

[7] Klaedtke, H.-G., Weichelt, H., Wagner, M.: „Remote Sensing Approach for Digital Aerial Imagery", ISPRS Workshop Hannover 2005.

Doctoral Theses:

[1] Schiele, O., J.: „Ein operationelles Kalibrierverfahren für das flugzeuggetragene Laserscanner-system ScaLARS", Universität Stuttgart, 16. August, 2005.

Activities in National and International Organizations

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

Education (Lecture / Practice / Training / Seminar)

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

Institute for Photogrammetry

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Dipl.-Inform. Martin Kada	3D-Visualisation
Dipl.-Geogr. Steffen Volz	Location Based Services

Photogrammetry and Remote Sensing

Head: Dr.-Ing. Michael Cramer	GPS/INS-Integration
Dipl.-Geogr. Timo Balz	SAR Image Analysis
Dipl.-Ing. Susanne Becker	Resolution Enhancement
Dipl.-Ing.(FH) Markus Englich	Sensor Laboratory
Dipl.-Ing.(FH) Werner Schneider	Digital Photogrammetry Laboratory

Terrestrial Positioning Systems and Computer Vision

Head: Dr.-Ing. Jan Böhm	Spatial Segmentation and Object Recognition
M.Sc.Eng. Yahya Alshawabkeh	Heritage Documentation
Dipl.-Ing. Sarah Schuhmacher	Terrestrial Laser Scanning

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Dipl.-Ing. Sabine Urbanke, Landesvermessungsamt Baden-Württemberg

Research Projects

Geoinformatics

Shortest path analyses in raster maps for pedestrian navigation in location based systems

Navigation is one of the main applications in location based systems. In order to navigate to a destination, a shortest path analysis has to be calculated. Shortest path analyses commonly are based on vector maps and calculate the shortest path (or route) between two points in a network. Fundamental research has been done in shortest path analysis for vehicle navigation in street networks. The algorithms for vehicle navigation are only of limited use for pedestrian navigation. The main reason is that the movement behaviour of pedestrians can only inadequately described with vector maps, especially when crossing places or in indoor areas.

The shortest path analysis in raster maps is done in four steps. In a pre-processing step (1) the input map is binarised in such a way that areas in which the user can move are represented with „1" and barricades are represented with „0". Then, the binary raster map is skeletonised with morphological operations and an undirected graph is calculated from the skeleton (2). In the following step, an A* algorithm calculates the shortest path in the skeleton from the start point to the end point (3). Finally, a final path is generated by using visibility calculations (4). The result is a natural path that can be used especially for pedestrian navigation.

Fig. 1 shows the result of a shortest path analysis at an example of the inner-city area of Stuttgart, Germany. Buildings are represented with black colour and areas in which pedestrian can walk are represented with white colour. The start and end points are represented with a red circle. The calculated skeleton of the white areas is represented with green lines. The shortest path which connects the start and end point by using the edges of the skeleton is represented with a thick blue line.

Typically, pedestrians don't walk parallel to the streets (at least in pedestrian or indoor areas) but use the shortest way to the next branch of the path. In order to calculate a shortest path that reflects this behaviour, visibility calculations are used. Beginning from the starting point, it is successive tested for each pixel if it is possible to reach that pixel with a direct line. If this is the case, this direct line is used for the final shortest path instead of the original shortest path. If the pixel cannot be reached with a direct line, a new starting point is set and the algorithm starts from the beginning. This is iterated until the end point is reached. The result is a smoother and more natural path from the start to the end point. Because the calculation is based on the skeleton which has typically a very irregular appearance, it is possible that there will be still some irregularities in the resulting shortest path. These irregularities are eliminated with a fine-smoothing, where for each two connecting line elements of the shortest path it is tested if they can be connected with a smoother path that consists of three lines. This fine-smoothing is calculated iteratively until no changes occur in the final result. The result of the whole process is represented in magenta colour in Fig. 1.

Fig. 1: Shortest path calculation in a raster map.

Semantic Generalization of Spatial Data

The generalisation methods introduced so far for 3D building models all work to a certain extent by feature detection and removal. Starting with the smallest features, the object is iteratively simplified until it has the required level of detail. During the simplification process, geometric relations like rectangularity, parallelism and coplanarity between the polygonal faces are strictly preserved. However, if the geometric relations are not explicitly provided, they can be hard or impossible to detect due to acquisition inaccuracies. These inaccuracies are consequently a huge problem when defining general simplification operators. Therefore, a new algorithm was developed which is based on spatial-partitioning representations. In contrast to other algorithms, the generalised model is generated en bloc. So no simplification operators are needed.

Rather, geometric planes are derived from the polygonal faces with the help of buffers. Each such plane approximates a facade or a part of the roof, including protrusions and other small structural elements. The infinite space is then subdivided by the planes, generating a number of 3D primitives in the process. For each primitive, the overlap with the original building model is computed. Primitives with a high overlap are kept and glued together to form the generalised building model. Due to the use of buffers, the algorithm works stable even for very complex models and also for geometrically erroneous data. It is not limited to rectangular structures or specific roof types. Furthermore, no additional information like geometric relations are needed. The planes that are derived from the buffers, however, can be adjusted to strictly enforce coplanarity, parallelism

or rectangularity of the final building faces. In an optimisation step, heuristic rules are used to evaluate if the resulting model can be further improved by adding or removing smaller primitives.

As the algorithms proved to work very well on 3D building data, it was also adapted for 2D building ground plans. In contrast to other 2D algorithms, the major axes of the ground plan are not needed and it can be applied on arbitrary ground polygons. It is planned to extend the prototypical implementation to a generalisation component and integrate it into the Nexus federation.
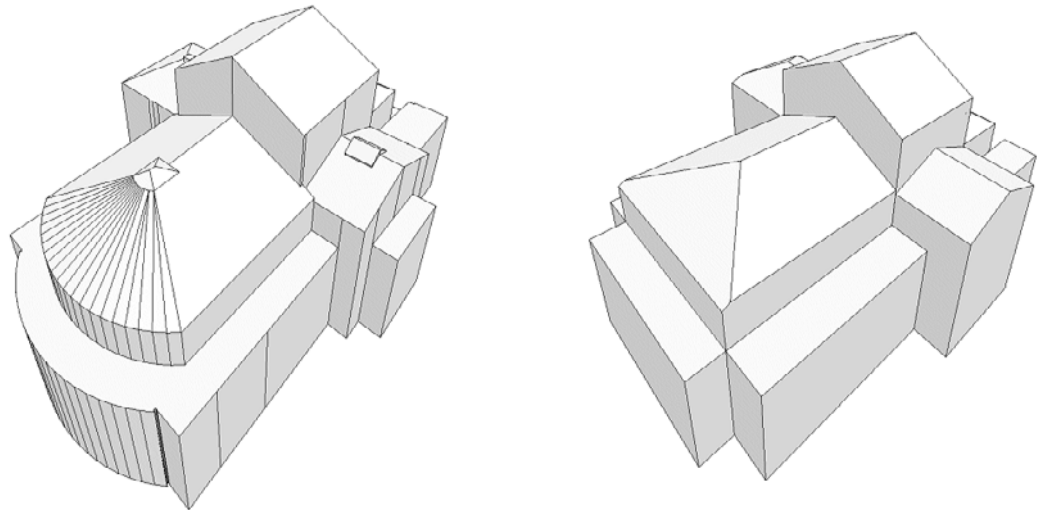

Fig. 2: Original (left) and generalized (right) 3D building model of the Stuttgart Opera House.

Raster-based Clustering of Vector Data

Clustering spatial data can be interpreted as a segmentation or classification process which tries to find meaningful patterns within geospatial databases. Such patterns are especially used to adapt further algorithms to the individual characteristics of the detected classes or clusters, respectively. The area of spatial data clustering has been extensively studied and various approaches are available. However, to the best of our knowledge, none of the existing techniques has tried to perform the clustering of vector data in the raster world. As we will show, this is a simple and straightforward approach that allows a fast computing of clusters.

In our study, we use vector street data from the Geographic Data Files (GDF) databases, in order to derive raster-based clusters of different degrees of urbanity. For conducting this research, we chose an area of approximately 4 square kilometres in the vicinity of Stuttgart/Germany that shows different characteristics in terms of urbanity. At the beginning of the process, an operator

can define two different parameters for generating the clusters: the grid size of the resulting raster map and the radius around the centre of each grid cell (cluster radius) so that the area for which the cluster indicators have to be observed can be calculated (area of influence). As indicators for recognizing different levels of urbanity, we use node density and rectangularity of streets, since we assume that (at least in Germany) in city centres there are usually more topological nodes and more irregular, non-orthogonal streets than in suburbs or rural areas.

While node density can easily be calculated from the number of topological nodes per area, a measure for expressing rectangularity is somewhat more difficult to obtain. The algorithm we developed determines for each node that has more than two incident edges the n - 1 smallest angles between these incident edges. Then, for all these angles, the arithmetic mean is calculated and it is taken as the value for characterizing the rectangularity of the streets emanating from a node. The closer this value is to 90, the higher the degree of rectangularity.

After the operator has chosen the clustering parameters, the whole area of investigation is sub-divided into equally sized, square-shaped grid cells. Then, using the centre point of each cell, the area of influence is determined and the indicators, i.e. node density and rectangularity, are calculated. The result is a raster layer for each indicator. In order to join the different layers and to achieve a final categorization of each individual grid cell, a function has to be defined enabling the combination of the different raster layers. This can easily be done with the weighted sum of all indicators for each grid cell. The weights can be determined manually or automatically by using a supervised or unsupervised classification.

Before joining the different raster layers, it is possible to pre-process them with image processing techniques. For example a Gaussian filter can be used to smooth the raster layers or a morpho-logical operator to decrease noise. This can also be done with the final result raster layer. At the end of the process the pixels of the final raster layer are subdivided into different classes by using thresholds. Again the thresholds can be determined manually or automatically by using a super-vised or unsupervised classification. Fig. 3 shows an example for calculating different clusters of urbanity according to our approach. The image contains four classes. High urbanity is repre-sented with dark grey pixels and low urbanity is represented with bright grey pixels. The approach is very powerful and can be implemented very easily. In order to segment vector data regarding other characteristics, other indicators can be defined and combined with the same techniques as described in this approach.
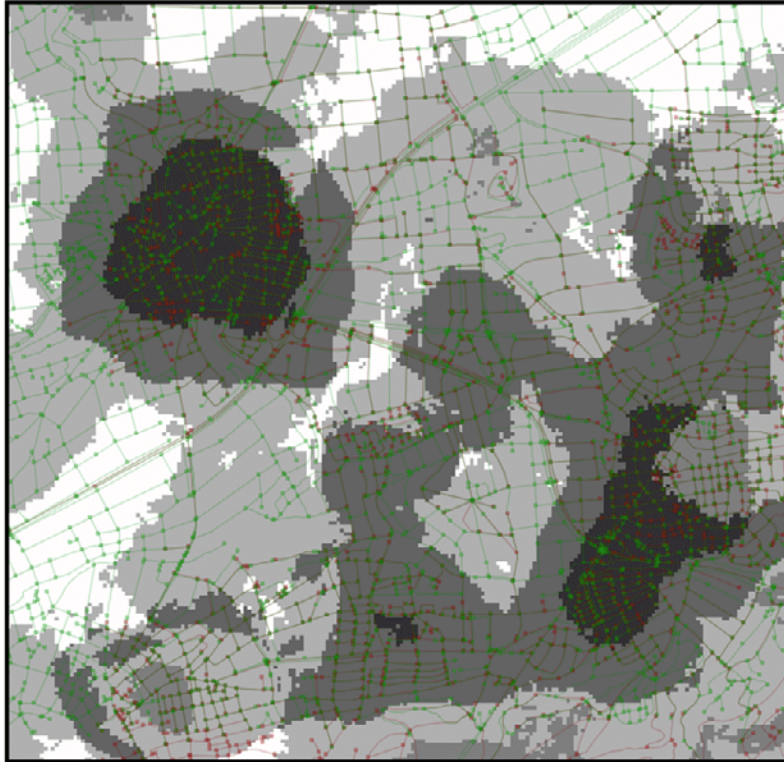
Fig. 3: Sample image displaying 4 classes of urbanity derived from the vector test data.

Photogrammetry and Remote Sensing

Resolution Improvement for Airborne Multispectral Imagery

Almost all digital aerial cameras collect multispectral images at a smaller spatial resolution than the panchromatic data. The respective images are then combined by suitable pan-sharpening algorithms to generate multispectral images at the resolution of the corresponding panchromatic data. This well-known approach has been used for satellite images for many years, thus several algorithms are available.

Pan-sharpening algorithms improve the resolution of the multispectral images while retaining their original colour values. This is especially important, if a spectral analysis like classification is aspired in subsequent steps. Within the project the capability of the different pan-sharpening approaches for colour preservation was examined using test data sets from the digital aerial camera

Leica ADS40. For quantification of the respective colour changes at first an appropriate colour space was defined. Standard colour spaces such as the RGB model are not suitable, since there the subjective perception of colour differences depends on the colour value itself. Instead, the CIE-L*a*b* colour space was used since their geometrical distances correspond to approximately the same perceptual colour differences. As it is confirmed by the computed colour distances in Table 1, all investigated pan-sharpening approaches showed noticeable colour deviations.

	ΔE			
	IHS	PCA	Brovey	HPF
without histogram match.	8.8	12.7	8.7	8.3
with histogram match.	2.4	2.7	2.4	3.9

*Table 1: Colour distances ΔE in the CIE-L*a*b* space.*

The investigated IHS (Intensity, Hue, Saturation) and the PCA (Principle Components Analysis) approaches are substitution methods, which replace the structural component of the multispectral image with the panchromatic image data. The Brovery filter is an arithmetic method, while the HPF (high-pass filter) approach is a filter-based technique, which filters high resolution spatial structures from the panchromatic image and adds them to the multispectral data.

Fig. 4: Original multispectral image (left) and pan-sharpening results (right).

However, the results could be improved by a histogram matching. This was realised by adapting the histogram of the originally captured panchromatic image to the histogram of the intensity image, which was extracted from the multispectral data. Thus, the remaining colour differences are reduced to values between 2.4 and 3.9, which is tolerable for most applications. Fig. 4 shows the original multispectral image (left) and the pan-sharpening results exemplarily for the IHS- and the HPF-methods with histogram matching.

Image edges, as provided from a Siemens star, were measured for the quantification of the resolution improvement. Based on these measurements the modular transfer function (MTF) and the point spread function (PSF) could be computed, respectively.
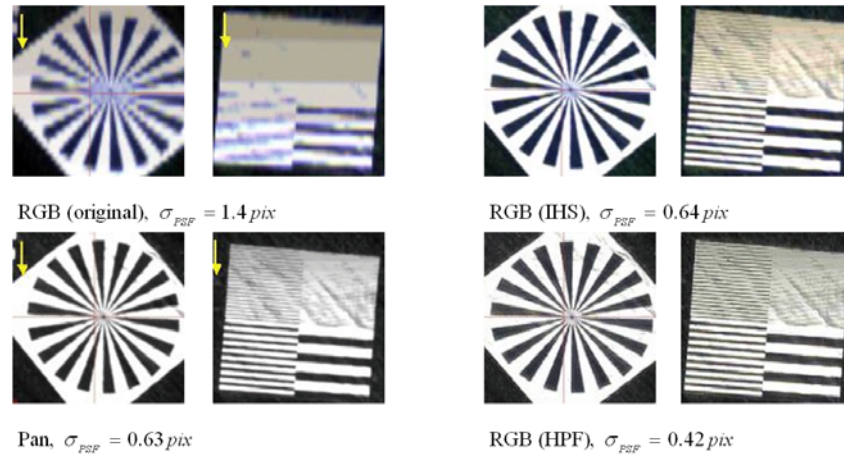
Fig. 5: Multispectral and panchromatic input data (left) pan-sharpening results (right).

Fig. 5 shows the original multispectral image ($\sigma_{PSF} = 1.4$ pixel), which is much more blurred than the panchromatic image ($\sigma_{PSF} = 0.63$ pixel). In order to have a visible effect of resolution improvement, multispectral data was used with a sampling distance in flight direction that is twice as large as the one in line direction, whereas the corresponding panchromatic image had the same sampling distance in both directions. As indicated by the yellow arrow, the flight direction in this example is from top to bottom. Fig. 5 (right) depicts the multispectral images after application of the IHS-algorithm which almost have the same spatial resolution as the panchromatic data. For the HPF-approach the resulting spatial resolution of 0.42 pixel is even better than the resolution of the panchromatic input. This resolution improvement could be realised by an integrated linear restoring finite impulse response (FIR) filter, which estimates the original grey value for each pixel position from the surrounding image values.

10 years of ifp airborne test site Vaihingen / Enz

The use of photogrammetric test sites is well known for the whole range of photogrammetry from space and airborne up to close range applications. Such test sites are typically used to provide external information for the independent estimation of camera or more generally spoken sensor system performance, where both geometric and radiometric parameters are considered. In many cases the use of test sites is closely related to the topic of camera calibration. This is especially relevant for non-metric camera systems mainly used in close-range photogrammetric tasks - in contrary to the laboratory calibration which is applied for metric cameras only. Nonetheless, even in this traditional field of airborne photogrammetry using analogue large format mapping cameras or their digital successors, the topic of test site calibrations becomes more and more relevant. In nowadays use, the cameras are quite often equipped with additional sensors, namely GPS/inertial components for direct measurement of exterior orientation parameters. The spatial

relation between those sensors and the camera itself can only be determined from on site calibrations. Focusing on the new digital airborne cameras the need for system driven calibrations realized via test site calibrations despite standard component driven approaches from lab calibration becomes obvious. This is due to the more complex system design, i.e. many of the new digital sensors are based on multi-head concepts and almost all are using integrated GPS/inertial systems, which are mandatory for digital line scanners.

The ifp test site Vaihingen/Enz was originally established summer 1995 for the geometrical performance acceptance test of maybe the very first operational digital airborne line scanning systems, the Digital Photogrammetry Assembly DPA. Starting from this, the test site was used several times for different kinds of investigations: For the independent in-flight evaluation of new digital airborne sensors as well as for investigations on the potential of direct georeferencing using integrated GPS/inertial systems in combination with standard analogue frame cameras. Besides DPA, the digital airborne line scanners WAAC and HRSC-A from DLR were flown and their accuracy potential was derived from this test field data. Focusing on the new commercial digital sensors the DMC engineering model (EM) was flown in 2000. The April 2003 test was done with the fully equipped system with its multi-head PAN and MS components. The latest flight in June 2004 was done with the ADS40 sensor. Besides these large format sensors the small format IGI dIGIcam-K14 system (based on Kodak small format camera housing and 14M pixel CMOS array), which may complement digital large format airborne sensor systems in terms of higher flexibility for smaller acquisition areas at lower costs, was flown in April 2004. In addition to that, commercially available GPS/inertial systems have been flown to explore the potential of direct sensor orientation and the use of directly measured exterior orientation measurements of high accuracy within an integrated sensor orientation.

The test site itself is located in a hilly area about 20km north-west of Stuttgart providing several types of vegetation and land use, mostly rural area with smaller forests and villages (Fig. 6). The overall spatial extension of the test area is 7.5 km (east-west) x 4.8 km (north-south). The terrain heights differ between 171m and 355m above mean sea level. Although the number of ground control points slightly varies throughout the different years, their principal locations remain unchanged. These locations are oriented on the ideal point distribution for fully signalized medium-scale (1:13000) wide angle analogue camera flights with 60% forward and side-lap conditions. This point raster is densified in the eastern half of the test site for lower flying heights. In the meantime more than 200 points are independently coordinated from static GPS surveys, with an estimated accuracy of 2cm for all three coordinate components. From that they may serve as independent check point information to estimate the (absolute) geometric quality of object point determination from airborne sensor data. In some cases additional mobile resolution targets (Siemens star, strip bar pattern) were prepared for the flights, to empirically analyse the spatial resolution potential of airborne sensors.
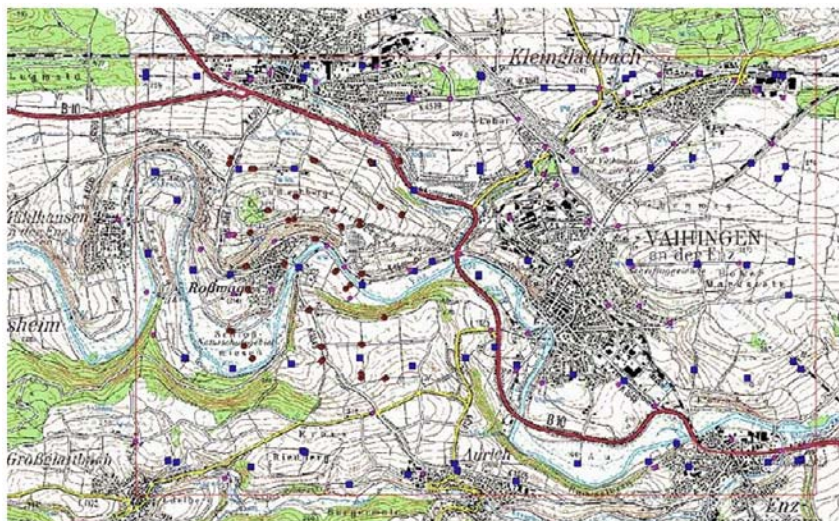
Fig. 6: Ground control points in ifp test site Vaihingen/Enz.

Performance of ADS40 digital airborne line scanner

The empirical airborne testing of different kinds of photogrammetric sensor systems is particularly necessary in case new sensors and systems become available. Since the advent of digital airborne imagers and their commercial availability main attention in the photogrammetric community was laid on the analysis of the new systems potential and their comparison to the well-known analogue mapping cameras. And this is still the case - even today new system configurations are showing up. Already available systems are modified and refinements in the processing software are continuously applied. From that, empirical tests are done by the system vendors, in order to guarantee and validate the systems performance from test field results, in some cases the sensors are independently analysed by organizations or universities and finally, tests are done by the potential customers itself before the final purchase decision is made.

A quite extensive test focusing on the geometric accuracy as well as the radiometric performance of ADS40 was done in summer 2004, as a joint project of Leica Geosystems and the Institute for Photogrammetry. Within this campaign the Vaihingen/Enz test field with more than 200 signalised and independently coordinated object points system was flown in different flying heights. In this test not only the empirical object point determination for the standard ADS40 system installation and process flow was analysed, additionally the influence of GPS/inertial system performance on the overall geometric accuracy and the quantification and the improvement of image resolution was of concern. It has to be mentioned, that in addition to the standard ADS40 system installation, additional GPS/inertial units were installed during the flight. Besides the standard ADS40 configuration including the Applanix LN200 fibre-optic gyro based IMU (Litton) two additional GPS/inertial

units were added to the camera housing, namely the Applanix AIMU dry-tuned gyro system based IMU (part of the Applanix POS/AV-510 system and based on the Inertial Science Inc. DMARS IMU) and the IGI IMU-IId fibre-optic gyro unit which is essential part of the IGI AEROcontrol-IId system. The IMU-IId is based on a Litef inertial unit. Since the rigid mount has to be guaranteed (no relative movements between camera and IMUs) for all three systems during the whole flight mission, a special metal hat was constructed by Leica and fixed on top of the ADS40 electronics head as it can be seen in the Fig. 7. The two additional IMUs are mounted on top of this hat, the LN200 is on its standard position inside the camera close to the CCD focal plate.

From this acquired data set a very thorough and comprehensive analysis of true operational ADS40 accuracy potential is possible. As one exemplarily example the accuracy from 1500m flying height mission should be given in the following. The ORIMA/CAP-A triangulation using the LN200-derived GPS/inertial trajectory solution matches the standard flow of ADS40 data processing. Three different processing configurations are considered: ORIMA/CAP-A triangulation based on 12, 4 and 0 GCPs, respectively. Within this first tests, no additional self-calibration is included in AT process. In addition to the inherent object coordinate unknowns, additional boresight misalignment parameters (reflecting the physical misalignment between IMU body frame and camera photo coordinate frame) and block-wise position offset and drift parameters are estimated as additional unknown parameters during adjustment only. Note, that position offset and drift parameters can only be considered as far as (at least one) GCP is introduced.

The empirical results are given in Table 2. The obtained statistical analysis from check point differences is very consistent and fits very well the theoretical expectations. If one compares the obtained accuracy to the theoretical ground sampling distance (GSD) of 9cm (assuming staggered arrays) the accuracy is very well below one pixel for the horizontal and about one pixel for the vertical component even though only non-staggered imagery was used during AT process. Even for the 0 GCP case the horizontal accuracy (RMS) is remarkable high, the vertical component is less than factor 2 worse to the theoretical accuracy expectation. This is quite satisfactory, keeping in mind that for this special case the absolute accuracy of object point determination is dependent on the absolute accuracy of the GPS/inertial trajectory. Without using any GCP there is no way to compensate for errors caused by sub-optimal GPS trajectory solutions, systematic effects or datum shifts. Such trajectory offsets - if present - will directly be transferred to global shifts in object point coordinates.

Fig. 7: Aircraft installation ADS40 Vaihingen/Enz test flight (June 26, 2004).

# GCP / ChP	Accuracy	East [m]	North [m]	Vertical [m]
12 / 190	RMS	0.052	0.054	0.077
	Mean	0.000	-0.022	0.045
	Std.Dev.	0.052	0.050	0.063
	Max.Dev.	0.133	0.188	0.242
4 / 198	RMS	0.055	0.054	0.106
	Mean	-0.008	-0.008	0.083
	Std.Dev.	0.055	0.053	0.065
	Max.Dev.	0.145	0.191	0.295
0 / 202	RMS	0.110	0.086	0.158
	Mean	0.094	-0.064	0.142
	Std.Dev.	0.057	0.056	0.068
	Max.Dev.	0.242	0.256	0.351

Table 2: ORIMA/CAP-A LN200 trajectory based geometric accuracy ADS40 test ($h_g = 1500m$).

Additional tests have been done for example focusing on the analysis of the influence of variance component weighting in AT, the influence of additional image coordinate measurements in PAN-B and all MS channels, the object point performance related on real-time GPS/inertial trajectory

computations and - quite important - the influence of additional self-calibration. All these tests were done for all different flying heights and are documented in the extended final project study report which is available at Leica Geosystems. Although not explicitly shown here, in all cases ADS40 fulfils the expectations and the push-broom concept again was re-confirmed from operational test flight data of this commercial photogrammetric sensor.

Real-Time SAR Simulation on Graphics Processing Units

SAR simulators are frequently used as a key tool for the analysis and interpretation of SAR data. Exemplary applications are mission planning to avoid occluded areas especially in dense urban environments, change detection, or training purposes, since the complex interaction of different SAR effects is very difficult to understand even for experienced human operators. One problem within these applications is the computational effort required for SAR simulation. To speed up this process an implementation of the required algorithms was realised based on modern graphic cards, which offer 3D hardware acceleration and programmable graphics processing units (GPU). Mainly due to the development of the computer game industry, these graphic cards are now widely available and inexpensive and can be programmed by suitable tools. Thus the implementation of SAR geometry to allow for a real-time SAR simulation by standard graphic hardware is possible.
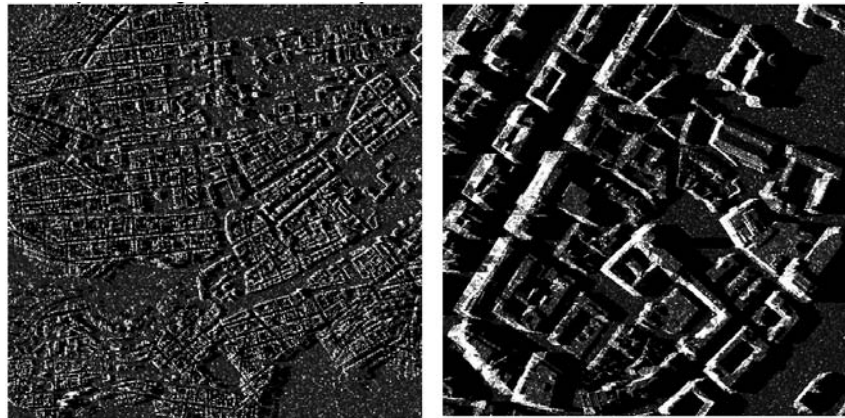

Fig. 8: SAR simulation of the Stuttgart city model with 5m (left) and 1m resolution (right).

The real-time SAR simulator SARViz, which has been developed at the ifp, is implemented using Microsoft's DirectX API and the High-Level Shading Language (HLSL) for GPU programming. Rasterization, as it is used by SARViz, is not based on the physical light transport and is therefore not able to simulate scenes containing complex reflections. Still, as it is possible to create realistic scenes for computer games, it is also possible to simulate realistic SAR images using rasterization. Simulations of complex urban environments are depicted in Fig. 8. The SAR simulated

city model includes 9950 buildings containing 548729 triangles and can be simulated in about 10 milliseconds, not including the time used to load the data into the video memory. Even though the simulation results are not based on exact physical models as ray-tracing simulators it is advantageous for many applications where fast results are more desirable than the exact physical modelling of effects like multi-bouncing. For these applications the next generation SAR simulator SARViz provides high-quality results in real-time.

Terrestrial Positioning Systems and Computer Vision

Georeferencing of Terrestrial Laserscanning Data

Terrestrial laserscanning has become popular for the acquisition of architectural scenes, due to the fact that it provides direct, reliable and dense surface measurement in a versatile fashion at independently varying standoff distance and resolution. In order to integrate data recorded at multiple stations with an existing dataset, such as a virtual city model, georeferencing of TLS data is essential. The common practice for georeferencing of TLS data, as suggested by the manufacturers, requires three-dimensional control points, preferably provided by specially designed targets. However in surveying, position and height are recorded separately due to historical reasons and therefore three-dimensional control points in a geodetic system are not naturally available. Georeferencing of TLS data typically is achieved by introducing a supporting measurement system, for example a total station, to transfer the geodetic control information onto the special targets. This process is regarded as the most precise way to give a geodetic datum to TLS measurements. The actual steps of the procedure are beyond the scope of this publication, it shall be noted however, that this process does not only cost extra time and effort, it also requires the user to provide a second measurement system and to be able to operate it. It is therefore of great interest to study alternative methods to establish a georeference in TLS data. We have investigated a two-stage process for georeferencing based on integrated sensor measurement and iterative refinement.

The advantage of sensor-driven methods for georeferencing laserscanner data is the possibility to save time and cost due to direct measurement and automation in determining the global position and orientation of every station. Compared to the conventional method of georeferencing with the use of a total station, the sensor-driven approaches require less additional equipment and are not in need of existing control points around the scene.

A simple and inexpensive possibility for directly determining the global position of the laserscanner is to use a low-cost GPS. The GPS receiver is centered close to the laserscanner's rotation axis. During the scanning process, the GPS position is simultaneously recorded. The results are available in real time. The expected accuracy of this absolute positioning is about 10 m and better, when a correction signal is applied.

The GPS receiver only measures the position of the stations. The orientation has to be determined by an additional procedure. One possibility is to use a digital compass and tilt sensor. The compass is co-located with the low-cost GPS. The whole construction is illustrated in Fig. 9.
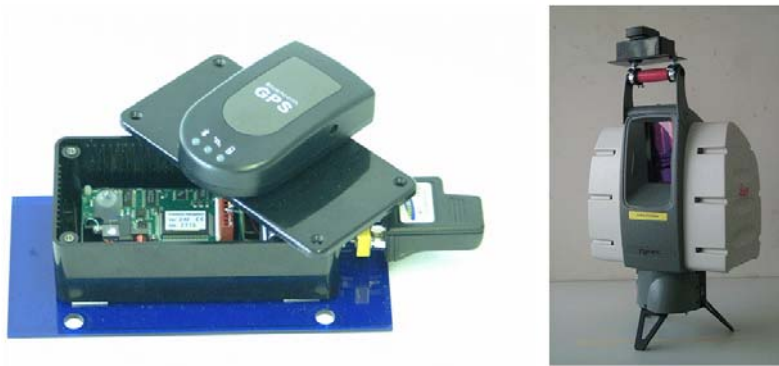
Fig. 9: Left: Integrated orientation device, consisting of a low-cost GPS and a compass and pan / tilt sensor. The sensors have a wireless connection to a laptop via Bluetooth. Right: The system mounted on top of a HDS 3000.
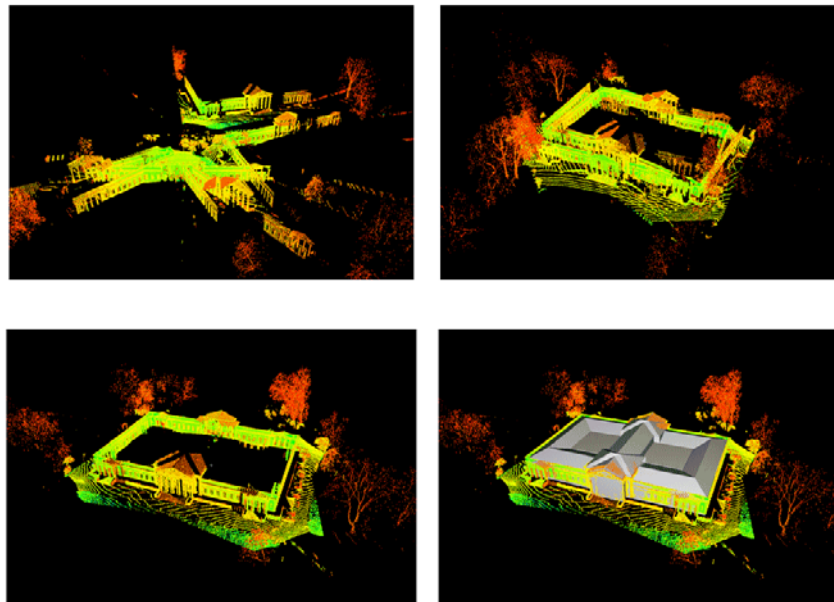

Fig. 10: An example for automated georeferencing of TLS data. Top left: The unregistered point clouds collected at five stations. Top right: Results obtained from the integrated orientation device. Bottom left: Result after iterative refinement using ICP. Bottom right: Super-imposition of georeferenced TLS data and a single building from a virtual city model.

3D facade texturing

A modern laserscanner is able to acquire densely sampled point clouds consisting of several million points. Using state-of-the-art meshing techniques, though not without problems, these point clouds can be converted to polygonal meshes, immediately suited for graphic rendering. While dense polygon meshes might be a suitable representation for applications in computer graphics, in the world of geomatics this representation lacks desirable features. Let alone the size of the data makes it unrealistic to derive such a representation for even a part of a city. Furthermore a dense polygon mesh is not grouped into meaningful entities, such as different architectural structures, for example wall, roof, and so on.

Deriving such a grouping leads to the task of modeling, where geometric primitives are fit to segmented portions of the data. For TLS data this is typically an interactive process, involving the manual segmentation of the point cloud and the selection of appropriate primitives. This approach is currently applied for the representation of industrial scenes, where objects can be described with a reduced set of geometric primitives and graphical realism is of little interest. For the representation of general architectural scenes this approach of modeling does not seem suitable. For one, the work load of manual interaction limits the approach to very small scenes or even single buildings. Secondly, most modeling environments for TLS data are limited to simple surfaces types such as ruled surfaces, seldom higher order curved surfaces are used. This set of geometric primitives is not suitable for the representation of highly detailed ornaments of historical buildings, which are of particular interest in any city model. This discrepancy in the ability to capture fine detail and the representation of surfaces in a model has long been noted in computer graphics. A solution, which is often chosen, is to separate the representation of coarse geometry from the representation of fine surface detail.

In the case of adding detail to a virtual city model, the coarse geometry is already given by the model extracted from aerial LIDAR data or photogrammetry. The coarse geometry is represented by the planar polygons of the boundary representation of a building. The task is to use the terrestrial laser data to add the detail. Since terrestrial laser scanners capture mainly the vertical structures, we concentrate on the facades of buildings. Following the approach described above, we aim to extract the displacement map of the CAD model surfaces to the terrestrial point cloud. In order to be able to bring the terrestrial laser data into relationship to the city model, the laser data has to be georeferenced as described in the previous sections. Once the data is brought into a common geometric reference frame, the difference of the point cloud to a planar facade can be computed easily, as is shown in Fig. 11.
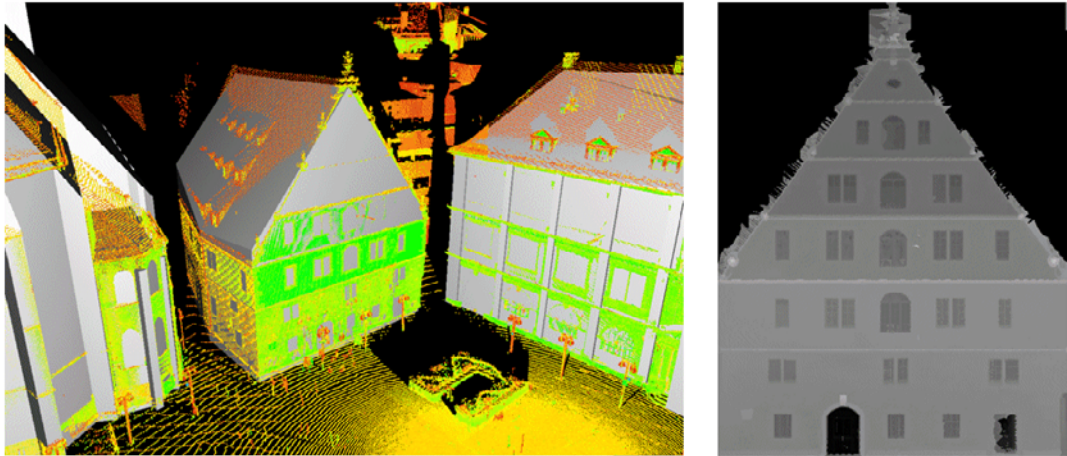
Fig. 11: Left: Multiple georeferenced point clouds from TLS aligned with a virtual city model. Right: The LASERMAP of a single facade extracted from the data.

Since we assume a multi station configuration for the acquisition of terrestrial data, we cannot restrict ourselves to ordered point clouds. Rather we have to work with an unordered point cloud where no neighborhood relation is available. We therefore re-interpolate the portion of the point cloud within a facade's buffer region to a regular raster centered on the plane of that facade. An example of such a re-interpolated displacement map is given in Fig. 11. The advantage of the re-interpolation mechanism is that we do not have to establish the neighborhood relation within the point cloud for example by triangulating the point cloud, which can be a complicated process. The disadvantage is that we are restricted to 2,5 D structures. However it is common to assume, that facades can be sufficiently described by a relief.

We call such a re-interpolated laser point cloud a LASERMAP. The term is composed from two terms describing the source of the data, a laser scanner, and the use of the data, as a displacement or bump map. The LASERMAP map can either be directly used as a displacement map, when a suitable rendering engine is available or a bump map can be computed using simple normal vector computation from a height field. The application of the LASERMAP as a bump map for the CAD model is shown in Fig. 12.
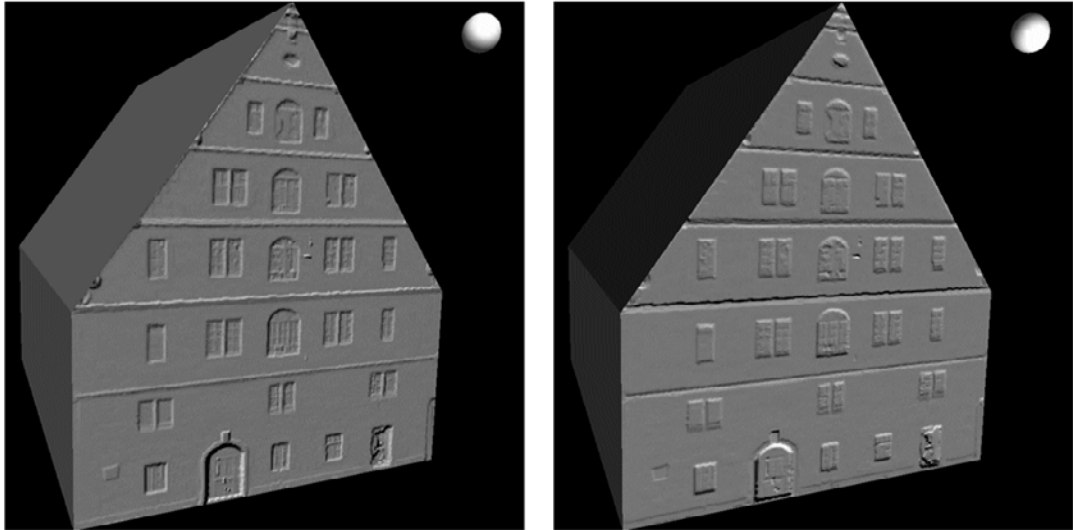
Fig. 12: The LASERMAP applied as a bump map to the CAD model of the building. Note the change in the shading of the surface due to the different direction of the light also visible on the sphere added in the upper right corner.

Automatic Multi-Image Texturing for Cultural Heritage Applications

The use of 3D laser scanner in documenting heritage sites has increased significantly due to the capability of such systems for the fast and reliable generation of dense 3D point clouds. In addition to geometric data collection for 3D model generation, texture mapping is especially important for cultural heritage applications. Based on this information, realistic visualizations and animations can be generated; colour image information is indispensable to document features like frescos and mosaics, it also provides information on the decay of the respective material.

A number of commercial laser scanners already provide a colour value for each 3D point from an integrated camera. However, while this can be useful during the data collection and interpretation process, the image quality can be insufficient for cultural heritage applications. Complex scenes require laser scanning from a number of viewpoints, which can be relatively time consuming. In an outdoor environment this large amount of time will result in considerable changes in illumination consitions. Thus, the recorded images will feature significant radiometric differences. This is demonstrated exemplarily in Fig. 13 for the Al-Khasneh monument in Petra, Jordan. Within a joint project of ifp and the Queen Rania's Institute for Tourism and Cultural Heritage the laser scanning system MENSI GS100 was applied for 3D data collection. The top row of Fig. 13 depicts images of 768*576 pixel resolution, which were captured additionally by an integrated camera during laser scanning. The considerable radiometric differences due to the changes in illumination are clearly

visible. The bottom row of Fig. 13 depicts images which were collected by a Fuji S1 Pro camera at a resolution of 1536*2034 pixels. Since a separate camera was used, the images were captured at optimal position and time. For this reason, the differences in radiometry are much smaller. This allows for an improved texture generation, which is especially important for the realistic documentation of heritage sites.
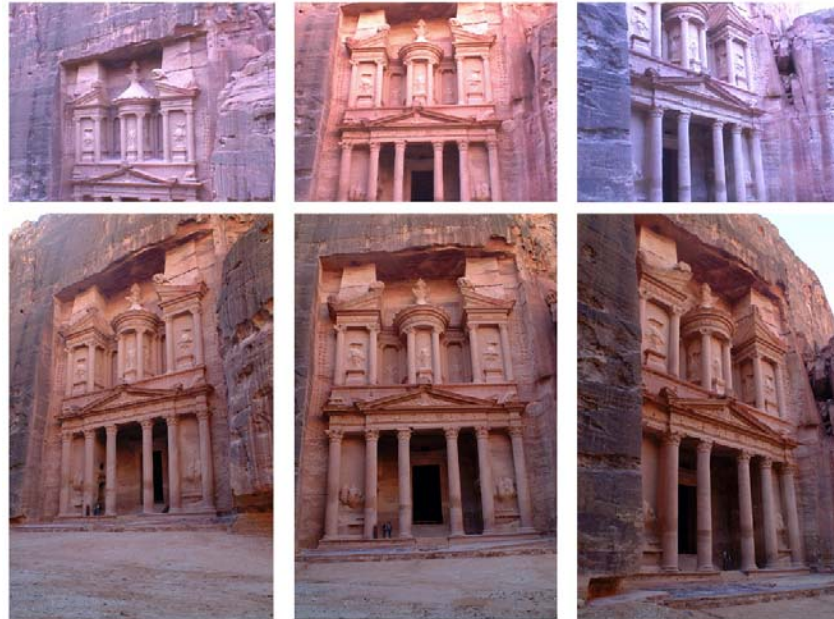

Fig. 13: Images of Alkasneh, Petra collected during point measurement by the camera integrated with the laser scanner (top) and by an independent digital camera (bottom).

If images are collected from multiple viewpoints, which do not correspond to the viewpoints of LIDAR data collection, occluded areas occur in the respective data sets. For this reason, after an integrated georeferencing of image and laser data, the visibility of the 3D model from laser scanning has to be determined within the respective images. During texture mapping, visible surface points from laser scanning are mapped to the corresponding sections of the texture image. As it is depicted in Fig. 14 left, first a so-called master image is selected, which has the largest number of visible surface patches. Subsequently, for all other images the visibility of the 3D model is checked and the appropriate image sections are separated automatically. Fig. 14 right depicts the final result of the 3D model after texture mapping from the five available images.
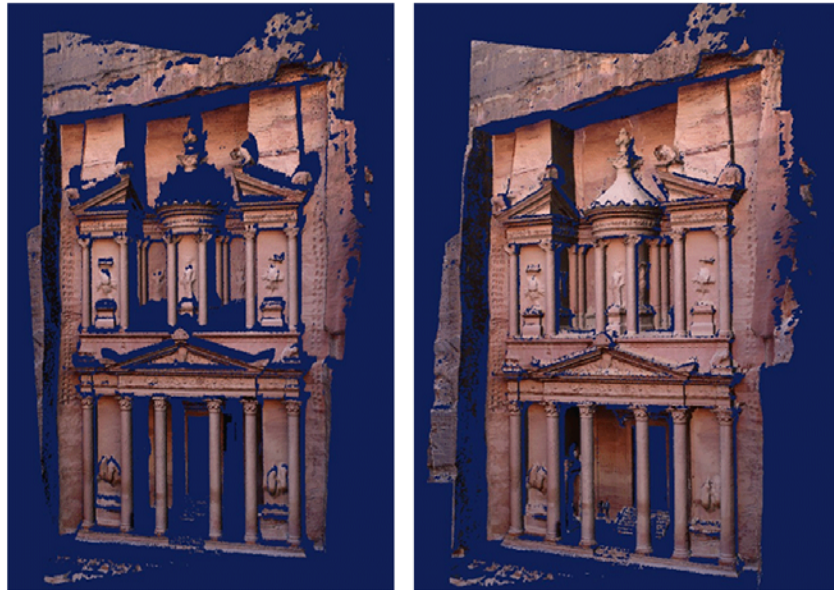
Fig. 14: 3D model textured from master Image (left) 3D model textured from all 5 images (right).

References 2005

Alshawabkeh, Y.: Using Terrestrial Laser Scanning for the 3D Reconstruction of Petra / Jordan. Photogrammetric Week '05, Wichmann, Heidelberg, pp. 39-47.

Alshawabkeh, Y. and Haala, N.: Automatic Multi-Image Photo-Texturing of Complex 3D Scenes. CIPA 2005 IAPRS Vol. 34-5/C34, pp. 68-73.

Balz, T. and Haala, N.: Interpretation of High Resolution SAR Data using Existing GIS Data in Urban Areas. IAPRS Vol. 36 Part 3/W24 Joint Workshop of ISPRS and DAGM CMRT05, pp. 111-116.

Becker, S., Haala, N. and Reulke, R.: Determination and Improvement of Spatial Resolution for Digital Aerial Images. Comm I and IV Hannover Workshop 2005 High-Resolution Earth Imaging for Geospatial Information, digitally published on CDROM.

Böhm, J.: Terrestrial Laser Scanning - A Supplementary Approach for 3D Documentation and Animation. Photogrammetric Week '05, Wichmann, Heidelberg, pp. 263-271.

Böhm, J.: Model-based segmentation and recognition from range data. Proc. SPIE Vol. 6051. Optomechatronic Machine Vision, pp. 605109-1 - 605109-8

Böhm, J. and Haala, N.: Efficient Integration of Aerial and Terrestrial Laser Data for Virtual City Modeling Using LASERMAPS. IAPRS Vol. 36 Part 3/W19 ISPRS Workshop Laser scanning 2005, pp.192-197.

Böhm, J., Haala, N. and Alshawabkeh, Y.: Automation in laser scanning for cultural heritage applications. International Workshop on Recording, Modeling and Visualization of Cultural Heritage, Ascona, Switzerland, pp. 443-450.

Böhm, J. and Schuhmacher, S.: Erste Erfahrungen mit dem Leica HDS 3000. Geo-Informations-Systeme (GIS), 4/2005, pp. 36-40.

Cramer, M.: Digital camera calibration and validation. GeoInformatics, Volume 8, March 2005, pp. 16-19.

Cramer, M.: Digital airborne cameras - status and future. Proceedings ISPRS workshop „High resolution earth imaging for geospatial information", University of Hannover, May 17-20, 2005, digitally published on CDROM.

Cramer, M.: 10 Years ifp Test Site Vaihingen/Enz: An Independent Performance Study. Photogrammetric Week '05, Wichmann, Heidelberg, pp. 79-92.

Cramer, M.: Positions- und Lagemesssysteme. In: Digitale Luftbildkamera - Ein Handbuch für die Praxis, Ed. R. Sandau, Herbert Wichmann Verlag, Karlsruhe, pp. 118-140 und pp. 258-268.

Fritsch, D.: Zur Lage der Universitaet Stuttgart. Mitteilungen Vereinigung Freunde der Universitaet Stuttgart.

Fritsch, D.: 175-jähriges Jubiläum der Universität Stuttgart. Reden anlässlich des Festakts am 9. Juli 2004. Universität Stuttgart, Reden und Aufsätze 67.

Fritsch, D.: Suzanne Mubarak. Speeches on the Occasion of the Conferment of Honorary Citizenship of the Universitaet Stuttgart Nov. 26, 2004. Universität Stuttgart, Reden und Aufsätze 68.

Fritsch, D.: Photogrammetric Week '05. Wichmann, Heidelberg, 346 p.

Fritsch, D.: The Photogrammetric Week Series - A Centennial Story of Success. Geo-Informationsysteme (GIS), 8/2005, pp. 17-22. (Also in: D. Fritsch (Ed.) Photogrammetric Week '05, Wichmann, Heidelberg, pp. 3-12)

Fritsch, D., Haala, N., Cramer, M. and Böhm, J.: The Best of Photogrammetric Image Data Processing. Lecture Notes, Tutorial Photogrammetric Week '05, Institute for Photogrammetry (ifp), Universität Stuttgart.

Fritsch, D.: Manfred Rommel. Reden anlässlich der Ernennung zum Ehrenbürger der Universität Stuttgart am 18. Mai 2005. Universität Stuttgart, Reden und Aufsätze 69.

Fritsch, D.: Universitaet Stuttgart 2001-02. Rechenschaftsbericht/Biannual Report Universität Stuttgart 1.

Haala, N.: Towards Virtual Reality GIS. Photogrammetric Week '05, Wichmann, Heidelberg, pp. 285-294.

Haala, N.: Laserscanning zur dreidimensionalen Erfassung von Stadtgebieten. 3D-Geoinformationssysteme: Grundlagen und Anwendungen Wichmann Verlag, pp. 26-38.

Haala, N. and Kada, M.: Panoramic Scenes for Texture Mapping of 3D City Models. Proceedings of the ISPRS working group V/5 'Panoramic Photogrammetry Workshop', IAPRS Vol. XXXVI-5/W8, digitally published on CDROM.

Kada, M.: 3D Building Generalisation. Proceedings of the 22th International Cartographic Conference, La Coruna, Spain, digitally published on CDROM.

Kada, M., Klinec, D. and Haala, N.: Facade Texturing for rendering 3D city models. Proceedings of the ASPRS 2005 Annual Conference, Baltimore, USA. 2005. pp. 78-85.

Schuhmacher, S. and Böhm, J.: Georeferencing of Terrestrial Laser scanner Data for Applications in Architectural Modeling. IAPRS VOLUME XXXVI, PART 5/W17, digitally published on CDROM.

Volz, S.: Modellierung und Nutzung von Relationen zwischen Mehrfachrepräsentationen. Miteilungen des Bundesamtes für Kartographie und Geodäsie, Arbeitsgruppe Automation in der Kartographie (Aga), Tagung 2004, pp. 119-129.

Volz, S.: Data-Driven Matching of Geospatial Schemas. In: Cohn, A.G., Mark, D.M. (eds.): Spatial Information Theory. Proceedings of the International Conference on Spatial Information Theory (COSIT '05), Lecture Notes in Computer Science 3693, Springer, pp. 115-132.

Volz, S.: Shortest Path Search in Multi-Representation Street Databases. Proceedings of the 3rd Symposium on Location Based Services and TeleCartography, Vienna, Austria, pp. 125-131.

Walter, V.: Phoogle the Web - Googles Approach of Spatial Data Visualisation. Photogrammetric Week '05, Wichmann, Heidelberg, pp. 321-330. Also in Geo-Informationssysteme (GIS), 8/2005, pp. 23-28.

Walter, V.: Object-based classification of integrated multispectral and LIDAR data for change detection and quality control in urban areas. Proceedings of the 3rd International Symposium on Remote Sensing and Data Fusion Over Urban Areas (URBAN 2005), Phoenix, Arizona, digitally published on CDROM.

Doctoral Theses

Böhm, J.: Modellbasierte Segmentierung und Objekterkennung aus Distanzbildern. Deutsche Geodätische Kommission, Reihe C, Nr. 583, München 2005, 94 Seiten.

Habilitation

Haala, N.: Multi-Sensor-Photogrammetrie - Vision oder Wirklichkeit? Deutsche Geodätische Kommission, Reihe C, Nr. 589, München 2005.

Diploma Theses

Martina Ott: Vergleich von Klassifikationsverfahren zur Detektion von Oberflächenfehlern. Betreuer: Haala, N. und Rohrmus, D. (Siemens AG)

Thomas Döring: Verfolgung von Verkehrsobjekten aus verschiedenen Kameraperspektiven. Betreuer: Haala N. und Reulke, R. (DLR, Institut für Verkehrsforschung)

Sina Binder: Optimierung eines Auswerteprozesses für Laserscanner-Daten mit Methoden aus der Bildverarbeitung. Betreuer: Haala, N., Pils, R. (intermetric GmbH) und Völter, U. (intermetric GmbH)

Study Theses

Sina Binder: As-buildt Dokumentation von Industrieanlagen mit dem HDS3000. Betreuer: Böhm, J.

Hainan Chen Kürzeste-Wege-Suche in Rasterdaten. Betreuer: Walter, V. und Kada, M.

Martina Ott: Textursynthese zur Korrektur von Orthophotomosaiken. Betreuer: Haala, N. und Braun, J. (inpho)

Katrin Zorn: Perspektive Darstellung von Kartenmaterial auf einem PocketPC. Betreuer: Kada, M. und Walter, V.

Activities in National and International Organizations

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President of the University of Stuttgart
Editor-in-Chief of the journal 'Geo-Informationssysteme GIS'

Education - Lecture/Practice/Training/Seminar

Adjustment theory and Statistical Inference I, II (Fritsch, Becker)	4/2/0/0
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, Grafarend, Keller, Kleusberg, Möhlenbrink)	0/0/0/4
Geoinformatics I (Fritsch, Walter)	2/1/0/0
Geoinformatics II (Walter)	2/1/0/0
Introductory Readings to Photogrammetry (Cramer)	2/0/0/0
Image Acquisition and Monoplotting (Cramer)	2/1/0/0
Practical Training in GIS (Walter, Volz)	0/0/4/0
Programming in C/C++ (Böhm)	1/1/0/0
Urban Planning (Schäfer)	1/0/0/0
Pattern Recognition and Image Based Geodata Collection (Haala)	2/1/0/0
Photogrammetry and GIS (Cramer)	2/1/0/0
Advanced Projects in Photogrammetry and GIS (Böhm, Cramer, Haala, Walter)	1/2/0/0
Animation and Visualisation of Geodata (Haala, Kada)	1/1/0/0
Cartography (Urbanke)	1/0/0/0