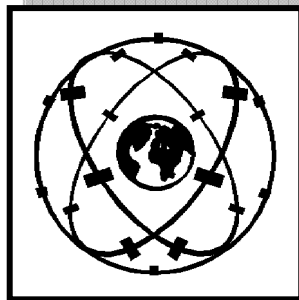
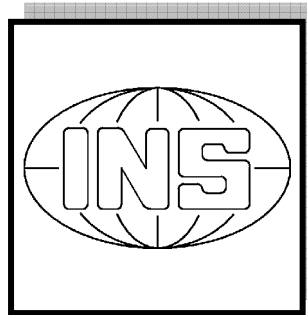


The Department of Geodesy and Geoinformatics



Stuttgart University
2004

editing and layout:

volker walter, friedhelm krumm, ulrich hangleiter, wolfgang schöller

Preface

It is with great pleasure to report about the highlights of the Department of Geodesy and Geoinformatics in the year 2004. Also in the twelfth year of its appearance this booklet aims at an information of our friends, colleagues and students about the achievements and changes in research and education. We consider the work done in 2004 as our contributions to the development of satellite and mathematical geodesy, navigation, land surveying and engineering and engineering surveys, telematics, photogrammetry, remote sensing, optical inspection, geographic information systems and location based services in research, development as well as in education.

The year 2004 was both a year of continuity and looming changes. The research pursued in 2003 was continued and expanded in 2004, which in detail is reported in this brochure. On the other hand with the celebration of the 65th birthday of Prof. E.W. Grafarend an era of successful teaching and researching of one of the most prominent German geodesists is about to come to an end. Still after his pending retirement Prof. Grafarend will surely influence the work and the life of the Department of Geodesy and Geoinformatics.

All four institutes are involved in a number of curricula of the Universität Stuttgart and run also their own curriculum. The attraction of this curriculum is demonstrated by the growing number of foreign students, which matriculate in studies of Geodesy and Geoinformatics. Also the number of German students is growing again after years of stagnation.

As before, this report is 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>

Dieter Fritsch
Alfred Kleusberg
Detlef Wolf

Erik W. Grafarend
Wolfgang Möhlenbrink

Wolfgang Keller
Ralf Reulke



Institute for Applications of Geodesy to Engineering

Geschwister-Scholl-Str. 24/D, D-70174 Stuttgart,
Tel.: +49 711 121 4041, Fax: +49 711 121 4044
e-mail: Sekretariat@iagb.uni-stuttgart.de or
firstname.secondname@iagb.uni-stuttgart.de
url: <http://www.uni-stuttgart.de/iagb/iagb.html>

Head of Institute

Prof. Dr.-Ing. Wolfgang Möhlenbrink
Dipl.-Ing. Ulrich Hangleiter, Akad. Direktor

Secretary

Christel Schüler

Emeritus

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

Scientific Staff

Dipl.-Ing. Roland Bettermann (up to 30.09.)	Traffic information
Dr.-Ing. Renate Czommer	Map matching
Dipl.-Ing. Andreas Gläser	Sensor Integration
Dipl.-Geogr. Thilo Kaufmann	Digital maps
Dipl.-Ing. Katrin Ramm	Kinematic positioning
Dipl.-Ing. Ralf Schollmeyer	Vehicle positioning
Dr.-Ing. Volker Schwieger	Surveying engineering
Dr.-Ing. Thomas Wiltschko	Information quality

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 geodesy, geodetic measurement techniques, surveying engineering, data processing and traffic information technologies. 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 traditional education in surveying of architects and civil engineers, lectures on „Acquisition and Management of Planning Data“ are presented to the diploma course of Immovables Techniques and Immovables Economy. Furthermore, lectures are given to students of Geography and Traffic Engineering as well as two special lecture in English within the master course Infrastructure Planning. Finally, eLearning modules are applied in different curricula e.g. for geodetic analyses or for cartographic animations. The current research in the fields of geodetic measurement techniques and traffic information techniques is reflected in most lectures. This is also represented in various case studies and diploma theses, often realised in co-operation with industry and public administration.

Research Work

The institute's current research work can be summarized by the main topic 'Positioning and controlling of moving objects in the digitally described 3D-space'. The institute's current research and development work focuses on the following main fields:

- ▷ surveying engineering, vehicle positioning
- ▷ traffic information techniques
- ▷ eLearning

Surveying engineering, measurement and positioning techniques

Map independent positioning of vehicles

The Kalman filter developed at the institute is applied for sensor integration of vehicle positioning. The filter algorithm was evaluated by empirical investigations, and the stochastic model of

the filter was extended. Especially, the automated realtime error detection was pushed. The fulfilment of this task requires the introduction of inter-epochal and intra-epochal correlations into the algorithm. The intra-epochal correlations deal with the measured quantities of one epoch, that are derived from the same sensor like the orientation changes and the distances derived from the odometer. These correlations may be integrated in the covariance matrix of the observations. The inter-epochal correlations arise from correlations of measured quantities of single sensors between two epochs e.g. for GPS. These time-dependent correlations will be modelled by the help of a FORM filter approach for the state vector.

The kinematic and modular data acquisition is realized using the software LabView®. The synchronisation is assured at the ns-level. The Mercedes Sprinter owned by the institute is used as measurement vehicle. Data of the following sensors may be integrated into the estimation of the position: (D)GPS, differential odometer, gyro (yaw rate sensor) and non-contact optical speed and distance sensor.



Fig. 1: Lateral view of odometer

Precise positioning using low-cost GPS receivers

The investigations regarding the static use of low-cost GPS receivers for positioning with geodetic accuracy were continued. For the navigation receivers of the Garmin eTrex series the possibility to estimate a differential solution using phase data is available. Therefore the code and phase data has to be stored on a computer during the measurement.

To assure a reproducible centring of the navigation receiver, a special adapter was constructed and tested in the IAGB-Lab. The reduction of multipath effects to increase the positioning quality is obtained through an additional shielding. Both were used for baseline measurements with two navigation receivers. The observation span of 30 minutes was realized for baseline lengths of

100 m up to 8 km. For sites showing small multipath effects the evaluation using Leica SkiPro® delivers maximum deviations of the known coordinates of 8 cm. If heavy multipath effects occur, the maximum deviations currently reach 30 cm. A dependence of the deviation from the baseline length could not be proven.



Fig. 2: Garmin eTrex Vista, adapter, shielding and laptop

Geometric guidance of construction machines

For highly precise guidance of construction machines like graders or a road paving machines, automated systems are in use nowadays. These systems integrate automated tachymeters or GPS receivers into the control loop for machine guidance. The accuracy demand for this guidance is some millimetres. The systems available on the market show the deficiency that they do not reach this accuracy level and that they are concentrated on the application of one type of construction machine.

At the institute a modular system for the automatic guidance of vehicles on given trajectories is developed. The Leica TCP1201 tachymeter is integrated as positioning sensor into the control loop. The modules are developed using LabView® and allow a flexible use of the system. Especially research regarding the integration of tachymeters into control systems, the dynamics of vehicles and the control techniques for construction machines are made possible by these developments. The aim is the increase of the guidance accuracy as well as the application flexibility of automated systems.

At the Intergeo 2004 in Stuttgart the system was presented in a model version. The vehicle was simulated by a model-lorry, that was guided automatically on a given trajectory stored digitally. In this case the position information to support the control loop was provided to the system by an integrated automated tachymeter.

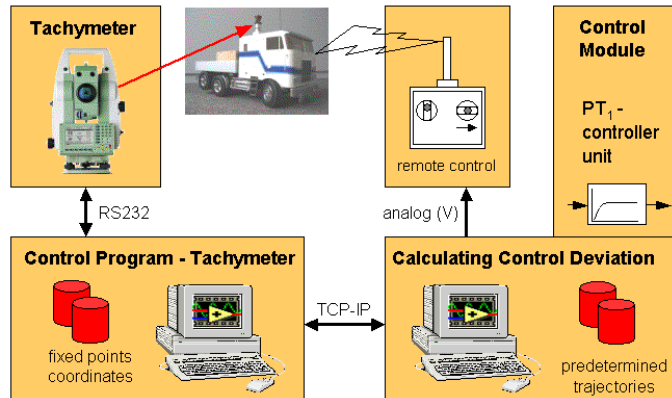


Fig. 3a: Modular system components for automatic guidance of the model-lorry on a given trajectory



Fig. 3b: Hardware components model version

Traffic Information Technology

Within the interdisciplinary field of traffic telematics, the IAGB is contributing with the traditional geodetic work of position determination, reality modelling in a digital map, as well as reliability of data acquisition and 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.

Geodata in Public Traffic - Project RUDY

In the third year of the project phase of RUDY¹ system specification for incident management and the respective functions of operation-close transformation for the demonstrators were finished. Furthermore the demonstrator for flexible service was effected. This is based on the GeoRBL (geodata based computerized operational control system).

¹RUDY = „Regional company spanned and dynamic networking of information, operational and planning systems in public and taxi transport“

Incident management

Workplace of the dispatcher:

In cases of incidents the dispatcher has to plan practicable detours. Based on digital road data and after enlarging the information relevant for public transport such as stops and preferred lines, functionalities were implemented into the dispatchers' workplace. The incident and the concerned vehicles are shown on the digital road map. The dispatcher now has the possibility to choose the detours proposed by the system or to determine own routes based on the map. For disposed detours new driving times are calculated by the GeoRBL. Passenger relevant information such as changes of stops and timetable deviations are shown and used as data basis for passenger information in the internet, at stops and in vehicle.

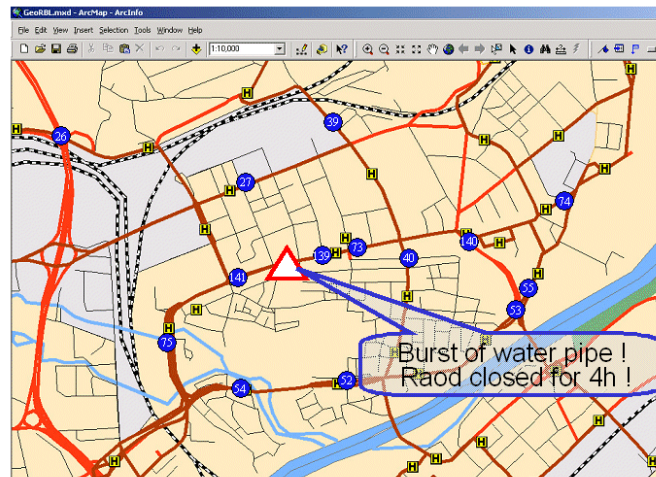


Fig. 4: View on the dispatcher desktop supported by geodata of the GeoRBL

Vehicle equipment:

By the GeoRBL all concerned vehicles are provided with the new line including actual times and the new route by GSM-GPRS data connection developed in the project. The drivers are assisted by a navigation system and guided around the incident location. Contrary to the RBL realised up to now, the vehicles inform area-wide about their current position via precise location functionalities of the navigation system. Thus the actual timetable situation can be calculated also in cases of incident at any time.

In summer 2004 the functionalities of GeoRBL as well as the RUDY busses equipped with the additional components were presented in a workshop with great success. Besides regular operation with navigation system and passenger information in vehicle also the view of the dispatcher in the control centre, the passenger and the driver in incident case could be presented.



Fig. 5: Vehicle equipment for driver with additional support by a navigation system

Flexible service

Specification:

A test phase of the flexible service is planned for nine months according to the demands at stops, by booking via internet and call-centres. For preparing this test phase a functionality specification and additional equipment of 4 busses with RUDY components were effected, as well as a data base by means of a driving time matrix.

It is planned to equip each bus with a navigation system for positioning and with a display for timetable relevant data. Besides realisation of planned at-least requirements for preparation, the IAGB plans to test the navigation functionalities of the navigation devices for research purposes and dispose as extended functionality.

Driving time matrix:

The driving time matrix stores all connecting times between stops in the service area. For completing this matrix, the data of the digital road map had to be integrated as a necessary data base for information purposes and for booking of flexible services. For this purpose a special calculating method based on ArcGIS was developed. The extended driving time matrix is a data base for the disposition tool of the project partner INIT. The geometries of the route are also stored in the matrix thus disposing driver and passenger information.

Quality concept for geodata - Project EuroRoadS

The project EuroRoadS which is funded within the eContent programme by the European Commission started on March 2004 and will be finished after 30 months. Key target of EuroRoadS is the development of a platform for supplying road data from the public sector (National Mapping Agencies, Road Administrations) for services and (private) providers. A simple data access for providers of mobility services and mobility systems should be achieved. For this purpose a specification framework will be built, consisting of a road data structure, characteristics of data, quality model and data exchange mechanisms. This framework will be tested through demonstrators.

The main focus of the IAGB within the project is the quality management through the information chain from data acquisition up to user. In the first phase of the project a quality model was developed, which allows a uniform description of quality within the information chain by using a fixed set of six inherent quality characteristics. Furthermore a method was developed based on reliability analysis, which will be used for description and evaluation of information quality within information processes.

In the forthcoming project phases the quality model should be integrated into the demonstrator. Therefore a corresponding metadata catalogue will be specified and the information processes will be analysed. In addition, quality assurance methods will be specified and implemented and evaluation quality will be evaluated by using corresponding evaluation methods.

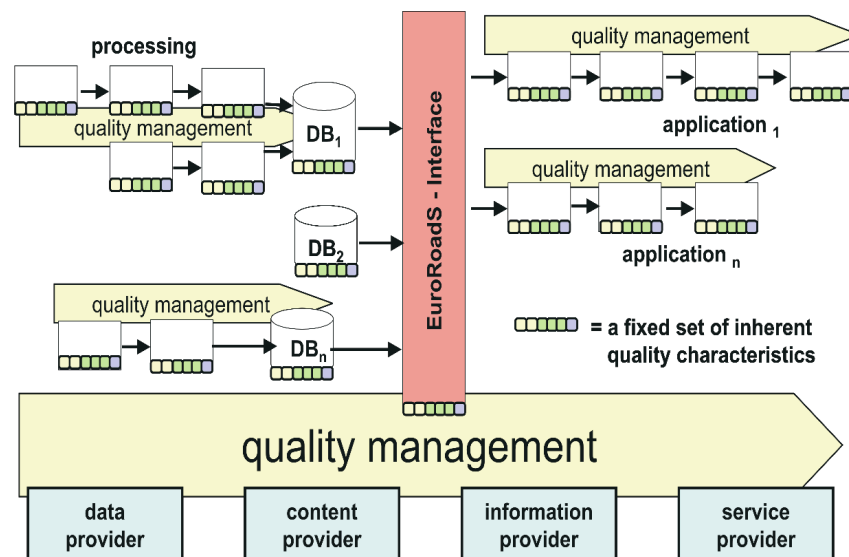


Fig. 6: Information chain in EuroRoadS including accompanying quality description as precondition for continuous quality management

Microscopic incident analysis for identifying conflict areas at junctions

In continuation of the investigation by order of DaimlerChrysler AG within the BMBF-project IN-VENT the distribution of incidents at special junctions (traffic light and road sign regulated junctions) was analysed. The aim is to identify conflict areas with increased numbers of incidents and heavy incidents resp. increased incident risks. Those investigations shall provide - based on the results of previous investigations - detailed hints to the sphere of support of driver assistance systems such as intersection assistance, turning assistance, changing lane assistance, etc.

Based on an investigation of Fastenmeier the roads were divided into segments by nodes. For the individual standardised nodes the analysis was effected with respect to the situation for

- ▷ distribution of incidents as indicator for frequency
- ▷ distribution of personal injuries
- ▷ distribution of incident costs as indicator for seriousness of incident

depending from the area fixed by the segment choice.

By this procedure, conflict areas with increased danger potential should be identified by aggregating incident data according to the respective situation element or situation elements. Focus was put onto incident consideration depending to junction regulation and driving direction. A high incident risk was obvious in inner nodal areas especially in case of driving direction changes to the left or in case the junction is crossed without changing of driving direction.

A further segment with high incident risk is the area for traffic situations at traffic light regulated nodal points with driving direction change. These incident situations and the investigation of Fastenmeier were compared.

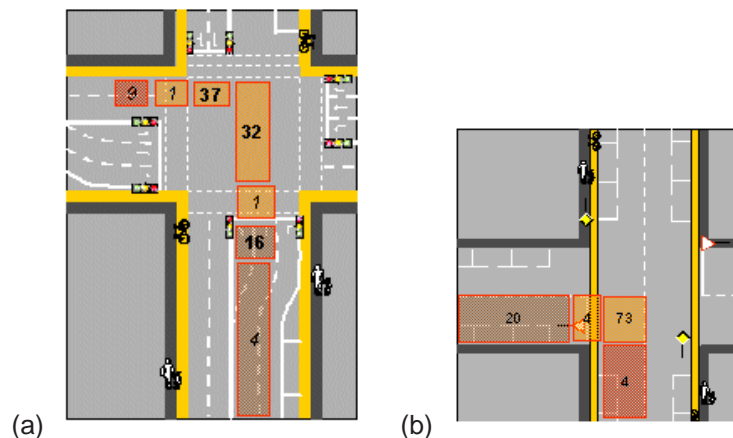


Fig 7: Allocation of accidents at (a) traffic light controlled intersections with turn left manoeuvre, and (b) traffic sign regulated intersections with turn left manoeuvre

New Media in physical teaching

Self-Study Online - project „ActiveMap“

The module ActiveMap (interactive training module for cartographic animations) was designed and developed within the program „self-study online“ of the University of Stuttgart. The module is directed to students of „geodesy and geoinformatics“ and „geography“ as well as further interested persons, and deals with the theme „dynamic visualization“ imparting knowledge about the basics of cartographic animation. Following a practice-oriented introduction into the animation software Macromedia Flash MX 2004 is given. Finally some practice-oriented exercises have to be solved.

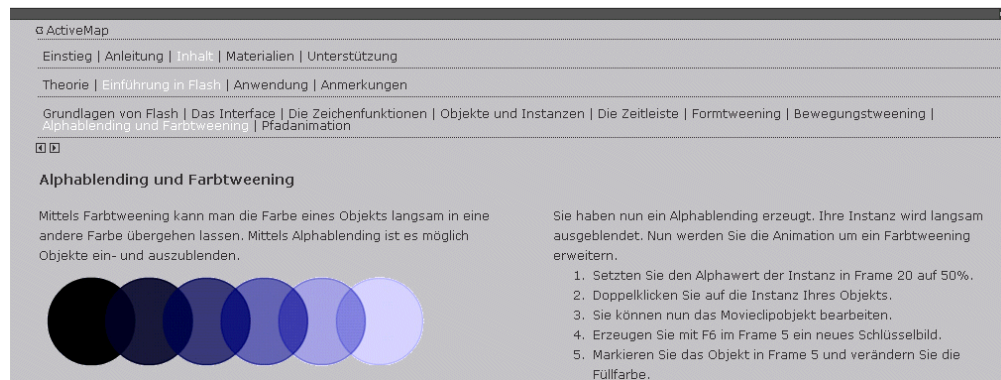


Fig. 8: Screen shot of the module ActiveMap

After completing the e-learning module the user should have theoretical knowledge about animated maps as well as the capabilities to create his own cartographic animations by using the software Flash MX 2004. The module is accessible through the GIMOLUS-platform and is integrated into the course „Thematic Cartography“.

Approximately 80 participants of this course have evaluated the module using a standardized questionnaire.

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

Formfinding of Lightweight Structures

The two-hour-lectures „Analytic Formfinding of Lightweight Structures“ for students of civil engineering, architecture and geodesy as well as for students of the master course „Computational Mechanics“ were held in English language. The appertaining practical computer exercises have been performed on windows-NT-computers of the CIP-pool of the master course WAREM. As part of the exercises the students did also interdisciplinary project works in some institutes of civil engineering and architecture.

Further lectures of K.Linkwitz

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

Seminars and Congresses

DVW Symposium „Kinematic Measurement Methods“

More than 100 specialists took part at the symposium „Kinematic Measurement Methods“ carried through by the IAGB in cooperation with the working group 3 „Measurement Methods and Systems“ of the DVW in February 2004. The main focus of the symposium with the subtitle „surveying in motion“ was on the application of kinematic methods. The spectrum contains the positioning of automobiles, the kinematic geodata acquisition for roads, rails and inland waterways as well as the guidance of construction machines. Special industrial measurement systems that reach the sub-millimetre, laser-based measurement techniques for kinematic applications and Location Based Services (LBS) for the mass market were presented.

2nd International Symposium „Networks for Mobility“

140 scientists and experts from 27 different countries participated in the 2nd International Symposium „Networks for Mobility“ organized by the Centre of Transportation Research (FOVUS). The IAGB was deeply involved by leading functions of Wolfgang Möhlenbrink (FOVUS-speaker) und Ulrich Hangleiter (symposium manager). The topics reached from planning of systems for passenger and freight transport, multi-modal systems, road-prizing systems, telematic and traffic control systems to the integrated spatial and transportation planning. Questions of system considerations, modelling and integrating of different solution methods for the complexity of transportation and mobility were of special interest in the congress. The symposium was accompanied by tutorials, in which the tutorial „Positioning and Map Matching for Traffic Application“ was presented by the IAGB.

Publications

Bettermann, R.: Entwicklungsperspektive für Geodaten im ÖPNV Beispiele aus dem Projekt RUDY. In: Geoinformation und Mobilität- von der Forschung zur praktischen Anwendung, Beiträge zu den Münsteraner GI-Tagen 2004, Hrsg. M. Raubal, A. Sliwinski, W. Kuhn, Schriftenreihe des Instituts für Geoinformatik, Universität Münster 2004.

Bettermann, R.: Das geocodierte ÖPNV-Netz: Grundlage für hochwertige Fahrgastauskunft, flexible Bedienformen und weitere Anwendungen. In: J.Strobl, T.Blaschke, G. Griesebner (Hrsg.): „Angewandte Geoinformatik 2004“, Beiträge zum AGIT-Symposium, Salzburg 2004, Seiten 45-50, Wichmann, Heidelberg 2004

- Bettermann, R., Kaufmann, T.: Verbesserungspotential der ÖPNV-Steuerung durch Verwendung von Geodaten - dargestellt am Beispiel Monitorsystem. - In: Kagermeier, A. (Hrsg.): Verkehrssystem- und Mobilitätsmanagement im ländlichen Raum (= Studien zur Mobilitäts- und Verkehrsforschung, Bd. 10). Mannheim 2004
- Bettermann, R., Kaufmann, T.: Upgrading of managing operations in public transport using geodata. In: Networks for Mobility - Proceedings of the 2nd International Symposium, September 29. - October 1. 2004 in Stuttgart. Stuttgart: FOVUS.
- Foppe, K., Schwieger, V., Staiger, R.: Grundlagen kinematischer Mess- und Auswertetechniken. In: Kinematische Messmethoden - Vermessung in Bewegung. Beiträge zum 58. DVW-Seminar am 17. und 18. Februar 2004 in Stuttgart, Wißner Verlag, Augsburg. 2004.
- Gläser, A., Schollmeyer, R.: Messwerterfassung und -synchronisation in Multisensorsystemen. In: Kinematische Messmethoden - Vermessung in Bewegung. Beiträge zum 58. DVW-Seminar am 17. und 18. Februar 2004 in Stuttgart, Wißner Verlag, Augsburg 2004.
- Holuba, K.-H., Schwieger, V., Ramm, K.: Low-Cost GPS-Empfänger im praktischen Reviereinsatz. Allgemeine Forstzeitschrift, Heft 23, 2004.
- Kaufmann, T., Schwieger, V.: Geodatenerfassung und -management. - In: Müller, M., Kaule, G. (Hrsg.): E-Learning mit GIS- und Modellanwendungen, Ergebnisse des Projektes gimolus, Wichmann-Verlag, Heidelberg 2004.
- Kaufmann, T., Makala, C., Weippert, H.: Visualisierung und Animationen. - In: Müller, M., Kaule, G. (Hrsg.): E-Learning mit GIS- und Modellanwendungen, Ergebnisse des Projektes gimolus, Wichmann-Verlag, Heidelberg 2004.
- Paul, M., Kaufmann, T., Schmidt, F., Makala, Ch.: Lernkontrolle und Lernsituationen mit internetbasierter Kommunikation. - In: Müller, M., Kaule, G. (Hrsg.): E-Learning mit GIS- und Modellanwendungen, Ergebnisse des Projektes GIMOLUS, Wichmann-Verlag, Heidelberg 2004.
- Kaufmann, T., Schwieger, V., Wiltshko, T.: Fachübergreifende eLearning-Module zu Geodatenerfassung und -management. In: Beiträge zum Workshop eLearning in Geoinformatik und Fernerkundung, Vechta, 16. / 17.02. 2004.
- Möhlenbrink, W., Kuhlmann, H., Dühnisch, M.: Prozessintegrierte kinematische Absteckung am Beispiel „Feste Fahrbahn“. In: Kinematische Messmethoden - Vermessung in Bewegung. Beiträge zum 58. DVW-Seminar am 17. und 18. Februar 2004 in Stuttgart, Wißner Verlag, Augsburg. 2004.
- Möhlenbrink, W., Schwieger, V.: Taxy Guidance using Map Matching Technology. Proceedings on International Symposium on „Navigation in General Aviation“, AVIGEN 2004, Linköping, Schweden, 9.-10.10.2004.
- Möhlenbrink, W.: Safety relevant information for telematic databases. In: Networks for Mobility - Proceedings of the 2nd International Symposium, September 29 - October 1, 2004 in Stuttgart. Stuttgart: FOVUS.

- Möhlenbrink, W.: High-Speed-Track Köln Rhein-Main - Robot tacheometers for semi-automatic construction process. In: Proceedings of the 3rd International Conference on Engineering Surveying, Bratislava, Slovak Republic, November 11 - 13, 2004.
- Ramm, K., Schwieger, V.: Low-Cost GPS-Empfänger für Anwendungen im Forstbereich. In: Flächenmanagement und Bodenordnung, Heft 4, 2004.
- Ramm, K., Kuhlmann, H., Möhlenbrink, W.: Schutz vor Datenmanipulation beim Aufmaß für die Bauabrechnung. Forschung Straßenbau und Straßenverkehrstechnik. Heft 882, Bonn, Februar 2004.
- Ramm, K., Schwieger, V.: Multisensorortung für Kraftfahrzeuge. In: Kinematische Messmethoden - Vermessung in Bewegung. Beiträge zum 58. DVW-Seminar am 17. und 18. Februar 2004 in Stuttgart, Wißner Verlag, Augsburg. 2004.
- Schollmeyer, R., Ramm, K., Wiltshko, T. und Bettermann, R. (2004): Autonomus map-based vehicle positioning for public transport prioritisation. In: Networks for Mobility - Proceedings of the 2nd International Symposium, September 29 - October 1, 2004 in Stuttgart. Stuttgart: FOVUS.
- Schwieger, V.: Variance-based Sensitivity Analysis for Model Evaluation in Engineering Surveys. Proceedings on 3rd International Conference on Engineering Surveying, Bratislava, Slowakei, 11.-13.11.2004.
- Schwieger, V.: Zum ingenieurgeodätischen Einsatz von Low-Cost GPS-Empfängern. In: Festschrift zur Emeritierung von Prof. Hans Pelzer, Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Heft Nr. 250, Universität Hannover, 2004.
- Schwieger, V., Foppe, K. (Red.): Kinematische Messmethoden - Vermessung in Bewegung. Beiträge zum 58. DVW-Seminar am 17. und 18. Februar 2004 in Stuttgart, Wißner Verlag, Augsburg. 2004.
- Schwieger, V., Kaufmann, T.: eLearning und Geodaten - Internetbasierte Wissensvermittlung zur Erfassung von Geodaten. GeoBit, Heft 1/2, 2004.
- Wiltshko, T.: Sichere Information durch infrastrukturgestützte Fahrerassistenzsysteme zur Steigerung der Verkehrssicherheit an Straßenknotenpunkten. Dissertation: Fortschritt-Bericht VDI, Reihe 12, Nr. 570. VDI-Verlag, Düsseldorf 2004.
- Wiltshko, T. und Möhlenbrink, W.: Unfallvermeidungspotenzial infrastrukturgestützter Assistenzsysteme. 5. Braunschweiger Symposium Automatisierungs- und Assistenzsysteme für Transportmittel. 17.-18. Februar 2004.

Diploma Thesis

Fürst, W.: Integration eines Qualitätskonzepts in ein Datenmodell für Geodaten

Hörschelmann, J.: Messaufbau für die Prüfung und Kalibrierung von EDM

Jahnke, M.: Entwicklung eines Werkzeuges zur Analyse der Informationsqualität auf der Basis von LabVIEW

Doctoral Thesis

Eichhorn, Andreas: Ein Beitrag zur Identifikation von dynamischen Strukturmodellen mit Methoden der adaptiven KALMAN-Filterung

Stark, Martin: Ein Beitrag zur modellgestützten Kostenprognose für den Aufbau von Geodatenbeständen unter Berücksichtigung der Datenqualität

Habilitation

Schwieger, Volker: Nichtlineare Sensitivitätsanalyse, gezeigt an Beispielen zu bewegten Objekten

Education

Surveying I, II for Civil Engineers (Möhlenbrink, Schollmeyer)	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
Data Acquisition and Management (Schwieger, Kaufmann)	1/1/0/0
Data Management and Analysis (Bettermann)	1/0/0/0
Adjustment Theory and Statistics III (Schwieger, Ramm)	2/2/0/0
Geodetic Measurements I, II (Wiltschko, Ramm)	4/2/0/0
Surveying for Geodesists (Czommer, Ramm)	2/1/0/0
Statistics and Error Theory I, II (Schwieger, Schollmeyer)	2/2/0/0
Field Practica in Surveying (Gläser, Schwieger)	10 days
Surveying Engineering I (Möhlenbrink, Gläser)	2/1/0/0
Surveying Engineering II, III (Schwieger, Gläser)	4/2/0/0
Causes and impacts of Deformations in Structures (Hangleiter)	2/0/0/0
Thematic Cartography (Bettermann, Kaufmann)	1/1/0/0
Traffic Telematics (Wiltschko, Bettermann)	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
Field Clearing (Mayer)	1/0/0/0
Land Consolidation II (Mayer)	2/0/0/0



Institute of Geodesy

Geschwister-Scholl-Str. 24/D, D-70174 Stuttgart,
 Tel.: +49 711 121 3390, Fax: +49 711 121 3285
 e-mail: gis@gis.uni-stuttgart.de or SECONDNAME@gis.uni-stuttgart.de
 url: <http://www.uni-stuttgart.de/gi>

Head of Institute

GRAFAREND Erik W, Prof. Dr.-Ing. habil. Dr.tech.h.c.mult. Dr.-Ing.E.h.mult.
 KELLER Wolfgang, Prof. Dr. sc. techn.
 KRUMM Friedrich, Dr.-Ing.
 WOLF Detlef, Prof. Dr. rer. nat. habil.

Secretary: VOLLMER Anita

Academic Staff

AUSTEN Gerrit, Dipl.-Ing.	Gravity Field Modeling GRACE/CHAMP
BAUR Oliver, Dipl.-Ing.	Satellite Gravity Gradiometry
CAI Jianqing, Dipl.-Ing. M.Sc.	Deformation Analysis, Mathematical Statistics
FINN Gunter, Dipl.-Ing.	Geoid determination
GÖTZELMANN Martin, Dipl.-Ing.	Satellite Geodesy
MOGHTASED-AZAR Khosro, M.Sc.	Geodynamics
NOVÁK Pavel, Ph.D.	Gravity Field Modeling GRACE
REUBELT Tilo, Dipl.-Ing.	Gravity Field Modeling CHAMP
SHARIFI Mohammad A, Dipl.-Ing. M.Sc.	Gravity Field Modeling GRACE

Administrative/Technical Staff

BAYERLEIN Wolfgang, Dipl.-Ing. (FH)
 HÖCK Margarete, Phys. T.A.
 KARBIENER Ingeborg
 SCHLESINGER Ron, Dipl.-Ing. (FH)

Guests

ASSI MI, Prof. Dr., Homs/Syria, 4.5.-6.11.
BILKER M, Masala/Finland, 18.10.-25.10.
GHITAU D, Prof. Dr., Bucharest/Romania, 20.6.-7.7.
HOLOTA P, Dr., Prague, Czech Republic, 1.11.-30.11.
KUBIK K, Prof. Dr., Brisbane/Australia, 6.11.-31.12.
MIRA S, Prof. Dr., Bandung/Indonesia, 12.7.-5.8.
MORITZ H, Prof. Dr., Graz/Austria, 3.5.-16.5.
SNEEUW N, Prof. Dr., Calgary/Canada, 1.7.-31.12.
VARGA P, Prof. Dr., Budapest/Hungary, 7.11.-5.12.
WANG J, Prof. Dr., Shanghai/China, 1.1.-31.8.

Additional Lecturers

ENGELS J, Dr., Stuttgart
HAUG G, Dr., Stadtplanungs- und Stadtmessungsamt, Esslingen/Neckar
RICHTER B, Dr., Deutsches Geodätisches Forschungsinstitut, München
SCHÖNHERR H, Präsident Dipl.-Ing., Landesvermessungsamt Baden-Württemberg, Stuttgart

Honorary Professors

HINTZSCHE M, Prof. Dipl.-Ing, Fellbach

Research

Gravity field determination from kinematic LEO-ephemeris by means of the GIS-acceleration approach: Latest results from the CHAMP-mission

Three LEO (low earth orbiting) satellite missions have been designed to fly in the next years. One of their main topics is the improvement of existing gravity field models. The first two missions, CHAMP - Challenging Minisatellite Payload for Geophysical Research and Application - and GRACE - Gravity Recovery and Climate Experiment - have already been launched successfully in summer 2000 and march 2003. GOCE - Gravity field and Steady-State Ocean Circulation Earth Explorer - should complete the gravity field determination in 2006. Besides various measurement principles applied in the different missions orbit analysis is carried out to determine the low frequency part of the gravity field. Since the LEO orbit ($h \approx 400$ km) can be tracked with

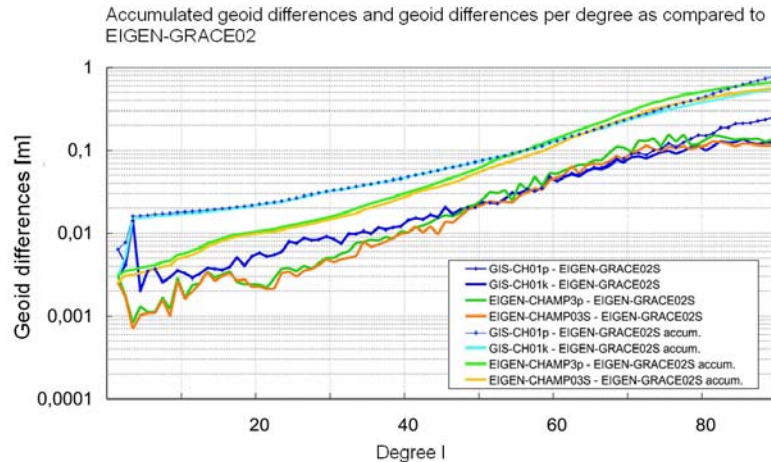
cm-accuracy in the kinematic mode, an algorithm has been designed which enables the determination of the parameters of the Earth's gravity field. In the midyear of 2004 a two-years-kinematic CHAMP orbit was computed at the IAPG (Institute for Astronomical and Physical Geodesy), TU Munich by D. Svehla and Prof. Rothacher, which was provided to various institutions for gravity field determination.

In the GIS-acceleration approach, the accelerations acting on the satellite are computed from the kinematic orbit, which was transformed into the quasi-inertial reference frame afore. This is realized by means of numerical differentiation of second order, where the application of Newton-interpolation has turned out to be suited. Normally numerical differentiation leads to an increase of noise, but if the noise is correlated, the effect of noise can be damped. 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.

The progression of the CHAMP-mission is demanding a higher resolution of the gravity field, since the data sets get larger and the descent of the satellite leads to an increase of signal. For a resolution up to degree 90 from a two years kinematic orbit data set 8278 parameters have to be estimated from 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 aimed, which can deal 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 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.

Additionally, further methods of interpolation such as spline interpolation and smoothing interpolation schemes (regression polynomials, smoothing splines) in order to reduce noise have been tested. It has turned out that the accuracy of the determined accelerations can be improved by a factor of 2-4 by means of smoothing interpolation methods. But concerning the estimated gravity field coefficients, no increase of accuracy was found. Obviously these smoothing methods not only reduce noise, they also filter out parts of the signal.

A new gravity field model of high quality was computed by means of the acceleration approach from a real two-years kinematic CHAMP orbit of the period march 2002 - march 2004, which was generated by the IAPG at TU Munich. Various versions of the gravity field model were estimated with different types of data-preprocessing, reduction of disturbing gravitative and non-gravitative effects as well as different regularisation parameters. Astonishingly the reduction of the non-gravitative disturbing accelerations in terms of accelerometer measurements rather lead to a deterioration than an improvement. This can be caused by a lack of accuracy of the provided calibration parameters. In the figure the two models GIS-CH01p (not regularized) and GIS-CH01k (regularized) were chosen from all determined models, where both models were determined without accelerometer data. Clearly the damping of noise can be seen in the coefficients of degrees higher than 80, which is caused by regularisation. For the detection of outliers during the data-preprocessing, a simple method was applied. By a comparison of the kinematic with a dynamic reference orbit and a comparison of the determined accelerations with accelerations, which were computed from an existing gravity field model, outliers have been detected and eliminated. More efficient procedures for outlier-detection, which are based on wavelets are under investigation.



Due to the high accuracy of the kinematic orbits of about 3 - 5 cm the estimated models are of a similar quality as the EIGEN-CHAMP-models (EIGEN-CHAMP3p, EIGEN-CHAMP03S), which were determined by means of the classical, dynamic approach without a preceding computation of kinematic orbits. This can be deduced from the figure, where the differences of the EIGEN-CHAMP-models and the GIS-CH-models to the more accurate GRACE-model EIGEN-GRACE02S are exhibited as geoid differences per degree (RMS-value) and as accumulated geoid

differences (RMS-value). As it can be seen, the coefficients of the EIGEN-CHAMP-models up to degree 45 are more accurate than those of the GIS-CH-models, for the coefficients between degree 55 and 70 the GIS-CH-models seem to be better. Regarding the accumulated geoid difference, which means the whole geoid difference up to a certain maximum degree, GIS-CH01p has a minor difference in comparison to EIGEN-GRACE02S with 21.6 cm up to degree 70 than EIGEN-CHAMP03S with 23.4 cm and thus can be classified as more accurate for this resolution. However EIGEN-CHAMP03S can be categorized as more precise for a resolution up to degree 50 with a geoid difference of 5.6 cm in contrast to an accuracy of 7.5 cm for GIS-CH01p. All in all it can be stated that the obtained accuracies are comparable to those, which were expected from the CHAMP-mission afore.

The space-wise approach to the LL-SST problem

Launching artificial satellite provides a homogenous and global coverage of observations, with which we are able to portray the Earth's gravitational potential globally. GRACE as the second mission of the Earth's gravity field dedicated mission is a NASA mission with a significant German contribution. Providing global and high accurate estimates of the Earth's gravity field and its temporal variations with unprecedented accuracy is the primary science objective of the GRACE mission.

Besides the two GRACE satellite position vectors, derived from the onboard GPS receivers, inter-satellites range and range rate measurements with high level of accuracy are the mission distinguished observations. Combining two types of observations provides us with invaluable information on the gravitational field. Equally well the measured sequence of observations may be viewed as a discrete time series, ideally spanning the entire mission length without interruption. This approach, which is called time-wise approach, is frequently used due to its simplicity. In this case, the determination of spherical harmonics becomes possible only after connecting the spherical harmonic representation of the potential with time series of the observations. However, it results in a huge linear system of equations and cannot be easily solved.

The alternative is assuming the observable as a function of the evaluation point position. A certain number of the mission revolutions traverse a boundary, which surrounds the Earth. The determination of the global gravitational potential in terms of spherical harmonics from such a functional given on the boundary is performed by different techniques. This approach is called space-wise approach. In spite of time-wise approach, the linear system of equations are relatively small and can be easily solved even in personal computers. This is the main advantage of space-wise approach over the time-wise. In addition, for local gravity field determination the later approach is preferred. Moreover, the satellite-based data can be easily combined with terrestrial and airborne gravimetry data to achieve higher accuracy and even fill the possible gaps in the data.

However, the observable is measured in the orbit, which is a relatively rough boundary. Having a smooth surface is a necessary condition for solving the problem as a BVP. Therefore, the observations should be reduced on a sphere or an ellipsoid.

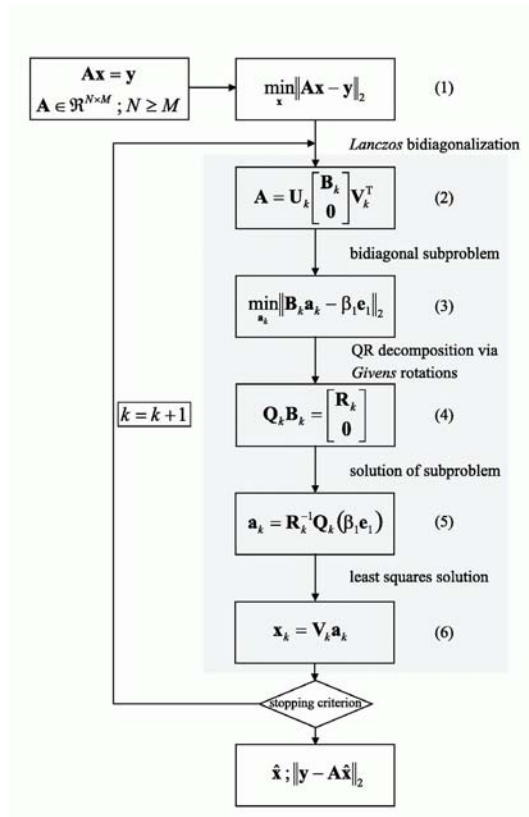
Data reduction is the most difficult step of the space-wise approach due to rather rough structure of the gravity field even at the LEO satellite altitude. To perform this step successfully, the well-known prediction methods are implemented on the observations and reduction quality is examined on the simulated data. Eventually, the optimal prediction method has been achieved by the Genetic algorithms implementation.

The GIS GRACE-processor

Completing a series of tests using simulated data in the first half of 2004, the developed processor for the analysis of the GRACE observations had been tested using real observations throughout the second half of the year. Results obtained for simulated data were reported at the Joint CHAMP/GRACE Science Meeting held in GeoForschungsZentrum in Potsdam, July 2004. Initial results for actual observed GRACE data were then presented at the International symposium „Gravity, Geoid and Space Mission“ in Porto, August-September 2004. The analysis of actual data became possible due to first kinematic orbits of the GRACE satellites processed by Mr. D. Svehla of the Technical University in Munich. The GRACE processor was implemented on an ordinary PC that allowed for a routine processing of 30-day batches of data. Their analysis resulted in time-averaged values of Stokes's coefficients up to the spherical harmonic degree and order 120. A single run for the spherical harmonic degree and order 140 was also performed testing capabilities of the processor. Finally, the processor was completed for different effects such as the solid Earth and ocean tides. A new transformation algorithm using new IAU Conventions 2000 for transformation between the Earth-fixed and inertial frames was also implemented in the software package.

LSQR method for gravity field recovery with GRACE

With the launch of the GRACE satellite mission in March 2002 the next step for the precise modelling of the Earth's gravity field and its temporal variations is made. One objective is the determination of the static gravity field in the medium wavelength range. To meet this requirement, it is necessary to solve for large-scale, linear and overdetermined systems of equations. Besides the well established direct equation solvers, such as provided e.g. by the LAPACK routines, an iterative solver, namely the LSQR (least-squares QR decomposition) method, is subject to present investigations. A parallel implementation of LSQR allows for the use of effective multi-processor hardware to meet the computational demands. Fig.1 presents the general procedure in the major work steps.



The GIS GOCE-Processor

Originally planned to be set in orbit in 2004, the launch of the ESA (European Space Agency) satellite mission GOCE (Gravity field and steady-state Ocean Circulation Explorer) is expected in autumn of 2006. Any launch date beyond 2006 would cause the operational phase, covering about 20 months, to enter the period of an increased solar activity. A fact that results in a negative manner on the mission design concerning the extremely complex compensation of non-gravitational forces such as air drag and solar pressure acting on the surface of the satellite.

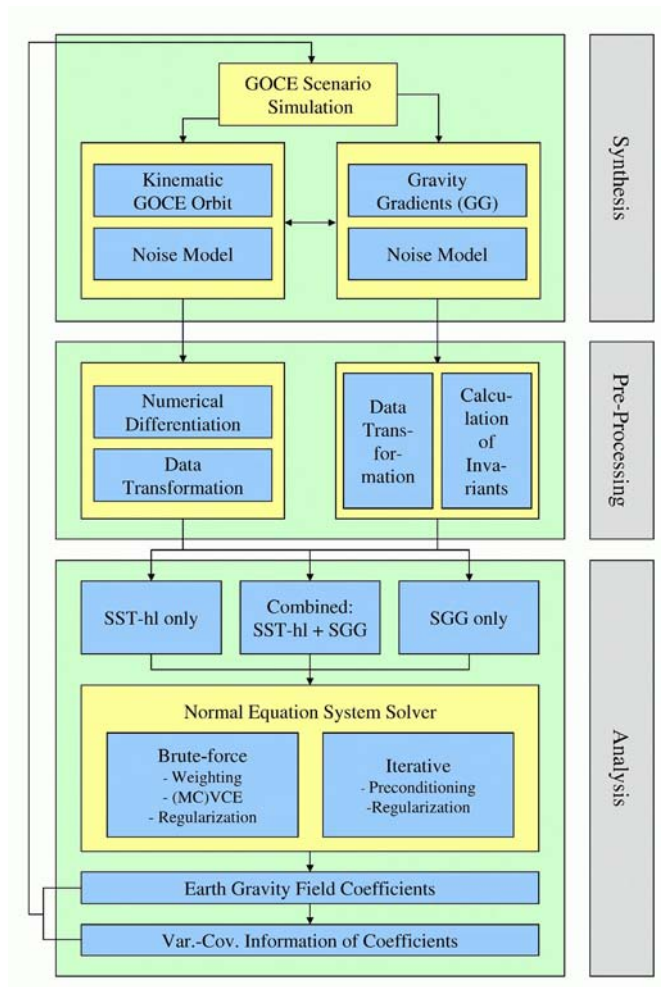
The Institute of Geodesy in Stuttgart (GIS) is member of a common project called GOCE-GRAND (GOCE GRavitationsfeldANalyse Deutschland). The further participants are the Universities of Munich, Bonn and Hanover as well as the GeoForschungsZentrum (GFZ) Potsdam. The common project is funded by the Federal Ministry of Education and Research (BMBF) within the scope of the GEOTECHNOLOGIEN II programme „Observation of the System Earth from Space“.

Primary objective of the GOCE mission can be constituted in modelling the short-wavelength part of the terrestrial gravitational field. To meet this challenge, for the first time in satellite geodesy a tri-axial gradiometer will deal as measurement unit (Satellite Gravity Gradiometry, SGG). Combined with the low satellite altitude of about 250km, the gradiometer instrument responds extremely sensitive to gravitational forces caused by the mass distribution inside the Earth. That guarantees the resolution of the harmonic expansion of the terrestrial gravitational field up to degree and order 250-300. Expressed in geometrical values, the accuracy of the geoid in the range of 2cm with a spatial resolution of about 70km (half wavelength) is enforced. The long-wavelength part of the terrestrial gravitational field is extracted from the kinematic orbit information provided by Satellite-to-Satellite Tracking in the high-low mode (SST-hl), namely phase measurements between GPS satellites and the on-board GPS receiver of the spacecraft (CHAMP principle). To meet the aforementioned objective, the GIS is engaged in gravitational field recovery (level 2 product) starting from pre-processed level 1b observation data. Figure 1 presents the necessary production steps, software modules respectively, of the so-called GIS GOCE-Processor.

Of course, so far real data handling is not possible in case of GOCE. The synthesis deals with the simulation of the mission scenario, namely the kinematic satellite orbit and the gravitational tensor, as well as appropriate noise models of the observables.

The connection of (pseudo-)observations to the functionals of the terrestrial gravitational field, namely is representation in spherical or ellipsoidal harmonics, is referred to as pre-processing in Figure 1. Different methods for numerical differentiation can be applied to estimate satellite accelerations based on satellite position data such as Gregory-Newton interpolation or polynomial regression. The accelerations (assumed to be unaffected by any kind of perturbation) equal the gradient of the gravitational potential. Thus, the functional model for SST-hl analysis is quite simple. The tri-axial gradiometer consists of six accelerometers whose combined measurements allow to set up the so-called gravitational tensor. The coefficient matrix of the tensor is both symmetric and trace-free. That is, only five of the nine elements (gravitational gradients) are linear independent. The gravitational gradients (GG) correspond to the second order derivatives of the gravitational potential (twice application of the gradient operator). Thus, the functional model between the pseudo observations (GG) and the unknown Stokes coefficients of the harmonic expansion of the Earth's gravitational potential is derived.

It is useful to avoid any rotation of the gravitational tensor from the gradiometer frame in an other frame of reference since this would affect the accuracy of the GG in a negative manner. This is why not the GG itself but the so-called fundamental invariants of the gravitational tensor deal as SGG observations. These values behave independently with respect to any rotation of the underlying reference frame. Notice, that the functional model becoming non-linear in terms of invariant analysis has to be linearized with respect to the unknown Stokes coefficients.



Main item of the GIS GOCE-Processor is the analysis procedure. Thereby, the dimension of the problem can be appraised as follows. The GOCE satellite is aimed to collect data covering a time span of about twelve months with a sampling rate of 1s. This results in about 30 millions observation points. Each of them provides three observations, namely the main diagonal elements of the gravitational tensor, respectively the fundamental invariants. Further, about 100.000 unknown parameters have to be estimated when assuming a spatial resolution of 70km, respectively a spectral resolution up to degree and order 300. Within the scope of an adequate least squares

adjustment procedure, terrestrial field recovery can be performed optionally based on SST-hl observations, SGG observations or their combined analysis. Two entirely different algorithms for the solution of the normal equation system are implemented. First, the brute-force method, characterized by the calculation and storage of the whole normal matrix. Normal matrix inversion allows for an estimate of the unknown parameters. Have in mind, that this approach requires an adequate main memory availability.

An alternative method is adopted, namely the iterative LSQR (Least Squares using QR decomposition) algorithm. The problem of limited storage availability is circumvented by replacing matrix-vector operations by repeated vector-vector multiplications at the expense of an increased amount of operations. Finally, the choice of the normal equation system solver depends on the available computation platform. However, both methods have to come along with an immense computational effort. No doubt, problems arising in satellite geodesy today can't be solved with an ordinary PC within a reasonable time frame. In fact, multi-processor systems should be applied. Hence, on the part of the GIS active effort has been undertaken to use the hardware resources of the High Performance Computing Centre Stuttgart (HLRS) within a project proposal. Since spring 2004, several computation platforms at the HLRS are used by the GIS for scientific computations.

Outlier detection of kinematic CHAMP orbit data by means of discrete wavelet filter techniques

Analyzing kinematic orbit data of CHAMP or any other Low Earth orbiting geophysical satellite mission, one usually faces the problem of intermittently occurring data gaps and outliers within the orbit signal. As simulation studies with synthetic outliers show, orbit analysis techniques like the acceleration approach, which are used to derive models of the Earth's gravitational potential field, are sensitive to the contamination of orbit data with local signal disturbances. On account of this, preprocessing of the real kinematic orbit data by means of outlier detection and elimination seems to be advisable.

A highly efficient method to remove sporadic, local outliers from the input data set is based on the time localizing ability of wavelet filter techniques. By means of fast discrete wavelet transformation, an input signal is developed into a consecutive series expansion of approximation signals and detail signals of increasing scales. All local signal occurrences are solely mapped to the coefficients on the smallest scales of the wavelet-transformed signal. Considering multiples of the mean signal energy on each scale, scale dependent thresholds are computed, in order to detect and eliminate outlying signal components without affecting remaining parts of the signal.

In connection with the analysis of a kinematic two year CHAMP orbit data set, which was computed and provided by IAPG/FESG Munich, this data preprocessing technique was applied and tested. Considering gravitational field analysis by means of the acceleration approach, data preprocessing may be implemented at the level of two different process steps. In order to remove single outliers or small spikes within the original kinematic orbit data set, data preprocessing firstly may be accomplished at the level of the input orbit data. As kinematic orbit disturbances lead to propagated errors in interpolated accelerations, an alternative option is to apply outlier removal

strategies after deriving the interpolated accelerations from the satellite position time series by means of numerical differentiation.

In order to be able to separate outliers from the rest of the input signal, difference signals have to be computed first in both cases. Subtracting comparatively smooth reduced-dynamic orbits from the kinematic input data set yields a resulting difference signal, which clearly reveals the outliers within the kinematic orbits. Dealing with acceleration signals, it turned out to be sufficient to subtract model accelerations up to degree and order 2.

As all considered reduced-dynamic orbits result from an orbit adjustment procedure, where pseudo-stochastic pulses, air drag and solar-radiation pressure parameters and initial state vectors are adjusted, while the coefficients of a chosen gravitational potential model are considered as a priori information and are not parameterized within the orbit adjustment, the generated reduced-dynamic orbits imply this predetermined geopotential model field.

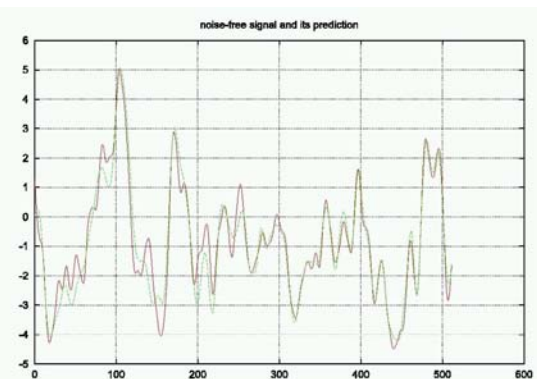
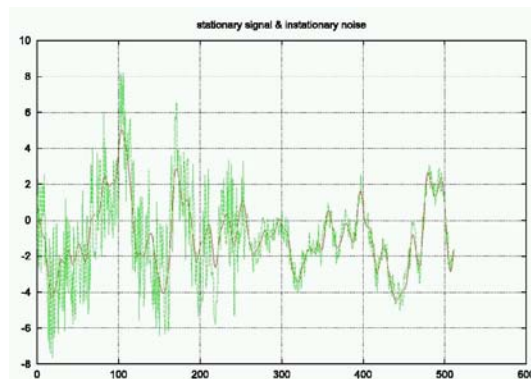
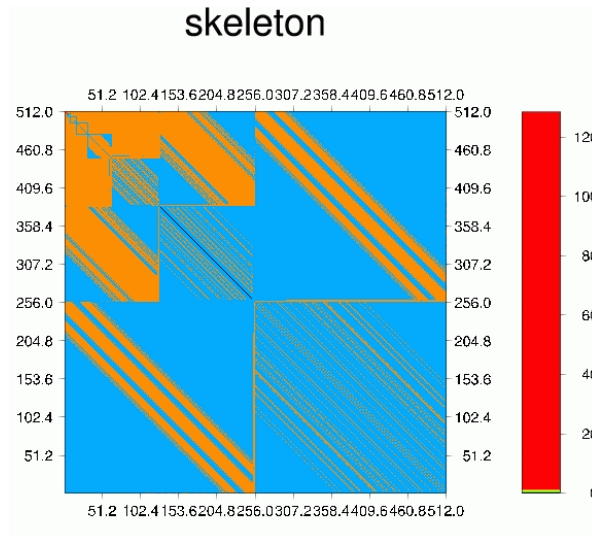
In order to guarantee, that the results of the orbit filtering process, and even more important the results of the following gravitational field analysis do not depend on the implied geopotential model, all computations were performed using two different kinds of reduced-dynamic orbits, based on EGM96 and EIGEN-GRACE02S respectively.

Wavelet Application in Geodesy and Geodynamics

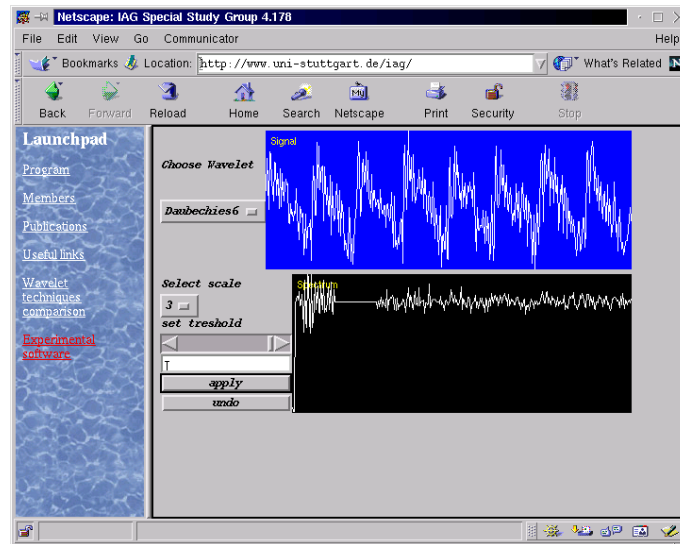
Wavelets are a recently developed tool for the analysis and interpretation of signals of various types. Compared to Fourier analysis, the standard tool for digital signal processing, wavelets provide two appealing features: (1) localization both in the time- and in the frequency domain and (2) discrete wavelet transformation algorithms, which are numerically even more efficient than the FFT. The DFG sponsored wavelet project aimed at an utilization of these properties in four fields of geodetic applications

- ▷ 1. Data compression. For an optimal compression of smooth data like geoid undulations or geoid heights the underlying wavelet has to be both smooth and orthogonal. As the results of the investigations a wavelet, derived from the quadratic spline wavelet showed the best overall performance for different types of data. Wavelet analysis and synthesis algorithm tailored to this special wavelet were developed.
- ▷ 2. Operator compression. Weak singularities are a typical feature of kernels of geodetic integral formulas. Using wavelets for their discretization thanks to the localization property of wavelets a very sparse matrix structure can be obtained. Then sparse matrix techniques can be applied for a numerically efficient treatment of the integral equation. Even more: Diagonality of the system matrix can be obtained, if the signal and the data are represented by different specially designed base function systems: wavelets and vaguelettes. For the planar approximation of the Stokes operator a corresponding wavelet-vaguelette pair together with the corresponding decomposition and reconstruction algorithms were developed.

- ▷ 3. Non-stationary collocation. Under the stationarity assumption the Wiener-Kolmogorov equations of collocation theory become convolution equations and can efficiently be solved by FFT techniques. In reality many data exhibit instationarities and the resulting Wiener-Kolmogorov equations are non-convolution integral equations. Applying the above mentioned operator compression techniques efficient numerical algorithms for the non-stationary case could be developed. For example this technique can be applied to filter a signal with varying noise intensity.



The international cooperation in the field of wavelet application was organized in the framework of the IAG Special Study Group 4.187. One important outcome of this cooperation is a wavelet package for the most common wavelet algorithms both in a command-line driven C version as in a platform independent JAVA version. Both versions can be downloaded from the SSG 4.178 homepage <http://www.uni-stuttgart.de/iag>.

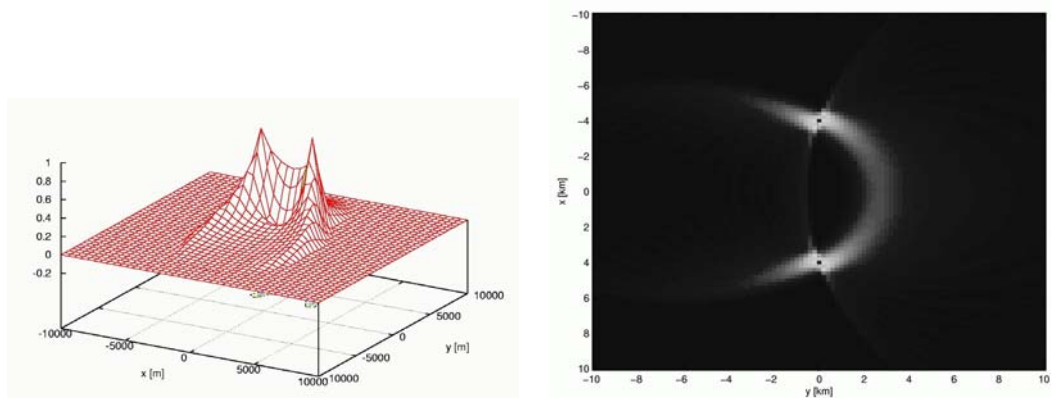


Bi-static GPS-SAR imaging

Traditionally, radar is mono-static, i.e. radar transmitter and radar receiver are at the same place. In bi-static radar transmitter and receiver are spatially separated. Such a bi-static radar configuration arises, when GPS signals, which are reflected at the sea-surface are recorded from a air-borne or space-borne down-looking GPS antenna. This bi-static GPS radar configuration has recently been used for the measurement of wave-heights and wind-speed.

Due to the roughness of the sea-surface, the received signals are not only signals reflected from a single point but from a whole glistening zone. Because of the relative motion between transmitter and receiver, the glistening zone moves over the sea-surface. Every point in the swaths is illuminated several times.

Completely analogue to the classical SAR imaging the multiple reflections of one point can be assembled to an image; only that the image geometry is much more complicated than in the classical mono-static SAR case. For typical aircraft or satellite configurations the resolution of the resulting images was investigated. The developed methods can be used for the detection of oil-spills in the open ocean.



SAR image of a single reflection point

Determination of the potential value of the Finnish height datum from the Baltic Sea Level Project and the new models of the gravity satellite missions

One of the aims of the new gravity field models determined from the satellite missions is the improvement of the geoid's potential value W_0 , which plays an important role in oceanography, in the definition of a height system and height determination with GPS. Based on the method of Ardalan and Grafarend the new gravity field models of the satellite missions CHAMP and GRACE and additional inland points of the Baltic Sea Level Campaign are included in a common Project with the FGI (Finnish Geodetic Institute, Masala/Finland). But the determined value for W_0 describes rather the potential value of the Finnish height datum since only Finnish GPS- and levelling data are applied. By comparison to a value of W_0 , which was obtained from global data sets, the offset of the Finnish height datum with respect to a global geoid can be determined.

At first, the potential values of the Baltic Sea Level points, which are determined from GPS measurements, are computed by means of a global gravity field model. Second, these potential values are reduced downwards to the geoid by means of orthometric heights and a gravity gradient, which is valid for a topography with an average density. Here attention has to be paid that the orthometric heights have been transformed into the tide-free-system before, since the gravity field models as well as the coordinates of the measurement points are given in this system. Since the orthometric heights of the inland points are known from the Finnish levelling, inland points can also be included in the computations. Finally the geoid's potential value and its accuracy are determined by the computation of the mean value.

From computations with CHAMP- and GRACE-gravity field models and the EGM-model up to the maximum degree of sensitivity of the satellite models (CHAMP: degree 70, GRACE: degree 120) it has turned out that the satellite-models can contribute to increase the accuracy for these

resolutions. If the full models are applied, the EGM leads to the best results due to a higher resolution which is caused by the terrestrial data. This means that a combination of EGM and the GRACE-models should be suited, to take advantage on the one hand of the higher accuracy of the satellite-data in the lower and medium degrees and on the other hand of the higher resolution in the terrestrial data. It was demonstrated that such a mixed-model leads to the most homogeneous results, since the analysis of measurement points near the sea and the analysis of all points gave similar values, and the analysis of only a few points (the points next to the sea) produced already a good result. Thus a potential value for the Finnish height datum of $W_0 = 62636856,60$ [m^2/s^2] was obtained, which was confirmed by computations from the EGM-model. In comparison to a potential value of a global geoid, which was received from Bursa et al. (2000) from TOPEX/POSEIDON altimetry-data, the Finnish height datum thus has an offset of 6 cm.

By inclusion of inland points and application of new gravity field models an improved potential value for the Finnish height datum could be determined. The tested method additionally allows the evaluation of existing gravity field models. The application of global GPS- and levelling datasets may contribute to compute a potential value for a global geoid with the described method.

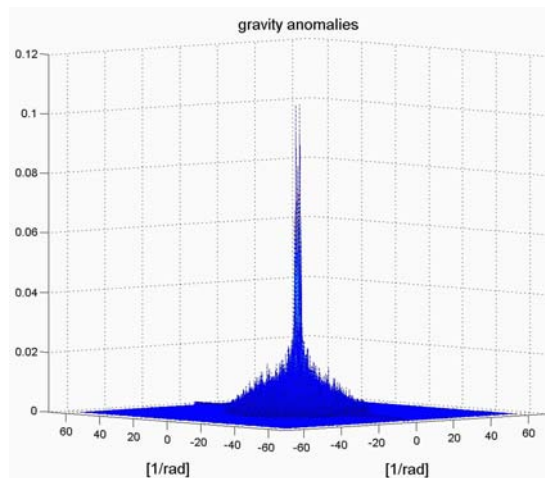
Astro-Gravimetric Geoid Determination

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 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.

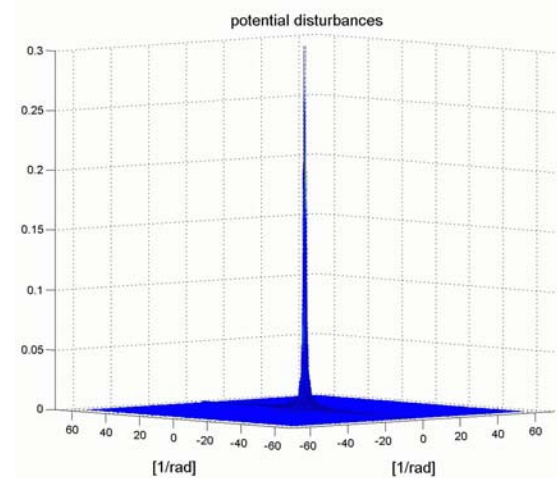
Geoid modeling in the singularity-free gravity space formulation

Within a German Research Foundation project a feasibility study is intended to decide whether the geoid model for the area of Central Europe can be improved if potential values instead of gravity data are adopted. Presently, high-resolution geoid models are computed by the combination of global satellite-based gravity field solutions and terrestrial gravity data. For further improvements of combination solutions for the geoid satellite-derived gravity field models, topographical information and gravity data have to be available with higher accuracy and higher density. Over the past years the knowledge of the Earth's gravity field and the Earth's topography has increased considerably due to the satellite missions CHAMP and GRACE and the space-shuttle mission SRTM (Shuttle Radar Topography Mission). In contrast, the gain in accuracy and density for the terrestrial gravity data available in Central Europe has been negligible. Potential values, as derived from gravimetric levelling, are available at high density and furthermore as visualized in Figs. 2 and 3 are substantially smoother in comparison to gravity data. The smooth behaviour of potential data is advantageous for the numerical realization of geoid determination software.

Theoretical background of the method is the singularity-free transformation of the problem into gravity space. The advantage of this approach is, that potential information is used instead of gravity data, but after appropriate linearization the mathematical formulation is identical with the linearized Molodenskij problem. Therefore all state-of-the-art numerical methods for geoid modeling can be transferred to gravity space.



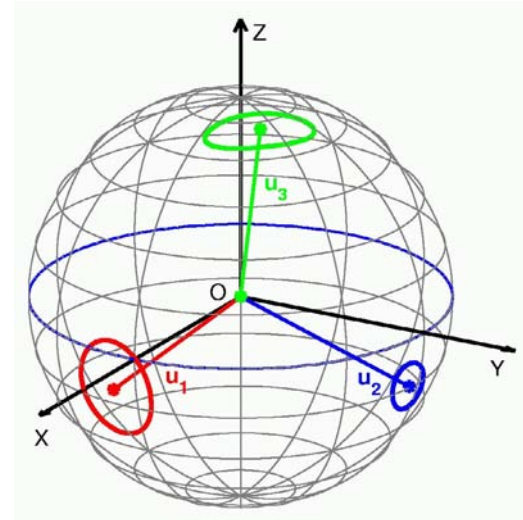
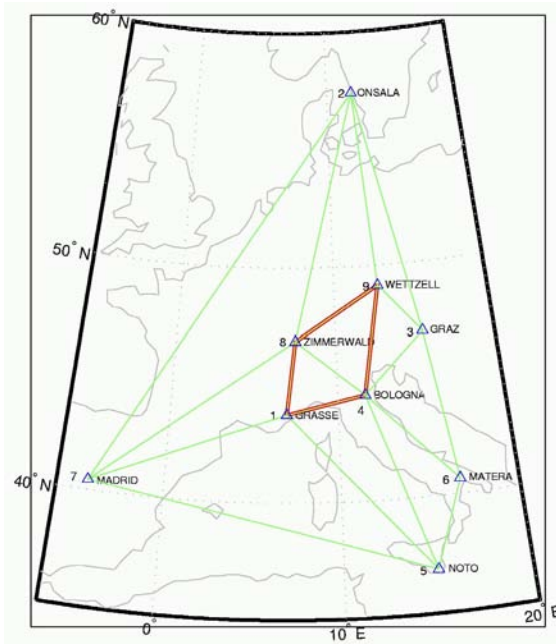
*Normalized 2D FFT-spectrum
of gravity anomalies*



*Normalized 2D FFT-spectrum
of potential disturbances*

Hypothesis tests and sampling statistics of the eigenvalues and eigendirections of a random tensor of type deformation tensor

For the validation of a symmetric rank-two random tensor, for instance of strain and stress, the eigenspace components (principal components, principal directions) play a key role. They classify deformation and stress patterns in earthquake regions, of plate tectonics and of glacially isostatic rebounds. The main purpose of this study is to develop the proper statistical inference for the eigenspace components of a three-dimensional symmetric deformation tensor. Let us assume that the strain or stress tensor has been directly observed or indirectly determined by other measurements. According to the Measurement Axiom such a symmetric rank-two tensor is random. For its statistical inference, we assume that the random tensor is tensor-valued Gauss-Laplace normally distributed. It is proven that the vectorized three-dimensional symmetric random tensor has a BLUUE estimate which is multivariate normally distributed. The BIQUUE sample variance-covariance matrix is Wishart distributed. The eigenspace synthesis relates the eigenspace elements to the observations by means of a nonlinear vector-valued function establishing a special nonlinear multivariate Gauss-Markov model. We have succeeded to establish the unique eigenvalue-eigenvector analysis and synthesis of a three-dimensional symmetric random matrix based on the review and choice of orthogonal similarity transformation matrices, which leads to the generalization of the BLUUE (Best Linear Uniformly Unbiased Estimation) of the eigenspace elements of three-dimensional random tensor and BIQUUE (Best Invariant Quadratic Uniformly Unbiased Estimation) of its variance-covariance matrix in the three-dimensional case. The test statistics, such as Hotelling's T^2 , Lawley-Hotelling's trace test, likelihood ratio statistics and Growth-Curve model are proposed. In one case study both model and hypothesis tests are applied to the three-dimensional, symmetric rank two strain rate tensor observations in Western Europe, which are derived from ITRF92 to ITRF2000 series station positions and velocities. The related linear hypothesis test has documented large confidence regions for the eigenspace components, namely eigenvalues and eigendirections, based upon real measurement configurations. They lead to the statement to be cautious with data of type extension and contraction as well as the orientation of principal stretches.



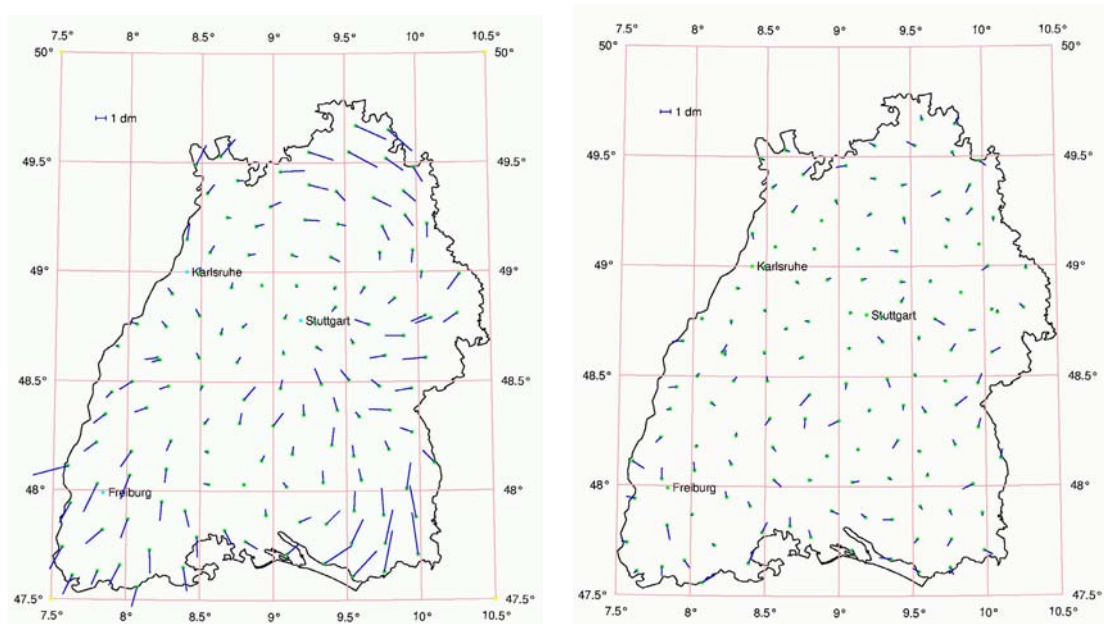
Eigendirections of the 3-D strain rate tensor and 95% confidence region (Subnet Grasse-Bologna-Wettzell-Zimmerwald)

ETRS89 in Baden-Württemberg

During the 88. and 96. Conference of the German working group of „Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV)“ in May 1991 and 1995 it was recommended to introduce the European terrestrial reference system 1989 (ETRS89) with the Universal Transversal Mercator Projection (UTM) as map projection on GRS80-ellipsoid uniformly into Germany and Europe. For this reason it is required to transform the existing two-dimensional Gauss-Krüger coordinates of German main triangular network (DHDN) into UTM coordinates of the ETRS89.

In cooperation with the Landesvermessungsamt Baden-Württemberg, three transformation models, the 7-Parameter-Helmert transformation, the 4-parameter Helmert transformation and the 6-parameter affine transformation, have been tested and analysed with 131 collocated points (131 BWREF-Points in Baden-Württemberg). Because of the special characters of the main triangulation network of Baden-Württemberg (country-wide variable network scales, inhomogeneous point accuracies and remaining network deformation in the range of decimeters), a new polynomial

transformation procedure has been studied. The first results show that the accuracy of this procedure is significantly better than the 7-Parameter-Helmert-Transformation: The quadratic mean of the horizontal residuals has been reduced from 12.4 cm to 4.9 cm in the total area of Baden-Württemberg. The network distortions could be well modelled by the new polynomial transformation model.

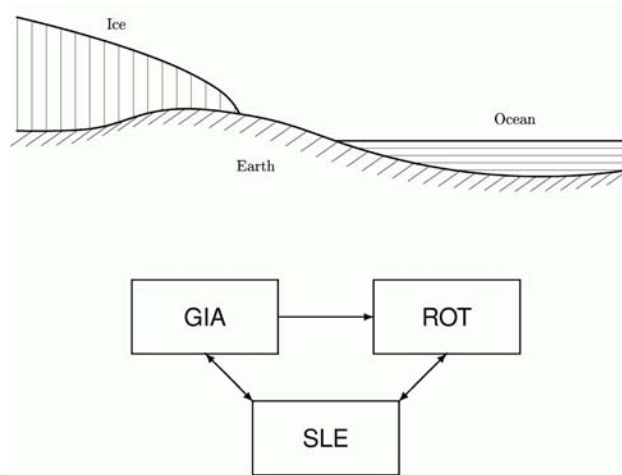


Displacements as a result of the 7-parameter Helmert transformation (left) and the 3-D transformation using a polynomial approach (right) in Baden-Württemberg

Glacial isostasy and global sea-level change

A problem with far-reaching consequences is the influence of the glacial-isostatic adjustment caused by the last Pleistocene deglaciation on the present-day sea-level change. This change can be determined both from satellite altimetry and from tide-gauge measurements. The resulting global mean sea-level rise usually ranges between 1.5 and 3.0 mm/a, with large uncertainties regarding the individual contributions (e.g. thermo-steric and halio-steric change, melt-water budget, ground-water storage). The objective of the study is to reduce tide-gauge measurements for the influence of the last Pleistocene deglaciation.

A model describing this influence must consider the glacial-isostatic adjustment (GIA) due to the time-variable ice and ocean loads. This is achieved by the sea-level equation (SLE), which considers the vertical displacement, the geoid-height change and the melt-water contribution from the Pleistocene ice sheets for the calculation of the sea level. Due to this surface-mass redistribution, the earth rotation (ROT) also changes and causes a variation in its centrifugal potential. This, in turn, gives rise to an additional geoid-height change, which must also be considered in the SLE (see figure).



Sketch of scenario considered (top) and schematic representation by three model components (bottom). GIA denotes the glacial-isostatic adjustment of the earth's interior, SLE the mass redistribution between ice and ocean described by the sea-level equation and ROT the variation of the earth's rotation.

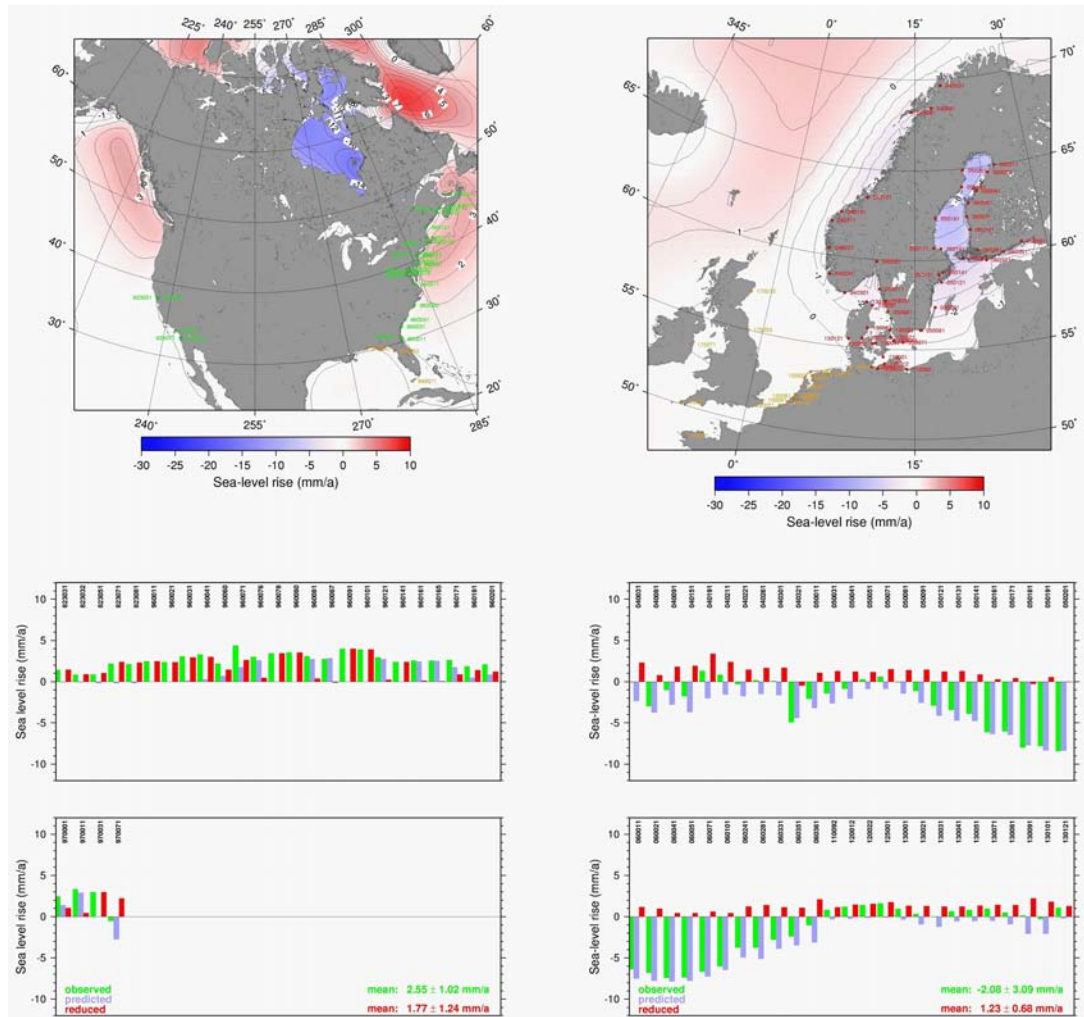
As theoretical description of the GIA, the spectral finite-element representation for a spherical, self-gravitating, incompressible, Maxwell-viscoelastic continuum is used. The main advantage of this method is that the equations are solved in the time domain. This simplifies the implementation of the SLE in comparison with Laplace-transform methods. Similarly, the ROT is described in the time domain using the Liouville equation, which is solved in terms of the MacCullagh formulae. This allows the determination of the vertical displacement and geoid-height change and, thus, the solution of the SLE.

For the numerical calculation, it is necessary to prescribe the earth and ice models. In the study, radially symmetric earth models parameterized by density, shear modulus and viscosity are used, where four models are tested for the parameterization of the viscosity. Furthermore, three ice models are considered.

To evaluate the earth and ice models, observables independent of tide-gauge measurements are required. For this, palaeontological and geological indications (e.g. shells, whale bones, isolation basins) of the former sea level are used, where each sample is dated and related to today's sea level. These observables are called sea level indicators (SLIs). Comparing the calculated and observed sea-level changes for the locations and times of the individual SLIs then allows the choice of optimum combinations of earth and ice models.

The tide-gauge time series are taken from the Permanent Service for Mean Sea Level (PSMSL) data base. The time series selected cover at least 45 a and are only weakly influenced by processes different from glacial isostasy (e.g. tectonically or anthropogenically induced vertical displacements, air-pressure variations or hydrodynamic effects). For these time series, linear trends are estimated from the monthly mean values. The previously determined optimum combinations of earth and ice models are then used to predict the influence of the Pleistocene ice-sheet evolution on present-day sea-level change and to reduce the estimated linear trends for this contribution.

A comparison with the unreduced linear trends shows a significant reduction of the variance and geographical variability of the reduced linear trends, in particular in the formerly ice-covered regions of North America and Fennoscandia (see figure). Tests using a fixed time interval of 70 a for the tide-gauge time series or using geographical groupings of the tide-gauge stations indicate only a weak dependence of the reduced global mean sea-level rise on the time interval or the grouping. The favoured value of the reduced global mean sea-level rise determined in the study is 1.46 ± 0.20 mm/a.



Calculated glacial-isostatic sea-level rise (top) as well as observed, calculated and reduced sea-level rise at PSMSL stations (bottom) for North America (left) and Fennoscandia (right).

List of Publications

- AMIRI-SIMKOOEI A and SHARIFI MA: Approach for Equivalent Accuracy Design of Different Types of Observations. *Journal of Surveying* 130 (2004) 1-5
- ARDALAN AA and GRAFAREND E: High-resolution regional geoid computation without applying Stokes's formula: a case study of the Iranian geoid. *Journal of Geodesy* 78 (2004) 138-156
- AWANGE J, FUKUDA Y and GRAFAREND E: Exact solution of the nonlinear 7-parameter datum transformation by Groebner basis. *Bollettino di Geodesia e Scienze Affini* 2 (2004) 117-127
- CAI J and GRAFAREND E: The Analysis of the Eigenspace Components of the Strain Rate Tensor in Central Mediterranean and Western Europe, 1992-2000. *Geophysical Research Abstracts*, Vol. 6, 06239, 2004, European Geophysical Union 2004
- CAI J, GRAFAREND E and SCHAFFRIN B: Statistical inference of the eigenspace components of a two-dimensional, symmetric rank-two random tensor. *Journal of Geodesy* 78 (2004) 12pp. DOI 10.1007/s00190-004-0405-2
- CAI J, GRAFAREND E and SCHAFFRIN B: The A-optimal regularization parameter in uniform Tykhonov-Phillips regularization - α -weighted BLE. In: F. Sanso (ed): V. Hotine-Marussi Symposium on Mathematical Geodesy. IAG Symposia 127, Matera, Italy, 17-21 June 2002, Springer, 309-324.
- CAI J: Statistical inference of the eigenspace components of a symmetric random deformation tensor. *Deutsche Geodätische Kommission Reihe C577*, München 2004
- FINN G and GRAFAREND E: Ellipsoidal Vertical Deflections: Regional, continental, global maps of the horizontal derivative of the incremental gravity potential. In: F. Sanso (ed): V. Hotine-Marussi Symposium on Mathematical Geodesy. IAG Symposia 127, Matera, Italy, 17-21 June 2002, Springer, 252-259.
- ILK KH, FLURY J, RUMMEL R, SCHWINTZER P, BOSCH W, HAAS C, SCHRÖTER J, STAMMER D, ZAHEL W, MILLER H, DIETRICH R, HUYBRECHTS P, SCHMELING H, WOLF D, RIEGGER J, BARDOSSY A and GÜNTNER A: Mass Transport and Mass Distribution in the Earth System: Contribution of the New Generation of Satellite Gravity and Altimetry Missions to Geosciences, 1st edn., GOCE Project Office Germany, Munich, and Geo-ForschungsZentrum Potsdam, 136 pp.
- KELLER W, KUBIK K and MOJARRABI B: Bistatic SAR using GPS signal reflected at the sea surface. 5th European Conference on Synthetic Aperture Radar, EUSAR2004, ULM, Germany, May 25-27, 2004, 779-783
- KELLER W: The use of wavelets for the acceleration of iteration schemes. In: F. Sanso (ed): V. Hotine-Marussi Symposium on Mathematical Geodesy. IAG Symposia 127, Matera, Italy, 17-21 June 2002, Springer, 81-87.
- KELLER W: *Wavelets in Geodesy and Geodynamics*, Walter DeGruyter Verlag, Berlin, 2004

- KÖSTERS F, KÄSE R, FLEMING K and WOLF D: Denmark Strait overflow for last glacial maximum to Holocene conditions, *Paleoceanography*, 19, PA2019, doi:10.1029/2003PA000972.
- MÄKINEN J, ENGFELDT A, HARSSON BG, RUOTSALAINEN H, STRYKOWSKI G, OJA T and WOLF D: The Fennoscandian land uplift gravity lines: status 2004. In: Ehlers C, Eklund O, Korja A, Kruuna A, Lahtinen R and Pesonen LJ (eds): Programme and Extended Abstracts of the Third Symposium on Structure, Composition and Evolution of the Lithosphere in Finland, pp. 81-87, Institute of Seismology, University of Helsinki, Helsinki.
- VAJDA P, VANICEK P, NOVÁK P and MEURERS B: On evaluation of Newton integrals in geodetic coordinates: Exact formulation and spherical approximation. *Contributions to Geophysics and Geodesy* 34 (2004) 289-314
- VARGA P, ENGELS J and GRAFAREND E: Temporal variations of the polar moment of inertia and the second-degree geopotential. *Journal of Geodesy* 78 (2004) 187-191
- WOLF D, KLEMANN V, WÜNSCH J and ZHANG FP: A reanalysis and reinterpretation of geodetic and geological evidence of glacial-isostatic adjustment in the Churchill region, Hudson Bay, *Sci. Techn. Rep. GFZ Potsdam, STR04/11*, 49 pp.

Doctoral Theses

- CAI J: Statistical Inference of the Eigenspace Components of a Symmetric Random Deformation Tensor

Diploma Theses

- SASGEN I: Geodetic signatures of glacial changes in Antarctica: rates of geoid-height change and radial displacement due to present and past ice-mass variations
- WITTWER T: High Performance Computing im Einsatz zur Schwerefeldanalyse mit CHAMP, GRACE und GOCE (High Performance Computing in use for gravity field analysis with CHAMP, GRACE and GOCE)

Study Works

- GEBERT CH: Neukonzeption eines Grundstücksmarktberichtes
- HOLST Ch: Bestimmung des Potentialwertes für das finnische Höhendatum unter Berücksichtigung der neuen Satelliten-Schwerefeldmodelle (Determination of the Geoid Potential Value for the Finnish Height Datum Incorporating the new Satellite-Derived Gravity Field Models)
- KLEINBAUER R: Kalman Filtering Implementation with Matlab

Guest Lectures and Lectures on special occasions

- HECK B, Prof. Dr. (Geodätisches Institut, Universität Karlsruhe): Von rand- und anderswertigen Problemen der Geodäsie (12.11.)
- HOLOTA P, Dr. (Research Institute of Geodesy, Topography and Cartography Prag/Tschechische Republik): Ellipsoidal Harmonics in Physical Geodesy and their Approximate Computation (25.11.)
- KUSCHE J, Prof. Dr. (Faculty of Aerospace Engineering, Delft University of Technology Delft, Niederlande): Earth's Large-Scale Mass Redistributions from Inversion of Space-Geodetic Data (13.5.)
- KUTTERER H, Prof. Dr. (Geodätisches Institut, Universität Hannover): Modellierung und Analyse geodätischer Daten mit Ansätzen aus der Fuzzy-Theorie (2.12.)
- KUTTERER H, Prof. Dr. (Geodätisches Institut, Universität Hannover): Modellierung und Analyse geodätischer Daten mit Ansätzen aus der Fuzzy-Theorie (2.12.)
- MARTINEC Z, Prof. Dr. (Universität Prag / Geoforschungszentrum Potsdam, Department 1, Sec. 1.3: Gravity Field and Earth Models): Linearised rotational response of a 3-D viscoelastic Earth induced by glacial isostatic adjustment (17.6.)
- MORITZ H, Prof. Dr. (Universität Graz): Chaos in Geodäsie und Geophysik (7.5., 10.5.)
- MORITZ H, Prof. Dr. (Universität Graz): Inverse Probleme in Geodäsie und Geophysik (6.5.)
- MORITZ H, Prof. Dr. (Universität Graz): Relativistische Effekte (11.5., 12.5.)
- SNEEUW N, Prof. Dr. (Department of Geomatics Engineering, University Calgary/Canada): Aliasing Problems in Spaceborne Gravimetry (16.12.)
- WITTENBURG R, Prof. Dr. (Institut für Markscheidewesen und Geodäsie, TU Freiberg/Sachsen): Spitzenleistungen der Triangulations-Ära betrachtet durch die GPS-Brille (1.7.)

Lectures at other universities and at conferences

- AUSTEN G and BAUR O: A parallel iterative algorithm for large-scale problems of type potential field recovery from satellite data. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- AUSTEN G and GRAFAREND E: Gravitational Field Recovery from GRACE data of type High-Low and Low-Low SST, Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.2004 (Posterpräsentation)
- AUSTEN G and GRAFAREND E: Gravitationsfeldbestimmung aus GRACE Daten. Geodätische Woche 2004, Stuttgart, 12.-15.10.

- BAUR O and GRAFAREND E: GOCE-GRAND AP4 Statusbericht (Bestimmung einer GPS-Schwerefeldlösung aus kinematischen GOCE-Bahndaten in Kollokation mit GOCE-Gradiometerdaten). GOCE-GRAND Projekttreffen, GeoForschungsZentrum Potsdam, 29.-30.3.
- BAUR O and GRAFAREND E: GOCE-GRAND: An approach for the GOCE scenario analysis in terms of Earth Gravity Field Recovery. GEOTECHNOLOGIEN II Status Seminar 'Beobachtung des Systems Erde aus dem Weltraum', GeoForschungsZentrum Potsdam, 5.7.
- BAUR O and GRAFAREND E: Zur Bereitstellung eines globalen Erdschwerefeldmodells aus GOCE Beobachtungen. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- BAUR O, AUSTEN G and WITTEW T: A parallel iterative algorithm for large-scale problems of type potential field recovery from satellite data. Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
- CAI J and GRAFAREND E: On the determination of the optimal α in the uniform Tikhonov-Phillips regularization (α -weighted BLE). Geodätische Woche 2004, Stuttgart, 12.-15.10.
- CAI J and GRAFAREND E: The analysis of the eigenspace components of the strain rate tensor in central Mediterranean and western Europe, 1992-2000. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- CAI J and GRAFAREND E: The linearized multivariate Gauss-Markov model for the estimation of eigenspace components of a symmetric rank two deformation tensor - Case study: ITRF92-2000 data sets in central Mediterranean and Western Europe -. Humboldt Symposium „Moderne Methoden der multivariaten Messdatenanalyse“, Berlin, 11.-12. 8.
- CAI J and GRAFAREND E: The statistical analysis of geodetic deformation (velocity and strain rate) derived from the space geodetic measurements (1992-2000 ITRF data sets) in central Mediterranean and Western Europe. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- CAI J and GRAFAREND E: The statistical analysis of the eigenspace components of a symmetric random deformation tensor - Case study: ITRF92-2000 data sets in central Mediterranean and Western Europe -. Geodetic Seminar, Finnish Geodetic Institute, Masala, Finland, 2.9.
- CAI J and GRAFAREND E: The statistical inference of eigenspace components of a three-dimensional, symmetric rank-two random tensor: Case study: strain rate tensor in central Mediterranean and Western Europe. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- CAI J, GRAFAREND E und KRUMM F: Einführung von ETRS89 in Baden-Württemberg. Workshop zum Gutachten, Landesvermessungsamt Baden-Württemberg, Stuttgart, 30.1.
- CAI J: The analysis of the eigenspace components of the strain rate tensor derived from the space geodetic measurements (1992-2000 ITRF data sets) in central Mediterranean and western Europe. Scientific Seminar, GeoForschungsZentrum Potsdam, 30.3.

- FINN G: Combined Astro-Gravimetric Regional Geoid Determination Case Study: Finland. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- FINN G: FINN2004 - Ein neues Geoidmodell für Finnland. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- FINN G: FINN2004: The New Model for the Finnish Geoid. IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- FINN G: Modelling the Finnish Geoid. Oberseminar, Finnisches Geodätisches Institut, Masala (Finnland), 12.8.
- FLEMING K, MARTINEC Z, HAGEDOORN J and WOLF D: Geoid movement about Greenland resulting from past and present-day changes in the Greenland Ice Sheet. Workshop on Geodynamik-Klimavariabilität, Potsdam, 13.5.
- FLEMING K, MARTINEC Z, WOLF D and SASGEN I: Detectability of geoid displacements arising from changes in global ice volumes by the GRACE gravity space mission. Joint CHAMP/GRACE Science Meeting, Potsdam, 7.7.
- GÖTZELMANN M, AUSTEN G, KELLER W and GRAFAREND E: Increasing the density of satellite position and velocity data. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- GÖTZELMANN M, REUBELT T and GRAFAREND E: A new CHAMP gravitational field model based on the GIS acceleration approach and two years of kinematic CHAMP data. Joint CHAMP/GRACE Science Meeting, Potsdam, 6.-8.7.
- GÖTZELMANN M, REUBELT T and GRAFAREND E: Preprocessing of kinematic CHAMP data. GRACE und CHAMP Status Meeting, Oberpfaffenhofen, 27.2.
- GÖTZELMANN M, REUBELT T, GRAFAREND E and KELLER W: Vorprozessierung von kinematischen Satellitenbahndaten mit Hilfe von diskreten Wavelet-Filtern und deren Auswirkung auf die Gravitationsfeldanalyse. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- GRUND V, NOVÁK P, MARCHENKO D and MEYER U: Regional geoid determination from CHICAGO airborne gravimetry using sequential multipole analysis, collocation and Stokes approaches. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- HAGEDOORN J, MARTINEC Z, WOLF D and KLEMANN V: Glacial isostatic adjustment and recent sea-level change: the influence of Pleistocene ice sheet evolution on tide-gauge measurements. 2004 Spring Meeting of the AGU, Montreal, Quebec, EOS, Vol. 85, No. 17, Suppl., Abstract G41A-02, 20.5.
- HAGEDOORN J, MARTINEC Z, WOLF D and KLEMANN V: Glacial-isostatic adjustment and recent sea-level change: the influence of Pleistocene ice-sheet evolution on tide-gauge measurements. Workshop on Geodynamik-Klimavariabilität, Potsdam, 13.5.

- HAGEDOORN JM, MARTINEC Z, WOLF D and KLEMANN V: Glacial-isostatic adjustment and recent sea-level change: the influence of Pleistocene ice-sheet evolution on tide-gauge measurements. 1st EGU General Assembly, Nice, France, Geophys. Res. Abstr., Vol. 6, Abstract EGU04-A-00377, 26.4.
- HAGEDOORN JM, MARTINEC Z, WOLF D and KLEMANN V: Glacial-isostatic adjustment and recent sea-level change: the influence of Pleistocene ice-sheet evolution on tide-gauge measurements. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- KLEMANN V and WOLF D: Using fuzzy-set classification to analyse sea-level indicators with respect to glacial-isostatic adjustment. 2004 Spring Meeting of the AGU, Montreal, Quebec, EOS, Vol. 85, No. 17, Suppl., Abstract G41A-03, 20.5.
- KLOKOCNÍK J, KOSTELCKÝ J and NOVÁK P: On future of gravity field models accuracy assessment. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- KLOKOCNÍK J, KOSTELCKÝ J and NOVÁK P: On future of gravity field models accuracy assessment. IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- MÄKINEN J, ENGFELDT A, HARSSON BG, RUOTSALAINEN H, STRYKOWSKI G, OJA T and WOLF D: The Nordic land uplift gravity lines 1966-2003. International Symposium of the IAG on Gravity, Geoid and Space Missions, Porto, Portugal, Book of Abstracts, p. 144., 3.9.
- NOVÁK P and GRAFAREND E: Global gravity field modelling using GRACE observables. Joint CHAMP/GRACE Science Meeting. GeoForschungsZentrum Potsdam, July 2004.
- NOVÁK P and GRAFAREND E: On the evaluation of global geopotential models. Geodätische Woche, Stuttgart, 12.-15.10.
- NOVÁK P and GRAFAREND E: On the global gravity field modelling using GRACE observables. IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- NOVÁK P, AUSTEN A, SHARIFI MA and GRAFAREND E: Recovery of spherical harmonic coefficients of geopotential from GRACE observables and modelling their temporal variations. Working Meeting of the GRACE project, Oberpfaffenhofen, February 2004
- NOVÁK P, SIMEK J and KOSTELCKÝ J: A feasibility of some transformation of terrestrial gravity anomalies for geophysical interpretations in Central Europe. European Geosciences Union 1st General Assembly, Nice, France, 25.-30.4.
- NOVÁK P, SIMEK J and KOSTELCKÝ J: Regional quasi-geoid for Central Europe and test of its high-frequency component. IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- REUBELT T, GÖTZELMANN M and GRAFAREND E: CHAMP-DACH: The CHAMP-Processor (GI Stuttgart) - Harmonic Analysis of the Earth's Gravity field by means of determined accelerations from CHAMP ephemerides. CHAMP/GRACE Geotechnologien Status Meeting, 27.2., Oberpfaffenhofen (GFZ Potsdam)

- REUBELT T, GÖTZELMANN M and GRAFAREND E: Determination of the Earth's Gravity Field by means of new GPS-tracked Satellite Missions CHAMP, GRACE and GOCE - a new algorithm for orbit analysis based on accelerations. Geomathematik-Workshop, Mathematisches Forschungsinstitut Oberwolfach, 23.-29.5.
- REUBELT T, GÖTZELMANN M and GRAFAREND E: Determination of the Earth's Gravity Field by means of new GPS-tracked Satellite Missions CHAMP, GRACE and GOCE - a new algorithm for orbit analysis based on accelerations. Finnish Geodetic Institute, Masala/Helsinki, Finnland, 12.8.
- REUBELT T, GÖTZELMANN M and GRAFAREND E: Neueste Ergebnisse der Schwerefeldbestimmung aus CHAMP-Daten mit dem „GIS-Beschleunigungs-Ansatz“. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- SASGEN I, HAGEDOORN J, KLEMMANN V, MARTINEC Z and WOLF D: Geoid-height change and vertical crustal motion due to present and past glacial changes in Antarctica. 2004 Spring Meeting of the AGU, Montreal, Quebec, EOS, Vol. 85, No. 17, Suppl., Abstract G41B-03, 20.5.
- SASGEN I, HAGEDOORN J, KLEMMANN V, MARTINEC Z and WOLF D: Temporal variations of the geoid and vertical crustal motion due to present and past glacial changes in Antarctica. Workshop on Geodynamik-Klimavariabilität, Potsdam, 13.5.
- SASGEN I, HAGEDOORN J, KLEMMANN V, MARTINEC Z and WOLF D: Temporal variations of the geoid and vertical crustal motion due to present and past glacial changes in Antarctica, Open Science Conference of the SCAR, Bremen, 27.7.
- SHARIFI MA and KELLER W: GRACE Gradiometer. IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- WITTEWERT T, AUSTEN G and BAUR O: High Performance Computing im Einsatz zur globalen Schwerefeldmodellierung. Geodätische Woche 2004, Stuttgart, 12.-15.10.
- WOLF D, KLEMMANN V, WÜNSCH J and ZHANG FP: A reanalysis and reinterpretation of tide-gauge, GPS, gravimetric and geomorphologic evidence of glacial-isostatic adjustment in the Churchill region, Canada. Joint CHAMP/GRACE Science Meeting, Potsdam, 6.7.
- WOLF D, KLEMMANN V, WÜNSCH J and ZHANG FP: Geodetic and paleo-shoreline evidence of glacial-isostatic adjustment in the Churchill region, Canada: reanalysis and inversion in terms of mantle viscosity. International Symposium of the IAG on Gravity, Geoid and Space Missions, Porto, Portugal, Book of Abstracts, p. 146, 2.9.
- WOLF D, KLEMMANN V, WÜNSCH J and ZHANG FP: Geodetic and paleo-shoreline evidence of glacial-isostatic adjustment in the Churchill region, Canada: reanalysis and inversion in terms of mantle viscosity. Geodynamik-Workshop, Hamburg, 28.9.
- WOLF D, MARTINEC Z, FLEMING K and SASGEN I: Detectability of global ice-volume changes by the GRACE gravity space mission. Geodätische Woche 2004, Stuttgart, 12.-15.10.

- WOLF D, WÜNSCH J, KLEMMANN V and ZHANG FP: A reanalysis and reinterpretation of geodetic and geomorphologic evidence of glacial-isostatic uplift in the Churchill region, Manitoba. 1st EGU General Assembly, Nice, France, Geophys. Res. Abstr., Vol. 6, Abstract EGU-A-01178, 26.4.
- WOLF D, WÜNSCH J, KLEMMANN V and ZHANG FP: A reanalysis and reinterpretation of geodetic and geomorphologic evidence of glacial-isostatic uplift in the Churchill region, Manitoba. 2004 Spring Meeting of the AGU, Montreal, Quebec, EOS, Vol. 85, No. 17, Suppl., Abstract G41A-04, 20.5.
- WOLF D: Climate, isostasy and gravity. Workshop on Geodynamik-Klimavariabilität, Potsdam, 14.5.
- WOLF D: Deformation, gravity and sea-level: indicators of processes in the system earth, ice and ocean. Workshop on Shaping Future of the Earth's Processes Modelling at the GFZ, Potsdam, 15.3.
- WOLF D: Glacial-isostatic adjustment in Iceland. GeoForschungsZentrum Potsdam, 7.9.
- WOLF D: Ice-mass balance, isostasy and viscosity. Geophysik-Treffen zur Schwere aus Satellitenmissionen (GRACE, GOCE), Frankfurt, 15.9.
- WOLF D: Sea level, glacial isostasy and gravity change. Department of Geophysics, Charles University, Prague, Czech Republic, 11.6.

Research Stays

- FINN G: Finnish Geodetic Institute, Masala, Finland, 8.-22.8.
- GRAFAREND E: Finnish Geodetic Institute, Masala, Finland, 26.7.-4.9.
- KELLER W: University of Queensland, Australia, 1.2.-18.4.
- KRUMM F: Geodetic and Geophysical Research Institute, Budapest, Ungarn, 6.-17.9.
- REUBELT T: Finnish Geodetic Institute, Masala, Finland, 8.-16.8.

Lecture Notes

- GRAFAREND E:
 Adjustment Theory III, Part 1 (Hypothesis Testing), ca. 175 pages
 Mathematical Geodesy, ca. 180 pages
 Map Projections, ca. 240 pages (plus 30 pages Attachments)
 Differential geometry for Geodesists,
 ca. 230 pages (http://www.uni-stuttgart.de/gi/education/diff-geo/lecture_notes.html)

HAUG G:

Property Valuation I,
ca. 35 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:

Coordinates and Reference Systems, ca. 80 pages (<http://gipc41.gis.uni-stuttgart.de/>)
Numerical Methods for Geodesists, ca. 60 pages (<http://gipc41.gis.uni-stuttgart.de/>)
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/>)

KRUMM F:

Mathematical Geodesy, ca. 180 pages

SCHÖNHERR H:

Official Surveying and Real Estate Regulation,
ca. 65 pages (http://www.uni-stuttgart.de/gi/education/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:**

CHAMP/GRACE Geotechnologien Status Meeting,
Oberpfaffenhofen (GFZ Potsdam), 27.2.
European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
Geodätische Woche 2004, Stuttgart, 12.-15.10.

BAUR O:

GOCE-GRAND Projekttreffen, GeoForschungsZentrum Potsdam, 29.-30.3.
European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Statusseminar zum GEOTECHNOLOGIEN Themenschwerpunkt „Beobachtung des Systems Erde aus dem Weltraum“, Potsdam, 5.7.
Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.

CAI J:

Workshop zum Gutachten „Einführung von ETRS89 in Baden-Württemberg“, Landesvermessungsamt Baden-Württemberg, Stuttgart, 30.1.
Projektbesprechung über GRACE und GOCE, Deutsches Geodätisches Forschungsinstitut, München, 13.-14.9.
European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Humboldt Symposium „Moderne Methoden der multivariaten Messdatenanalyse“, Berlin, 11.-12.8.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.

FINN G:

European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.
IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.

GÖTZELMANN M:

CHAMP/GRACE Geotechnologien Status Meeting, Oberpfaffenhofen (GFZ Potsdam), 27.2.
European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Statusseminar zum GEOTECHNOLOGIEN Themenschwerpunkt „Beobachtung des Systems Erde aus dem Weltraum“, Potsdam, 5.7.
Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.

GRAFAREND E:

Wissenschaftliche Beiratssitzung, Deutsches Geodätisches Forschungsinstitut, München, 25.6.
Projektbesprechung über GRACE und GOCE, Deutsches Geodätisches Forschungsinstitut, München, 13.-14.9.
INTERGEO, Stuttgart, 13.-15.10.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
Geomathematik-Workshop, Mathematisches Forschungsinstitut Oberwolfach, 23.-29.5.

KELLER W:

5th European Conference on Synthetic Aperture Radar, EUSAR2004, ULM, Germany, 25.-27.5.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.

KRUMM F:

Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.

NOVÁK P:

CHAMP/GRACE Geotechnologien Status Meeting, Oberpfaffenhofen (GFZ Potsdam), 27.2.
European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
Geodätische Woche 2004, Stuttgart, 12.-15.10.

REUBELT T:

CHAMP/GRACE Geotechnologien Status Meeting, Oberpfaffenhofen (GFZ Potsdam), 27.2.
Geomathematik-Workshop, Mathematisches Forschungsinstitut Oberwolfach, 23.-29.5.
Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
Geodätische Woche 2004, Stuttgart, 12.-15.10.
INTERGEO, Stuttgart, 13.-15.10.

SHARIFI MA:

IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.

WOLF D:

- Final SEAL Project Meeting, GFZ Potsdam, 27.1.
- Workshop on „Shaping future of the earth's processes modelling at the GFZ“, GFZ Potsdam, 15.3.
- European Geosciences Union 1st General Assembly, Nizza, Frankreich, 25.-30.4.
- Workshop „Geodynamik und Klimavariabilität“, GFZ Potsdam, 13.-14.5.
- Joint CHAMP/GRACE Science Meeting, GeoForschungsZentrum Potsdam, 5.-8.7.
- IAG International Symposium „Gravity, Geoid and Space Missions“, Porto, 30.8.-3.9.
- Geodynamik-Workshop, Hamburg, 27.-29.9
- Geophysik-Treffen zur Schwere aus Satellitenmissionen (GRACE, GOCE), Frankfurt, 15.9.
- Geodätische Woche 2004, Stuttgart, 12.-15.10.

Activities in National and International Organizations**ENGELS J:**

- Member Special Study Group 4.189 (IAG): „Dynamic theories of deformation and gravity fields“

FINN G:

- Member board of managers Stuttgarter Studentenwerk e. V.
- Member Internationale Union für Geophysik und Geodäsie (IUGG)
- Member IAG Special Study Group „Spatial and Temporal Gravity Field and Geoid Modeling“
- Member European Geosciences Union (EGU)

GRAFAREND E:

- Member Prüfungsausschuss der Fakultät Luft- und Raumfahrttechnik und Geodäsie an der Universität Stuttgart
- Member Fakultäten Luft- und Raumfahrt und Geodäsie, Mathematik und Physik (kooptiert), Bau- und Umweltingenieurwissenschaften (kooptiert) der Universität Stuttgart
- 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
- Member Deutsche Geodätischen Kommission bei der Bayerischen Akademie der Wissenschaften
- Member Deutsche Physikalische Gesellschaft
- Member Deutsche Geophysikalische Gesellschaft
- Member Gauß-Gesellschaft e.V.

Member Deutscher Verein für Vermessungswesen
Member Deutscher Markscheiderverein
Member Royal Astronomical Society
Member American Geophysical Union
Member Bernoulli 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

NOVÁK P:

Member IAG Special Study Group „Forward gravity field modelling and global databases“
Member Editorial board of Journal of Geodesy
Member IAG Study Group „Inverse problems and global optimization“
Member IAG Study Group „Satellite gravity theory“

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

Education - Lecture/Practice/Training/Seminar

Analytic Orbit Computation of Artificial Satellites (Grafarend)	2/1/0/0
Applied Graph Theory (Grafarend)	2/1/0/0
Coordinates and Reference Systems (Keller)	1/1/0/0
Foundations of Satellite Geodesy (Keller)	1/1/0/0
Geodesy and Geodynamics (Grafarend)	2/1/0/0
Geodetic Reference Systems (ICRS-ITRS) for Satellite Geodesy and Aerospace (Richter)	2/1/0/0
Geodetic Seminar I,II (Fritsch/Grafarend/Keller/Kleusberg/Möhlenbrink/Wolf)	0/0/0/4
Gravimetry and Earth Tides (Grafarend)	2/1/0/0
Integrated Field Work Geodesy, Navigation, Photogrammetry and Surveying (Fritsch/Grafarend/Keller/Kleusberg/Möhlenbrink/Wolf)	10 days
Map Projections (Krumm)	1/1/0/0
Mathematical Geodesy (Krumm)	2/2/0/0
Modeling and Data Analysis in the Field of Physical Geodesy (Engels)	2/1/0/0
Official Surveying and Real Estate Regulation (Schönherr)	2/0/0/0
Physical Geodesy IV (Keller)	4/2/0/0
Potential Theory and Special Functions (Keller)	2/1/0/0
Real-Estate/ Property Valuation I,II (Haug)	2/1/0/0
Stochastic Processes for Geodesists (Keller)	2/1/0/0



Institute of Navigation

Breitscheidstrasse 2, D-70174 Stuttgart,
 Tel.: +49 711 121 3400, Fax: +49 711 121 2755
 e-mail: ins@nav.uni-stuttgart.de
 homepage: <http://www.nav.uni-stuttgart.de>

Head of Institute

Prof. Dr.-Ing. A. Kleusberg
 Deputy: Dr.-Ing. Karl-Heinz Thiel
 Secretary: Helga Mehrbrodt
 Emeritus: Prof. em. Dr.-Ing. Ph. Hartl

Staff

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

EDP and Networking

Regine S c h l o t h a n

Laboratory and Technical Shop (ZLW)

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

Guest Research Staff

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

External teaching staff

Dr.-Ing. Gerhard S m i a t e k - Fraunhofer Institute for Atmospheric Environmental Research

Dr.-Ing. Volker L i e b i g - Programme Directorate DLR-GE

Dr.-Ing. B r a u n - RST Raumfahrt Systemtechnik AG, St.Gallen

Research Projects

Close Range Laser Scanning

The experiments were proceeded with PLP-CAM (integrated panoramic camera, laser scanner, position and orientation system) introduced in the last report. The possibilities of the use of „low-cost“ Position and Orientation Systems (POS) were studied. Especially for surveying tasks of small volumes further alternatives for the position and orientation determination were studied, such as e.g. tracking of special targets on PLP-CAM by an external laser scanner and the application of ARTtrack system. In Figure 1 the position and orientation determination is realized by using a reprogrammed 3D-LS as tracking sensor. Figure 2 shows a laboratory with ARTtrack. Most attention was turned to the synchronization of the different independent sensors. Figure 3 depicts realized synchronization when ARTtrack was used.



Figure 1: Position and Orientation Determination by external 3D-LS

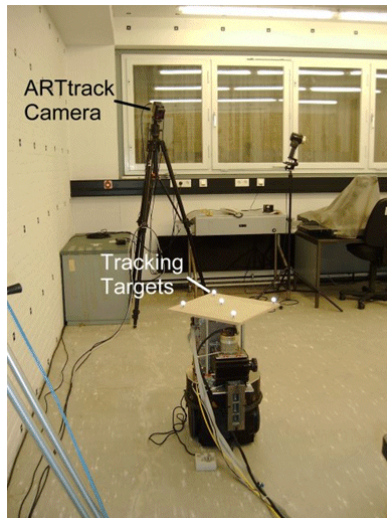


Figure 2: Position and Orientation on Determination by ARTtrack

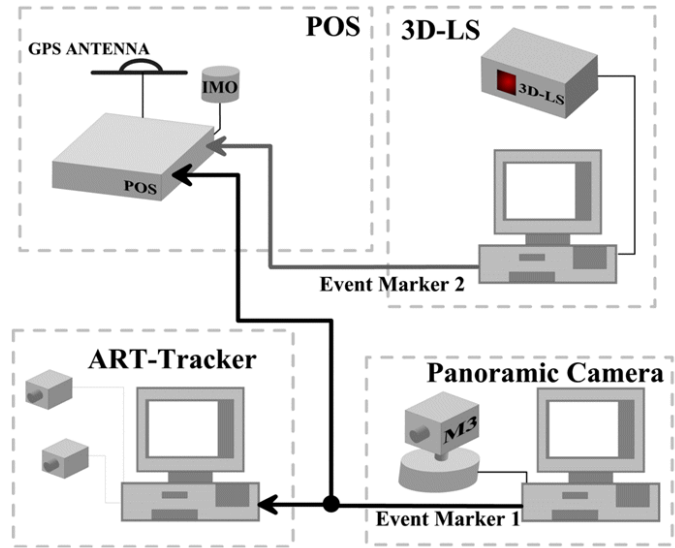


Figure 3: Synchronization

Navigation with integrated microelectromechanical systems (imemsR) and micromagnetic integrated circuits

Recently the development of very small electronic devices which contain accelerometers, angular rate sensors and magnetic sensors lead to new possibilities particularly in navigation systems.

These sensors are used now more than a decade in motor vehicles. Because of mass production they can be acquired at reasonable prices.

In a first step we analyzed the properties of the different sensors in respect of precision, temperature drift, noise response, dependence of supply voltage etc. In an all-aluminium cube we have mounted the printed boards with the sensors, aligned in three orthogonal axes (Figure 1 and 2). First horizontal stationary measurements and measurements on a turntable provided satisfactorily results.

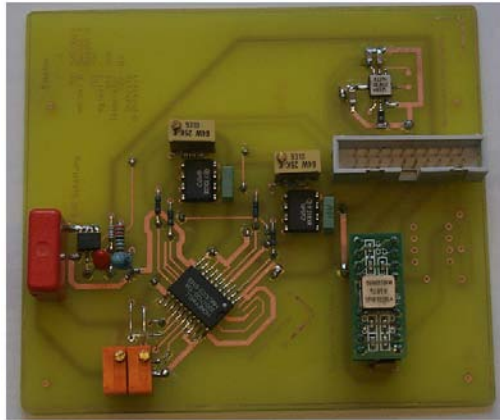


Figure 1



Figure 2

Setting-up of GPS Reference Stations and Investigating the Effects of Antenna Radome

The precisions and accuracies at which the reference stations are established and monitored are very high. All possible sources of error to which the antennas and receivers at the site are susceptible to, must be identified and minimised or eliminated. This include Phase Centre Variation (PCV) and multipath. To protect them from bad weather and vandalism, the reference station antennas are usually covered. The PCV patterns are further complicated from the fact that addition of antenna covers (radomes) are known to have effects on the positions and the existing several correction models.

In this project, two reference stations were established and an investigation on the effect of conical radome on one of the reference stations was carried out. A baseline of about 5 metres was set-up on top of the building housing the Institute of Navigation. At one end of the baseline was station 1, mounted with a choke ring antenna, and the other end station 2, mounted with a compact L1/L2 antenna. Twenty four hour GPS observations at a data rate of 2 seconds were carried out in six consecutive days. The antenna setting for every two days was the same. Part of the data files collected on day 1 was used to fix the positions of the two reference stations with respect to the SAPOS network. A further analysis was done with the six day data files to determine the effect of the radome and the radome mount plate on station 1.

The solutions obtained show that the reference stations were successfully established and that the conical radome has a negligible effect of about 1.5 mm on the height component of station 1.



Figure 1: The antennas of station 1 and 2 on top of the institute

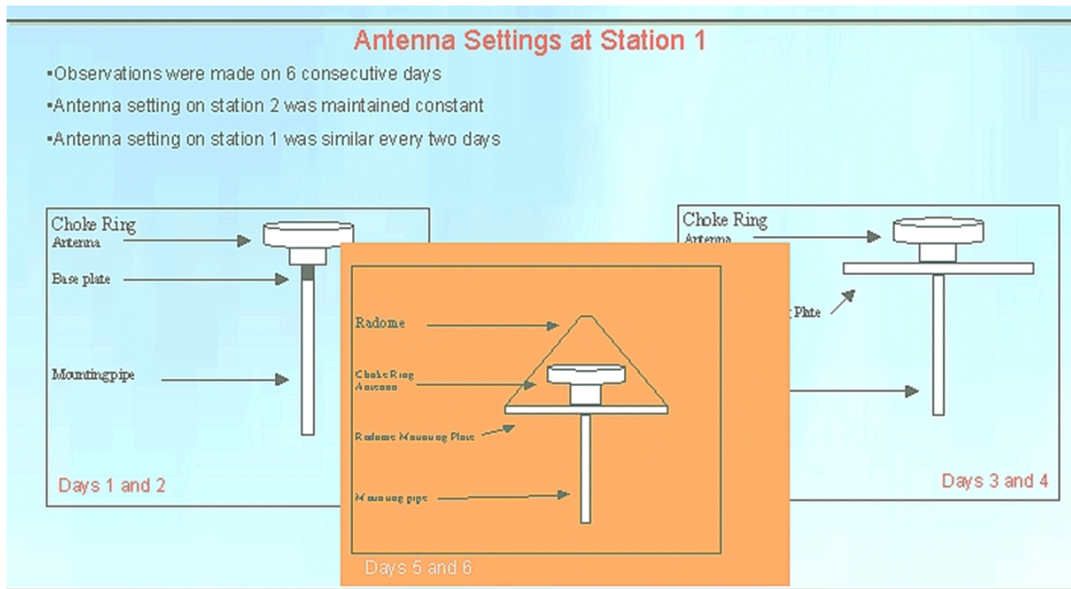


Figure 2: The antenna set-ups at station 1 during the data collection process

Remote sensing - PROJECT ERLLEN-E

The TerraSAR-X Satellite, developed in Germany, will be available in April 2006. TerraSAR-X will provide high resolution radar remote sensing data that allow an accurate determination of land use 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 ERLLEN-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). ERLLEN-E is a remote sensing project of the ProSmart campaign coordinated by the InfoTerra company. ERLLEN-E is part of the environmental research.

A set of multi-temporal multi-frequency and multi-polarisation L-Band and X-Band ESAR-data have been made available for the INS test area Ehingen, located in the „Schwäbische Alb“ region. These data have also been converted into TerraSAR- simulation data. The data have been acquired in two different vegetation periods. A detailed ground truth data acquisition of more than 1500 agricultural fields has been performed by the INS during the periods of the SAR-acquisition. Additional ground truth information for the forested areas and the heath land has been extracted from ortho-photos.

The SAR-data potential has been demonstrated with respect to the needs of typical reference clients: The Ministerium für Ländlichen Raum, Ernährung, Landwirtschaft und Forsten Baden-Württemberg (MLR) and the Landesamt für Flurneuordnung Baden-Württemberg (LFL) as well as the Landesvermessungsamt Baden-Württemberg (LV) have agreed a partnership to define their requests for the future remote sensing data. They defined the aims for the project and gave an evaluation of the results.

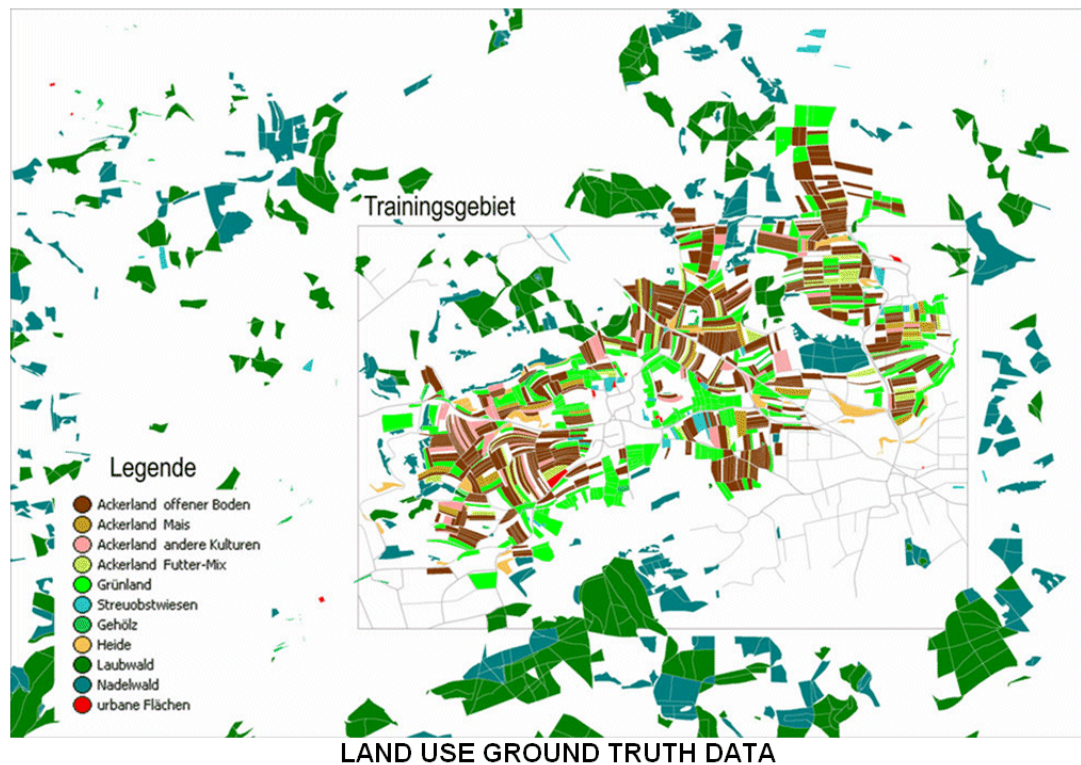
A multi-layer hierarchical classification process was developed by INS. We applied segment based classifiers (eCognition 3.0 software) for the classification. A statistical analysis of the radar features was performed for all different land cover types to define qualified customised channels together with suitable class membership functions for the classification hierarchy.

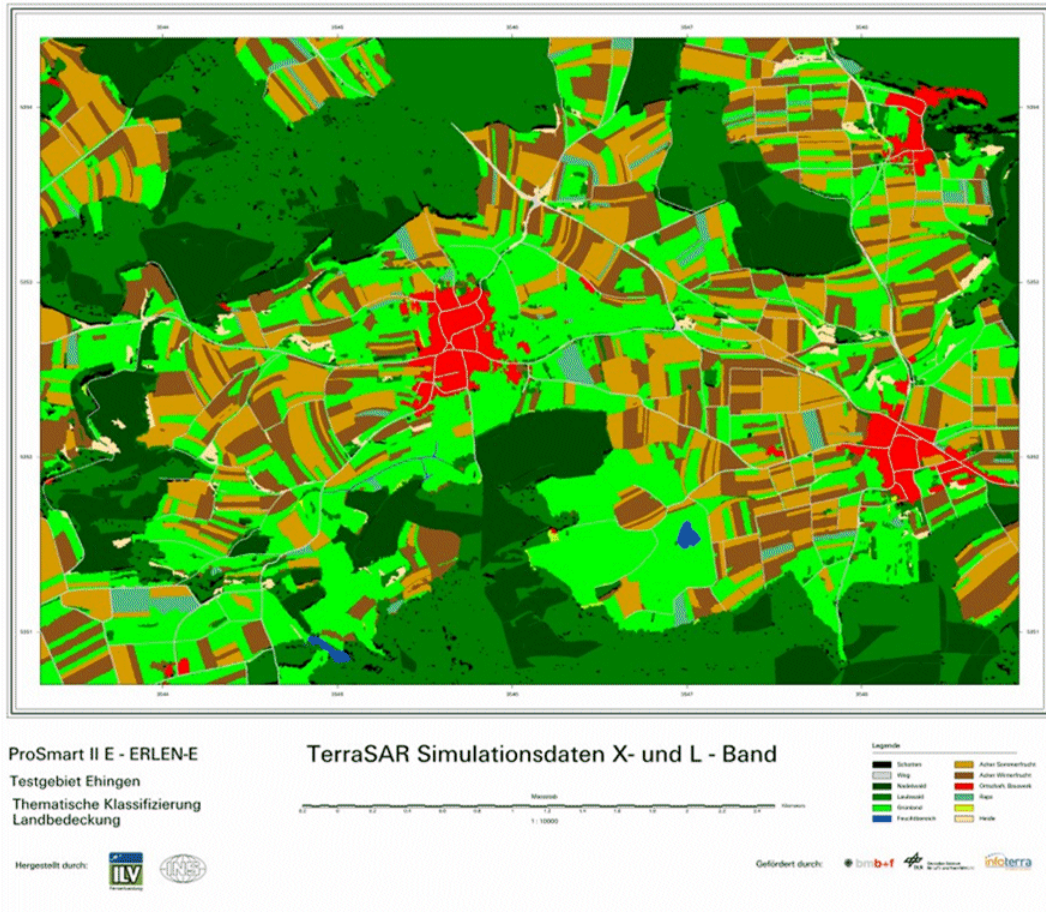
Classification accuracies of more than 98% could be achieved for the separation of forest and open land. Coniferous forest and deciduous forest were identified with 90% accuracy. The agricultural fields could be separated from the grassland with 90% accuracy. Due to the fact that the radar data were only available for an early stage of the vegetation development (March and May), the individual agricultural crops could not be separated from one another. It was however possible to isolate three groups (SUMMER CROPS, WINTERCROPS and RAPE) with an accuracy of 85% to 90%.

Heath and marsh could be separated from grassland. A mono-temporal classification within the grassland mask allowed the discrimination of short cut grass from high grass. The information of several mono-temporal grassland classifications shows the intensive or extensive use of the grassland.

The accuracies achieved are sufficient for many applications. The classification accuracies can be further improved if a continuous monitoring of the whole vegetation period will be available.

With ERLIN-E it could be demonstrated that it is possible to develop a new method for the continuation of the ATKIS-landuse data, based on radar remote sensing data. The results of the ERLIN-E project have been presented to a large number of interested users in the framework of two discussion forums for TerraSAR-users held at Stuttgart [1] and Berlin [2].





THEMATIC CLASSIFICATION of LANDUSE

Publications and Presentations

- Anwender-Forum TerraSAR. „Neue Möglichkeiten zur Beschaffung von Geoinformationen.“ Universität Stuttgart am 17. September 2004.
- Kleusberg, A. (2004): Effect of temporal correlation on accuracy estimation in GPS relative positioning. *Journal of Surveying Engineering* (129)1, 28-32.
- Kleusberg, A.: Navigation für mobile Menschen, Presentation within the scope of the Intergeo 2004 in Stuttgart.
- Seifert, A.; Kleusberg, A.: An Alternative GPS/INS Integration Method, Proceedings of 11th Annual Saint Petersburg International Conference on Integrated Navigation Systems, Saint Petersburg, Russia, May 2004.

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
- Adjunct Professor, University of Main, USA

Education (Lecture / Practice / Training / Seminar)

Introduction to Navigation (Kleusberg)	2/0/0/0
Flight Navigation und Avionic (Schöllner, Wehr)	2/0/0/0
Introduction to Electronics for Geodesists (Wehr)	2/1/0/0
Electronics for Geodesists (Wehr)	2/1/0/0
Remote Sensing I (Thiel)	1/1/0/0
Remote Sensing II (Smiatek)	1/1/0/0
Navigation I, II (Kleusberg)	3/1/0/0
Navigation III / Radartechniques (Braun)	2/1/0/0
Electrical Engineering for Geodesists (Schöllner)	3/1/0/0
Practical Course in Navigation (Schöllner)	0/0/2/0
Practical Course in Electrical Engineering (Wehr, Selig)	0/0/2/0
Practical Course in Electronics (Wehr, Selig)	0/0/4/0
Applied Kalman Filtering (Schöllner)	2/0/0/0
Software Development (Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink)	0/0/4/0
Geodetic Seminar I, II (Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink)	0/0/0/4
Satellite Systems and Programs in Remote Sensing (Liebig)	2/0/0/0



Institute for Photogrammetry

Geschwister-Scholl-Str. 24/D, D-70174 Stuttgart,
Tel.: +49 711 121 3386, Fax: +49 711 121 3297
e-mail: firstname.secondname@ifp.uni-stuttgart.de
url: <http://www.ifp.uni-stuttgart.de>

Head of Institute

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

Working Groups at the ifp:

Geoinformatics

Head: Dr.-Ing. Volker Walter	GIS and Remote Sensing
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. Darko Klinec	Pedestrian Navigation
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 Alshwabkeh	Heritage Documentation
Dipl.-Ing. Sarah Schuhmacher	Terrestrial Laser Scanning

External teaching staff

Prof. Volker Schäfer, Ltd. Verm. Dir., Wirtschaftsministerium Baden-Württemberg

Research Projects

Geoinformatics

Object-based classification of integrated multispectral and LIDAR data for change detection and quality control in urban areas

A lot of research in the field of automatic data acquisition, update and quality control of spatial databases has been done. One of the main problems is, that the used methods are often based on a high number of data dependent tuning factors, like thresholds for example. This leads to the situation that the approaches work very well for specific test areas but become problems if there are variations in the input data. But especially remote sensing data have a very high variability because of different seasons, positions of the sun, atmospheric conditions, soil humidity, etc. In order to solve the problem of data dependent tuning factors, we suggest an approach that is based on the evaluation of automatically generated training areas (supervised classification). Supervised approaches are already used for pixel-based classification of remote sensing data since many years.

Another problem of the automatic interpretation of remote sensing data is that most of the existing approaches work only in rural areas. The interpretation of urban areas is still a problem because of the complexity of these areas. One approach to overcome this problem is to increase the information content in the input data. The information content is limited mainly by the spatial and spectral resolution of the images. If we combine data from different sources that have different spatial or spectral characteristics, it can be possible to detect objects that are not detectable with only one of the sources. In our approach we combine multispectral and laser data. Using object information from an existing GIS database further supports the image interpretation.

The approach (see Figure 1) consists of two classification steps. In a first step, a pixel-based classification is calculated. The result of the pixel-based classification as well as the input channels (the multispectral and LIDAR data) are used as an input for the object-based classification that classifies not single pixels but groups of pixels that represent already existing objects in a GIS database. Both classification steps are based on a supervised maximum likelihood classification.

The pixel-based classification is a well-known approach and is not described further. In the following we describe how the object-based classification is calculated. An n -dimensional feature vector f describes each object in the object-based classification. The components of this vector are measures m_i that describe the spectral and textural characteristics of an object:

$$f = (m_1, m_2, \dots, m_n)^T$$

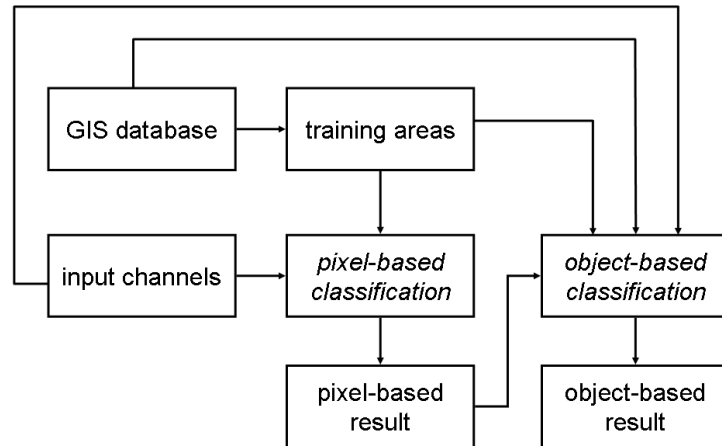


Fig 1: Workflow.

In this research we distinguish between residential and industrial settlement objects. The following five characteristics are used in order to decide if a settlement object represents a residential or an industrial area (these characteristics are especially valid in Germany - in other countries they may differ):

- ▷ $m_1 = \text{average size of houses}$: in industrial areas houses are typically very large whereas in residential areas houses are typically smaller
- ▷ $m_2 = \text{average roof slope of houses}$: in industrial areas are typically houses with flat roofs whereas in residential areas are typically houses with sloped roofs
- ▷ $m_3 = \text{percentage of trees}$: trees can be found very often in residential areas but only rarely in industrial areas
- ▷ $m_4 = \text{percentage of sealed ground}$: the percentage of sealed ground is typically higher in industrial areas as in residential areas
- ▷ $m_5 = \text{textural appearance}$: the textural appearance of industrial areas is more homogenous as in residential areas

Not all characteristics must be valid for an object. Very often only three or four characteristics apply for a specific object but this is not a problem because the object-based classification classifies the object to the most likely class. This is a very robust approach that can handle also fuzzy descriptions of objects. The decision to which object class K_i an object with vector f belongs is calculated with the distances d_i :

$$d_i(f) = p_1(K_i)p_2(f|K_i)$$

p_1 are the apriory-probabilities that an object is classified to an object class K_i . These probabilities are normally unknown and have to be estimated. p_2 are the conditional probabilities that an object with vector f is classified to an object class K_i . The distances are calculated for each object class and the object is classified to that object class where the distance d_i has its maximum. In the maximum likelihood classification an n -dimensional Gaussian distribution is assumed and the conditional probabilities are approximated with:

$$d_i(f) = -\frac{1}{2\pi^{\frac{n}{2}}} \det(C_i)^{-\frac{1}{2}} \exp\left(-\frac{1}{2}(f - z_i)^T * C_i^{-1} * (f - z_i)\right)$$

where C_i is the covariance matrix and z_i is the mean vector of all training vectors that are derived automatically from a GIS database in order to avoid the time consuming task of manual acquisition.

The approach was tested on a test area with 24 km² that contains 190 residential settlement objects and 84 industrial settlement objects. The test site is Vaihingen/Enz that is located in the southern part of Germany and represents a rural environment and smaller settlements. The multi-spectral data were captured with the DMC camera system, which is a CCD-matrix based camera system with 4 multispectral channels: R, G, B and Near Infrared. The LIDAR data were captured with the TopScan system and have an average point distance of approximately 1m. The LIDAR data and the multispectral data were resampled into regular raster images with a pixel size of 1m. The tests were carried out with ATKIS datasets. ATKIS is the German national topographic and cartographic database and captures the landscape in the scale 1:25,000.

In a manual classification all residential and industrial settlement objects of the database were compared with the images and subdivided into the classes *OK*, *unclear* and *not OK* (see Figure 2). The class *OK* contains all objects with no change in the landscape (234 objects). The class *unclear* contains all objects where it is unclear if there is a change or not without evaluating additional sources (37 objects). The class *not OK* contains all objects where definitely a change in the landscape happened or which were captured wrongly.

The result of the automatic classification can also be seen in Figure 2. The automatic approach classified 214 objects of the class *OK* to same object class as they were collected in the GIS database. The classification of the objects of the class *unclear* reflects the situation that even a human operator is not able to classify these objects unambiguous: 24 objects were classified to the same object class as they were collected and 13 were classified to the other class. All objects of the class *not OK* were classified to the other class, as they were collected. It is very important for a change detection approach that all objects where definitely a change has happened, are found by the program. Otherwise an operator has to overwork the whole result of the automatic approach which is nearly as much work as a manual change detection.

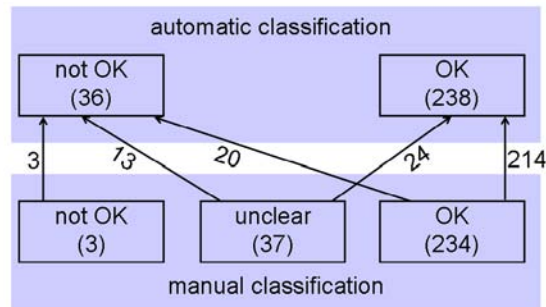


Fig 2: Classification result.

Data-driven Matching of Geospatial Schemas

In recent years, tendencies to provide global, generic geospatial information platforms that are accessible by different kinds of GIS applications can be observed. Building up such platforms is basically identical with the task of integrating existing local, heterogeneous databases into one system that allows access to the associated data sources. Mostly, such an infrastructure is realized as a federated database system which acts as a single, homogeneous database to the global applications, facilitating a common view on the underlying data.

A data-driven approach for the matching of spatial schemas has been implemented for street data of the Geographic Data Files (GDF) schema and the schema of the Authoritative Topographic Cartographic Information System (ATKIS) of Germany. GDF is an international standard that has especially been developed for car navigation applications and thus is used to describe and transfer street networks and street related data whereas ATKIS contains data of different topographic units like settlements, vegetation, traffic, etc. Both data models capture street objects as linear features in approximately the same scale (1:25,000).

Generally, the approach of this work is based on the idea to build up explicit relations between multiple representations, i.e. between corresponding digital instances of different geospatial databases which have been captured according to different conceptual schemas. These relations have to describe, how consistent/inconsistent two corresponding representations are with respect to geometry, topology or thematic properties. Within this work, they are called Multi-Representational Relations or MRep Relations in short.

Thus, a formal structure has to be built up for MRep Relations at first. Afterwards, MRep Relations must be generated for real data which are available in multiple representations. By analyzing the MRep Relations and especially the affiliations of the instances constituting corresponding representations to object classes in their source schemas (i.e. ATKIS and GDF), schema similarities can be detected (see Figure 3).

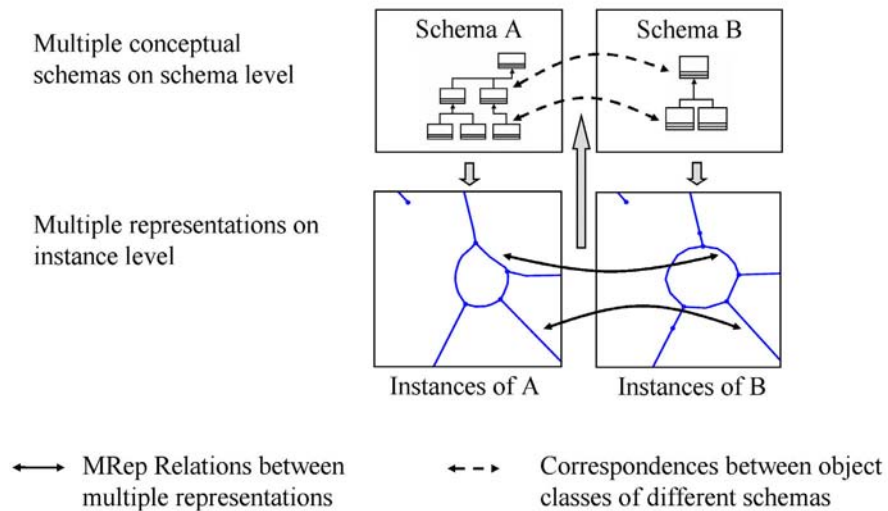


Fig. 3: The basic assumption of our approach is deriving correspondences between different conceptual schemas by analyzing the MRep Relations.

For two structurally similar test areas in the inner city of Stuttgart/Germany, each about 4 square kilometers in size, street data sets of ATKIS and GDF were available in multiple representations. The ATKIS object instances either were associated with the classes „Strasse“ („Street“), „Fahrbahn“ („Lane“) or „Weg“ („Way“), whereas the object instances of GDF consisted of three types of Road Elements: Road Elements which belonged to a complex feature of the object type „Road“, Road Elements which belonged to a complex feature of the object type „Intersection“, or Road Elements which did not belong to a complex class.

For the acquisition of MRep Relations, a semi-automatic software, the so-called Relation Builder Toolbox, has been developed. Using this tool, a human operator can manually select the instances of corresponding representations by analyzing mainly geometric and topologic criteria (see Figure 4).

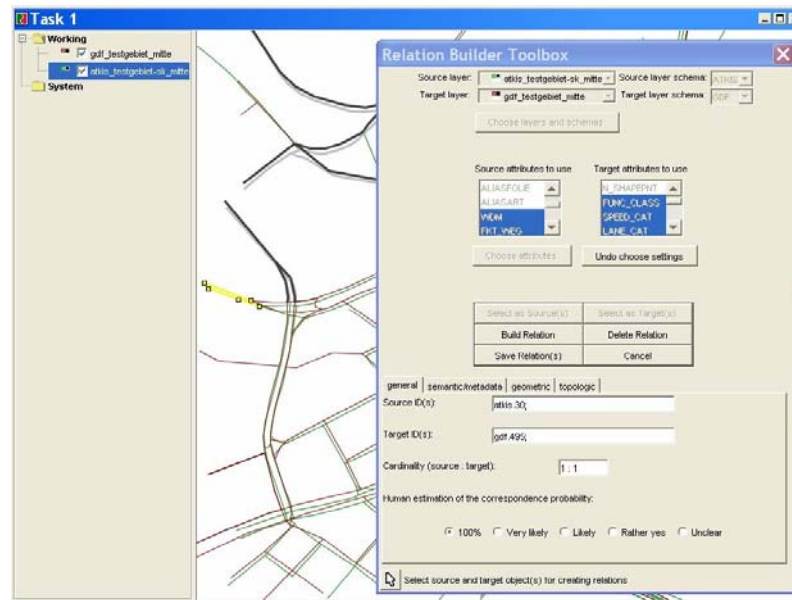


Fig. 4: The Relation Builder Toolbox allows selecting corresponding representations and automatically calculates MRep Relations between them.

The basic assumption of the schema matching approach is that if instances of one data set belonging to a certain object class in schema a are mainly assigned to instances of another data set belonging to a certain object class in schema b , we do have clear evidence for a semantic correlation of the respective object classes of the different schemas.

Considering this assumption, algorithms have been developed that are able to detect these semantic correspondences on the schema level between ATKIS and GDF by analyzing the information stored within the MRep Relations that have been generated for the test areas mentioned in the previous section.

As it can be seen in Figure 5, significant inter-schema correspondences can be detected. For example, all ATKIS Way representations were only assigned to representations of Road Elements. Applying a set-based terminology here, we can say that the Way object class is semantically included in the Road Element class ($\text{Road Element} \subseteq \text{Way}$). Furthermore, no Road or Intersection representations have been matched with Way objects and vice versa. Thus, these object classes can be considered as being disjoint ($\text{Intersection} \neq \text{Way}$, $\text{Road} \neq \text{Way}$). For all other correlations semantic overlaps can be observed (e.g. $\text{Road} \cap \text{Lane}$, $\text{Road Element} \cap \text{Street}$) with the degree of overlap varying from very high (like $\text{Street} \rightarrow \text{Road Element}$) to very low (like $\text{Street} \rightarrow \text{Road}$). Obviously, no equivalence relations of the type $\text{Class}_{\text{ATKIS}} \equiv \text{Class}_{\text{GDF}}$ could be detected between

the investigated object classes. For human operators, the results of the schema matching approach seem to be reasonable, i.e. knowing the semantics of the schemas or the object classes investigated, respectively, the correspondences found can basically be confirmed.

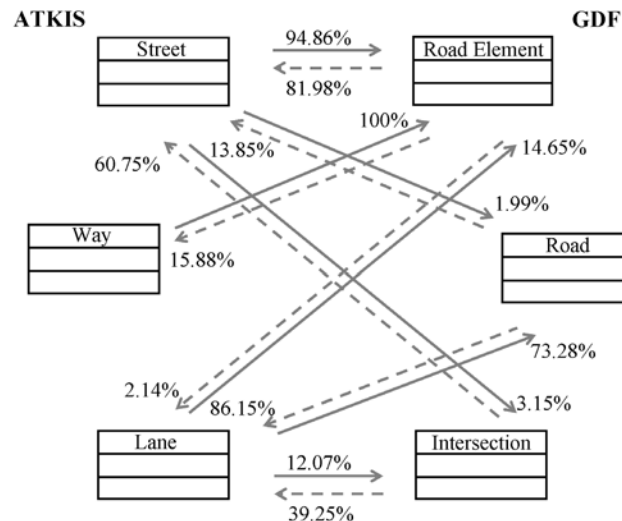


Fig. 5: Correlations of ATKIS classes (continous lines) and GDF classes (dashed lines) as derived by the data-driven schema matching (all MRep Relations considered).

Photogrammetry and Remote Sensing

Digital airborne camera calibration and validation

Comparing the today's situation in digital airborne photogrammetric imaging to year 2000, where the very first commercial digital large format airborne sensors ADS40 (Leica Geosystems) line scanner and DMC (ZI-Imaging now Intergraph) frame based camera were launched into the market, an increase in number of new digital airborne sensors (some of them already introduced into operational use) is clearly obvious from the last 5-years period. And the advent of new airborne system is still an ongoing and very viable process! From photogrammetric point of view mainly the medium and large format systems are of interest. Besides the already fairly well introduced ADS40 and DMC systems, the Ultracam_D (Vexcel) and DiMAC (DiMAC Systems) have to be mentioned as new-comers for large format multi-head frame based cameras. On the other hand new line scanners are showing up like the JAS-150 (Jenaoptronik), 3-DAS-1 scanner (Wehrli Ass.)

and the Starimager (Starlabo Corp.) line scanning system which was formerly known as TLS system. Besides this, medium format systems (typically based on medium format analogue camera housings extended with digital sensor backs using 4k x 4k CCD arrays or higher) can be found as stand-alone systems or in combination with other airborne sensors (multi-sensor platforms) like laser scanners. There are several other systems (experimental or operational) available and in use without having the big market attention yet.

Reflecting this situation the following major trends can currently be observed:

- ▷ The world of digital airborne imaging is very heterogeneous, especially when comparing the different design of new digital systems to the classical airborne film cameras. Additionally, such digital image sensors quite often are used as part of multi-sensor systems supplemented with other components like GPS/inertial sensors or laser scanners. This somehow makes the systems more complicated to handle.
- ▷ Many digital airborne systems are beyond their experimental stage and already used in practice worldwide. In future, a strongly increase in use of new systems has to be expected, where the spectrum of applications will become broader, i.e. from standard photogrammetric mapping tasks to other applications like land use monitoring, disaster and risk assessment, forestry, tourism, real estate search and promotion to fully exploit the potential of digital airborne imaging
- ▷ The advantages of large format image recording based on high-end high-performance digital sensors are well known. Nonetheless, for smaller area projects or due to less financial conditions or risks there definitely is a market for medium to smaller format cameras to be used in a more flexible and cost effective way.

From this background a certain need is obvious to provide and transfer fundamental knowledge on the characteristics of such digital sensor systems and their proper use in practice to the growing user community - especially as it has to be expected that many of them will be not familiar with those new digital airborne sensor technologies or not even more with airborne imaging at all.

When focussing on object reconstruction from images special attention has to be laid on the topic of camera calibration and overall system calibration. This in general is one essential necessity in the process of image data processing. Since the design of the new digital sensors is quite different compared to the analogue cameras used so far the classical methods of sensor calibration have to be extended and modified. Even more important, these new methodologies have to be transferred to the system users and additional recommendations on optimal system calibration and validation for the different system set-ups have to be specified. This was the motivation to establish a network of experts on Digital Camera Calibration in the framework of EuroSDR (European Spatial Data Research). Within the last year the current status of digital camera calibration has been thoroughly investigated and documented in an extensive report (digitally available at <http://www.ifp.uni-stuttgart.de/eurocdr/EuroSDR-Phase1-Report.pdf>). All this finally leads to the following status overview in brief:

- ▷ A decreased use of standard collimator based lab calibration seems to be evident, whereas the importance of in-situ calibration is definitely increasing.
- ▷ Such in-situ calibrations, i.e. self-calibration determined from dedicated calibration flights, have to be done by the users regularly, in order to validate and refine the manufacturers system calibration parameters.
- ▷ Due to the fact, that such techniques are not as common in the traditional airborne photogrammetry field, clear knowledge deficits, concerning the features and advantages of system calibration in flight, are present right now on the users' side.

These statements basically are the motivation for a second experimentally oriented test phase, where real test flight data from digital systems are offered to the network members to be evaluated from their individual software processing chains and knowledge. So far, the project has access on several data sets from DMC, Ultracam_D and ADS40 systems. These data sets were kindly provided by national mapping agencies and private companies. A very promising one was acquired by TerraTec/Norway. This data will be distributed within the network and the individual network members should then apply their software methodologies and knowledge to obtain overall best system calibration for the individual system at the evaluated flight campaign. These results are then validated by the Pilot Centre of the project and documented and discussed within the final project report.

The technical aspects of calibration have to be treated with different priority. At the beginning of the empirical analysis focus is laid on geometry. Later on investigations concerning radiometric aspects, colour and general aspects of image quality are covered. The long-term perspective of the network activities is geared towards the development of optimal calibration setups, which is appropriate for individual sensor system designs. The goal is not to compare between individual camera systems, but to transfer such new information on calibration to a wide range of users who then can be adopted to any other digital camera of comparable system architecture. In general, experiences within this network have already resulted in the fruitful interaction between system providers and system users. Since camera calibration has a world-wide interest, the EuroSDR initiative has a close link with other calibration activities, mainly in the United States. From this point the project not only supports camera users but system providers also in designing their optimal calibration process for newly developed digital imaging systems. First results on the experimental tests will be expected in 2005.

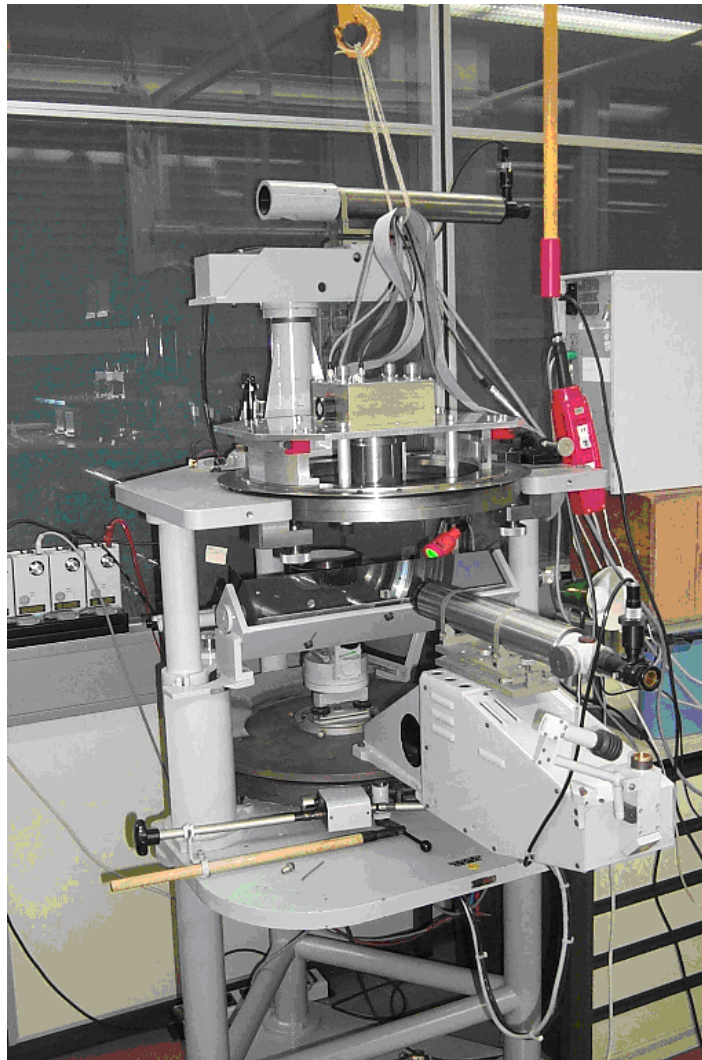


Fig. 6: Goniometer calibration of individual DMC camera head at Zeiss (© Zeiss)

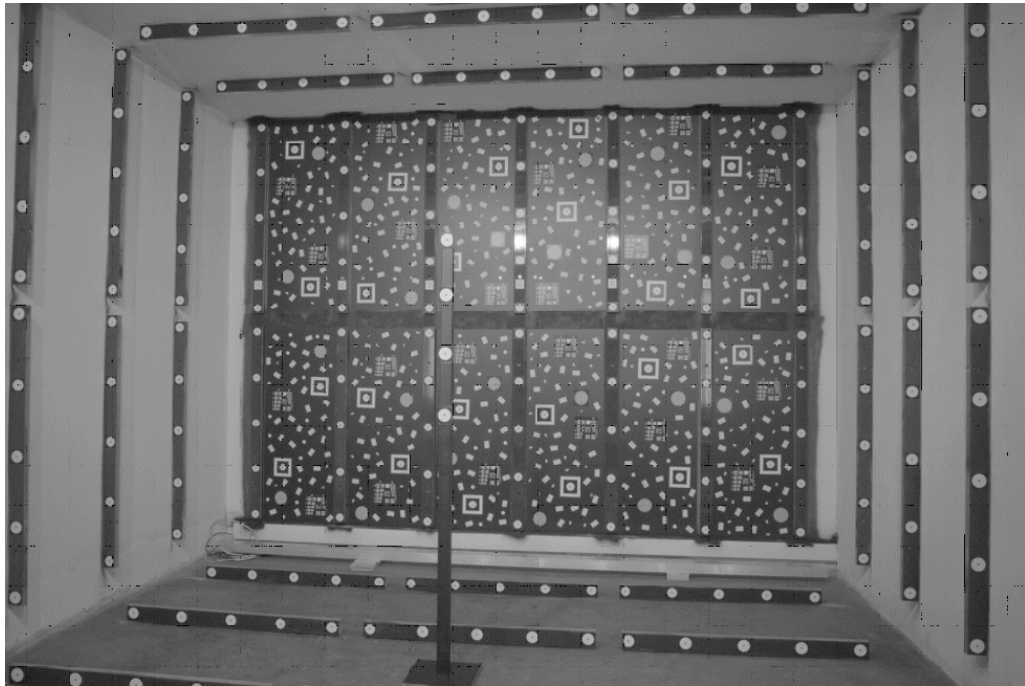


Fig. 7: Terrestrial 3D calibration site used for Ultracam_D lab calibration (© Vexcel)

Determination and Improvement of Spatial Resolution for Digital Aerial Images

The quantification and improvement of image resolution has been a topic of considerable interest within the remote sensing community for more than 20 years. Due to the availability of digital airborne cameras, these techniques are meanwhile also used within photogrammetric applications. In order to quantify the spatial resolution of spaceborne or airborne data, frequently the ground sampling distance (GSD) of the image is determined. This parameter is defined by pixel distance in the camera's focal plane projected to the ground. For this reason, the GSD can be computed easily for images captured from digital airborne cameras. Nevertheless, if the images to be evaluated are transformed geometrically before photogrammetric processing, the determinability of this parameter is limited. Such geometric pre-processing is frequently applied to high-end digital airborne cameras since these systems realise a large field of view and a high geometric resolution either by a multi-component or a pushbroom approach. As an example, systems like the ZI/Imaging DMC and the Vexcel Ultracam integrate several component images to one large full-frame image, while pushbroom cameras like the Leica ADS40 scan the terrain surface with CCD-line sensors in order to collect large image strips at large swath widths. Both approaches require a geometric transformation during pre-processing in order to generate „virtual“ images prior to

further photogrammetric evaluation. Within the multi-head approach, the original images as they are provided from single staring arrays are stitched together resulting in one large image, which is used for further processing. In the case of pushbroom cameras, geometric pre-processing comprises the rectification of the original image strips to a reference surface in order to remove image distortions due to aircraft movement. These pre-processing steps during generation of the virtual images can hinder the direct link of their spatial resolution to the respective parameters of the digital camera. In order to measure the spatial resolution of such virtual images, the size of the smallest details that can be identified by an operator in an image can be determined, alternatively. Nevertheless, since this parameter depends on an operator-based interpretation, this type of values can be subjective.

Searching for an objective and simple measurement of spatial resolution for digital airborne images, a resolution concept, which applies the definition of Rayleigh, seems to be appropriate. According to this definition, the resolution limit of a system is equivalent to the angular distance of two point sources that just can be distinguished. The advantage of this approach is, that distances in the object space can be directly linked to properties of the camera system. The resolution of an imaging system can be described in terms of the point spread function (PSF) of the system. Since the PSF can be measured easily at image edges, the impartial and simple quantification of image resolution is feasible. A convenient approach is the analysis of the radial modulation of the Siemens star. Different diameters correspond to variable spatial frequencies. The evaluation of the modulation for different radii leads to the modular transfer function (MTF) (Figure 8) and the PSF, respectively.

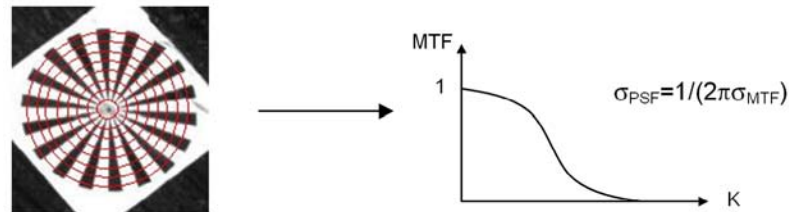


Fig. 8: Radial modulation analysis of the Siemens star.

By these means also the improvement of image resolution, which can be obtained by the use of dedicated filters and algorithms, can be quantified. Such an improvement of spatial resolution by suitable post processing steps is frequently aspired in order to support the evaluation and interpretation of the imagery by a human operator. One possibility is given by image restoration algorithms, which reconstruct the original image from its degraded version. Effects from blurring, which occur in any imaging system that uses electromagnetic radiation, can be eliminated at least partially. Of considerable interest is a restoration method based on a linear restoring finite impulse response (FIR) filter. By means of a regularisation parameter ε , which contains a priori knowledge

of the scene and the noise, the filter result can be controlled. For large ε -values (Figure 9, left) the algorithm provides a smoothing filter, while for smaller (ε -values (Figure 9, right) the resolution improves but the image noise increases.

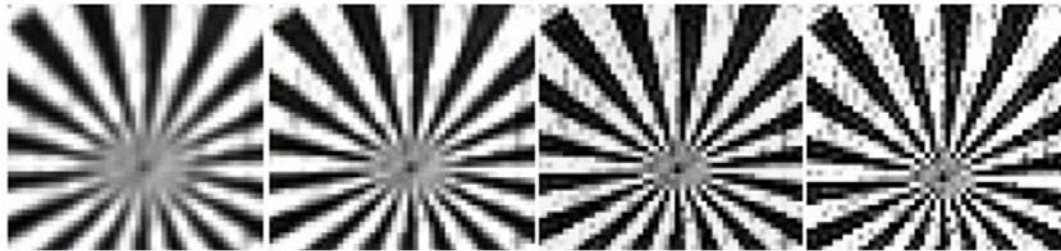


Fig. 9: Result of the FIR restoration algorithm for different ε -values.

The FIR restoration algorithm is especially suitable, if images from different camera modules are available. This is demonstrated using image data captured from so-called staggered arrays, which are for example available in the digital aerial camera ADS40. There, two parallel CCD lines are shifted against each other by half a pixel in order to get an increased sampling rate. Since aliasing effects are suppressed, staggered images provide higher quality (Figure 10). The resolution enhancement is quantified by analysing the MTF. If the staggered array approach is combined with image restoration, the spatial resolution can be improved of about 30%. The contrast and sharpness especially for smaller structures are increased and details are visible more clearly (Figure 11).

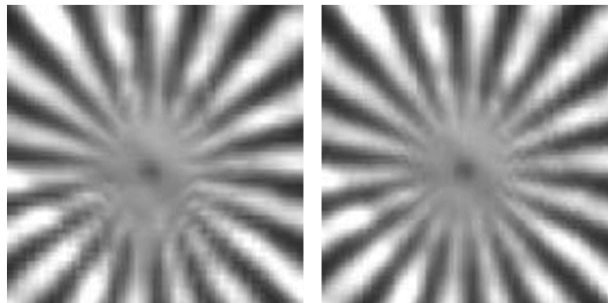


Fig. 10: Single line image (left), staggered line image (right).



Fig. 11: Original image (left), staggered and restored image (right).

Model based geo-referencing of SAR-scenes

Within this project the automatic matching of existing GIS data to airborne SAR scenes for geo-referencing is aspired. For this purpose simulated SAR images are generated based on the available GIS objects using a SAR simulator. These simulated scenes are then be matched against the captured SAR image in order to detect the given GIS objects in the SAR scene. This has been realised by the automatic localisation of street data, which is available area covering for car navigation purposes. Since the horizontal accuracy of this data is limited, the georeferencing is further refined. For this purpose landmark buildings, which are selected from a 3D city model are detected fully automatically. Since good initial values are available from the preceding localisation of street regions, the matching problem can be solved despite the relatively high complexity of SAR imagery at building objects. The high accuracy requirements, which can be met by matching the SAR scene against a 3D city model, are for example required for combining the SAR scene with data from other sensors like optical images. In principle, the matching process can also be applied to detect inconsistencies between SAR scene and given GIS data. Thus potential applications for change detection and update of the existing GIS data are feasible.



Fig. 12: GDF street data with footprint of the SAR image and the search areas.



Fig. 13: Result of automated matching between the GDF-street data and SAR image.

Nexus project - Integrated sensor orientation

Objective of this project - as one project within the Sonderforschungsbereich (Center of Excellence) Nexus established in 2003 - is to provide model-based methods for interaction between Nexus users and the spatial world model. Therefore our research was focused on the following two research areas: Integration of sensors for positioning and the combination of image data and information from the spatial world model for object identification and user localization.

To describe the situation in the real world, e.g. to collect environmental data, but also for localization different sensors are used, which have to be integrated to the Nexus platform. For this reason we developed a concept for sensor and sensor data integration in our research during the last year. In the meantime the concept is available as technical report and it will be implemented to the Nexus platform. Within the sensor related research also the indoor positioning was an important topic. For evaluation a commercial system based on ultra wideband technology was installed and tested.

Within the second research area, which deals with image processing we are using a line feature based spatial resection approach for co-registration of image and model data (Figure 14). The algorithm was developed at the beginning of the project, but in the first instance it was assumed that approximate values for initialization are available. During the last year the algorithm was extended and a new method was implemented which solves the mentioned problem and which provides the required approximate values. The new algorithm offers the possibility of direct estimation of object and user position only by the knowledge of corresponding image and model features. In addition to the research aspects the 3D world model was extended by deriving model information from aerial images and other sources of information.



Fig. 14: Co-registration of image and model data

Terrestrial Positioning Systems and Computer Vision

Multi-image fusion for occlusion-free facade texturing

Today many approaches for the creation of three-dimensional virtual city models are reported in literature. As widespread as the approaches for their generation are the applications of such models. When it comes to visualizing virtual city models, a key point in most applications, facade texturing is essential for realistic rendering. Due to the modern media and entertainment industry and their use of highly sophisticated computer equipment and specialist in the field, today's audience has high expectations to the quality of computer-generated visualizations. This raises the demand for high-quality texturing in virtual city models. One problem, and a major cause for the lack in the quality of facade textures, is the disturbance of images by partial occlusion of the facade with other objects, such as pedestrians, cars, trees, street signs and so on. Especially in inner-city areas it is impossible to avoid these occlusions, as the choices for the camera stations are limited. Therefore strategies for the detection and removal of these disturbances are essential.

The creation of facade textures is usually a labor-intensive manual task involving the acquisition of terrestrial images of the facade, the rectification of the images, the mapping onto the geometry of the model and various improvements to the imagery. Automated approaches, which have been reported in literature, solve the tasks by projecting primitives (triangles or texels) from the images to the object geometry. This requires absolute orientation of the images, derived from bundle adjustment. If more than one mapping is available for a primitive, redundancy can be used to remove occlusions. Our approach differs in that it does not explicitly map image points to 3D geometry, but that we rather attempt to warp the images in 2D using perspective transformation. Thereby pixel-level registered image sequences are generated providing the redundancy to eliminate occluding objects by means of background estimation.

The occluding objects can roughly be categorized into two classes: moving objects and static objects. To detect and remove moving objects from terrestrial images of a facade, it is sufficient to acquire a sequence of images from a single camera station. This image sequence can be processed with algorithms from the field of video-sequence analysis known as background estimators, normally used for change detection. However these algorithms usually require long sequences (> 100 images) to converge to a satisfactory result. To acquire such long sequences with high-resolution digital cameras would significantly increase the time and effort to acquire texture images. Therefore we explore alternative approaches suitable to short sequences (< 10 images).

For the case of static objects, a single camera station is insufficient. Images from several different stations have to be acquired and fused. We solve the fusion of these images without entering the three-dimensional domain, avoiding over-proportional computational costs and unnecessary complexity. Instead we attempt to solve solely in the two-dimensional image domain by mapping the image to the planar surface of the facade. This step of mapping, also referred to as rectification, is always involved when using terrestrial imagery for facade texturing. We have studied both manual and automated approaches for rectification in the past. When an occluding object lies in front of the facade plane at a certain distance, its mapping to the plane varies across the image sequence, due to the oblique angles of the different camera stations. Thereby the case of a static occluding object is transformed to the case of a moving object in the rectified sequence and hence the same approaches for detection and removal as in the case of moving objects can be applied.

Sensor fusion of terrestrial laserscanner data

Any architectural site has multiple aspects, which are of interest when creating a computer model of the site. Typically it is the geometry, which receives most attention, but increasingly spectral properties, reflectance, material, and others are gaining interest as well. These different aspects can rarely be captured with a single sensor system. Furthermore for complex architectures these aspects can never be recorded from a single point of observation. It is therefore common practice to integrate several measurements from different sensors and varying stations in order model the complete object. This process is also referred to as sensor data fusion. Certain combinations of separate data sources have become standard procedures in the field of photogrammetry, such as the integration of ground plans and digital elevation models for virtual city modeling and the integration of multiple terrestrial imagery and CAD building models for facade texturing and many more are being investigated, such as the combination of aerial and terrestrial laser scanning for improved building modeling and the combination of high resolution panoramic images with city models.



Fig 6: Top row: Four images from a fixed viewpoint of a facade imaged from across a busy street. Traffic and pedestrians partially occlude the lower portion of the facade. Bottom: The result of the proposed algorithm on the input sequence is a synthetic image with no occlusions.

A crucial step preceding the data fusion is the geometric alignment of the separate dataset into a common reference frame. In the case of geodata fusion this is known as georeferencing. Georeferencing has certain advantages in comparison to registration in an arbitrary local coordinate system. It transforms simple sensor data into geodata and thereby opens the opportunity for an almost unlimited number of combinations with other geodata. An example of available georeferenced data are virtual 3D city models. These models contain the facades and the shapes of the roofs of buildings composed of polyhedral structures. Other georeferenced datasets, available for larger areas than those covered by virtual city models, are digital surface models derived from airborne laserscanning.

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. However versatile they are, a TLS system is seldom enough for complete scene modeling. Combining data recorded at multiple stations and integrating independent sensor data are essential.

Two measurement campaigns were carried out. In all cases the Leica HDS 3000 was used to perform the laserscanner measurements. The HDS 3000 is a pulsed laser scanner operating at a wavelength of 532 nm. The scanner is able to acquire a scene with a field of view of up to 360° horizontal und 270° vertical in a single scan. The manufacturer specifies the accuracy of a single point measurement with 6 mm. The first experiments were carried out on the Schillerplatz, which is the square in the heart of the old city that has been reconstructed true to the source after its destruction in World War II. The monument of the poet Friedrich Schiller in the center of the square is surrounded by several historically important buildings like the „Altes Schloss“, the „Prinzenbau“, the „Fruchtkasten“, the „Alte Kanzlei“ and the „Stiftskirche“. There is a natural interest to record and to visualize this meaningful place in detail for a virtual 3D city model of Stuttgart. The terrestrial laserscanner offers the possibility to acquire a detailed 3D texture from all facades around the square. The coordinates of the tie points were determined using a Leica TCR 307 total station. With the knowledge of the global position of the point clouds, it is possible to super-impose and to compare the laserscanner measurement with other georeferenced datasets. A second experiment was performed at Schloss Rosenstein. The palace was build from 1822 to 1830 by King Wilhelm I. It is located on a small hill in a park just outside the city center and gives a beautiful view over the Neckar valley. The main goal was to acquire dense range data of the facades on all sides of the palace.

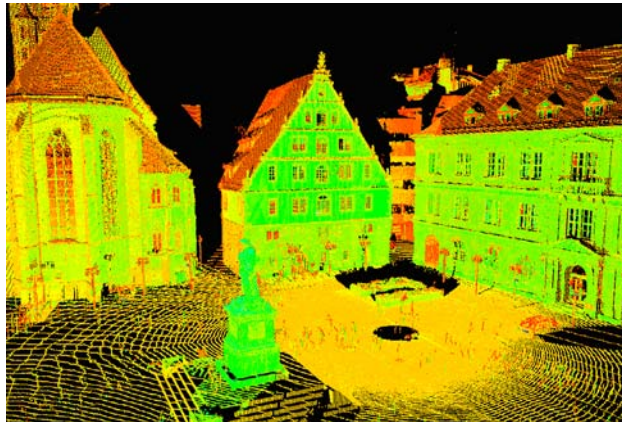


Fig 7: Point cloud rendered in a multi-hue coloring scheme.

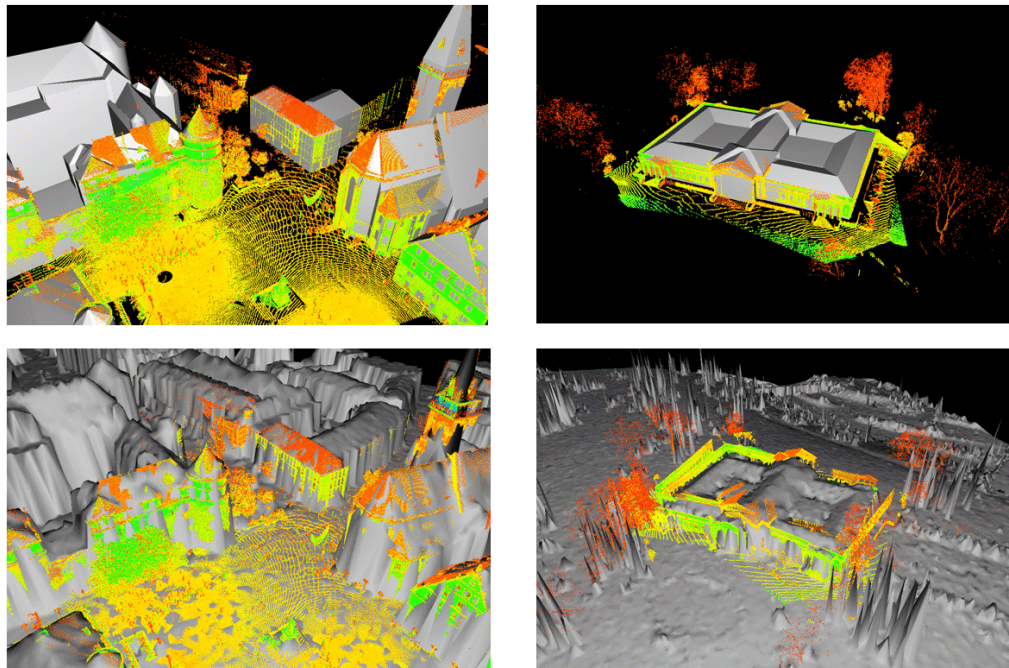


Fig 8: Super-imposition of terrestrial laserscanner data and virtual 3D city model (top) / aerial LIDAR (bottom) at Schillerplatz (left) and Rosenstein (right).

Cultural heritage documentation

Terrestrial laser scanning in spite of its costs has become a popular tool for the documentation of cultural heritage sites. No other measurement system can parallel the speed, range and accuracy of its dense point cloud acquisition. Naturally TLS was the first choice of methods, when the cooperation in the documentation of cultural heritage sites in Jordan was established in-between the Institute for Photogrammetry of the Universität Stuttgart, Germany and the Queen Rania's Institute for Tourism and Cultural Heritage of the Hashemite University. The collection of the data, which has been used for our investigations, was performed in cooperation with the Hashemite University of Jordan. The project aims on the exemplarily generation of 3D documentations for the two main heritage sites in Jordan, Petra and the ancient city of Jerash.

Al-Khasneh Monument

The ancient Nabataean city of Petra has often been called the eighth wonder of the ancient world. Petra city in southwestern Jordan prospered as the capital of the Nabataean empire from 400 B.C. to A.D. 106. Petra's temples, tombs, theaters and other buildings are scattered over 400 square miles, these architectures are carved into rose-colored sandstone cliffs. After a visitor enters Petra via Al-Siq, a two-kilometer impressive crack in the mountain, the first facade to be seen is Al-Khasneh, which is considered as the best-known monuments in Petra city. The Al-Khasneh facade is 40m high and remarkably well preserved, probably because the confined space in which it was built has protected it from the effects of erosion. The name Al-Khasneh, as the Arabs call it, means treasury or tax house for passing camel caravans, while others have proposed that the Al-Khasneh Monument was a tomb. Behind the impressive facade of Al-Khasneh, large square rooms have been carved out of the rock. An image of the Al-Khasneh facade is depicted in Figure 9.

Jerash

Jerash, which was selected as the second test area, is probably one of the best preserved Roman provincial cities worldwide. Built in the 2nd century BC, it was conquered in 63 BC by the Roman emperor Pompey. The ancient Arabic name of Garshu was changed to Gerasa, and Jerash became part of the Roman Empire. Jerash's prosperity reached its zenith in the 1st and 2nd century AC under the emperors Trajan and Hadrian, when the city was ranked as a Roman Colony and became the administrative, civic, commercial and cultural center of the Province of Arabia. The decline of the city began after Persian invasion 614 AD, in the 13th century the city was abandoned, completely. The rediscovery of Jerash came about in 1806, when a German traveler recognized a small section of the ruins buried in sand. Significant archeological work took place since 1928 when the city has been gradually revealed through a series of excavations. Due to the exceptional condition of its colonnaded streets, baths, theaters, plazas and arches the city Jerash is probably the second most frequently visited tourist site after Petra in Jordan. Within the project image and LIDAR data was collected for two theatres, an exemplary view of the so-called North Theatre is depicted in Figure 10.

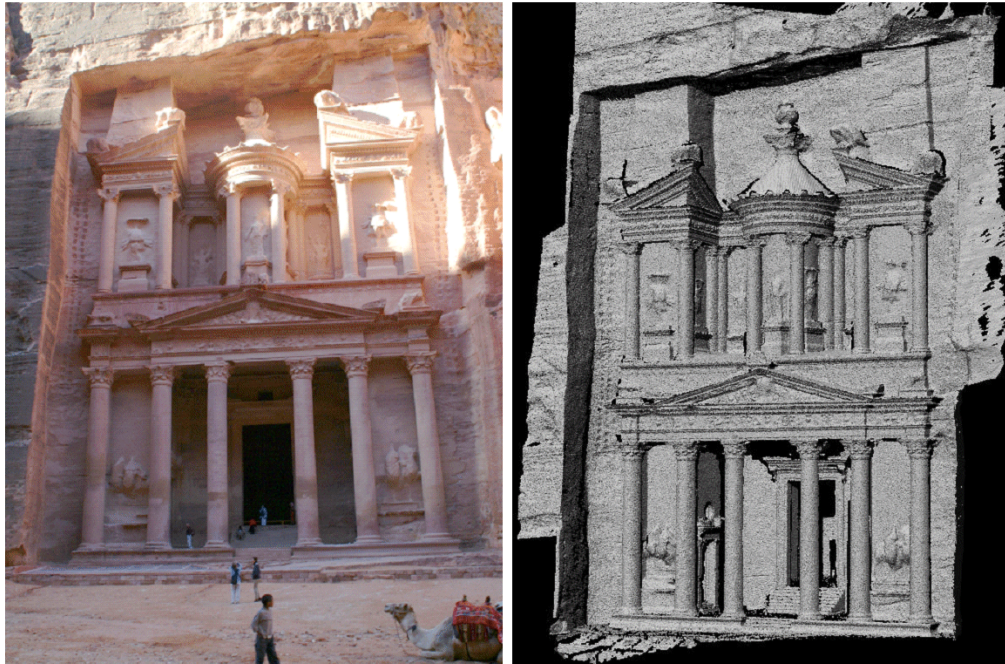


Fig 9: Image and 3D model of the Al-Khasneh facade in Petra.



Fig 10: Data collection for the North Theatre in Jerash. The recording with the laser scanner is carried out together with surveying work using a total station.

Sensors Applied

For point collection, the 3D laser scanning system GS100, manufactured by Mensi S.A., France was applied. The scanner features a field of view of 360° in the horizontal and 60° in the vertical direction, enabling the collection of full panoramic views. The distance measurement is performed by the time of flight measurement principle based on a green laser at 532 nm. The scanning range of the system allows distance measurements between 2 and 100 meters. The scanner's spot size is 3 mm at a distance of 50 meters; the standard deviation of the distance measurement is 6 mm for a single shot. The system is able to measure 5000 points per second. During data collection a calibrated video snapshot of 768 * 576 pixel resolution is additionally captured, which is automatically mapped to the corresponding point measurements.

In addition to the laser data, digital images were captured for photogrammetric processing using a Fuji S1 Pro camera. The camera provides a resolution of 1536 * 2034 pixels and is able to store the images in raw format. We used a high quality lens with a focal length of 20 mm. The camera was calibrated before and after the campaign at the institute's calibration lab to ensure the stability of the interior orientation. Due to the strict photogrammetric calibration we can compute the exterior orientation of each camera station using simple spatial resection from natural control points extracted from the TLS point cloud. The oriented images can thus be used both for texturing the point cloud and for further three-dimensional reconstruction and feature extraction.

All the acquired 3D models have been processed using Innovmetric Software, PolyWorks. The model of Al-Khasneh facade resulted from merging the five scans in an independent coordinate system into a common coordinate system. After registration of the scans using a variation of the ICP algorithm, the software constructs a non-redundant surface representation, where each part of the measured object is only described once. The result of the combination of the five laser scans is given in the right picture Figure 9. The produced model has an average resolution of 2 cm with more than 10 million triangles.

In contrast to Petra, where data collection was hindered by the fact, that most monuments are located in a narrow canyon, viewpoints could be selected more freely during data collection in Jerash. Figure 11 gives two rendered views of the 3D data collected at this site.

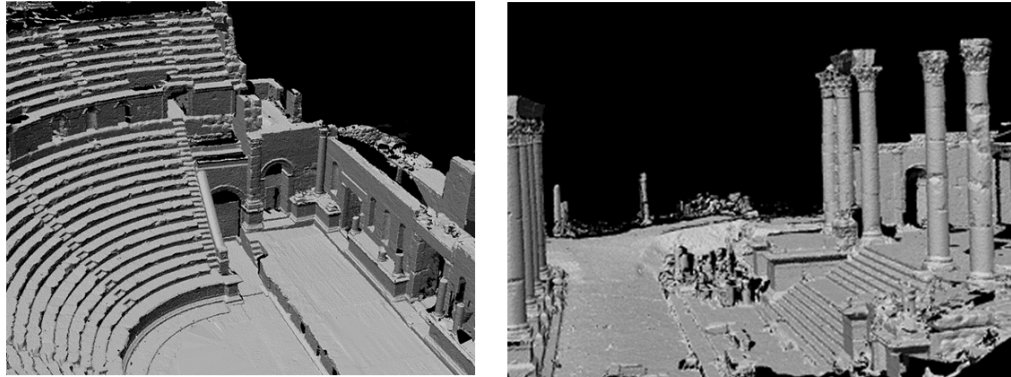


Fig 11: LIDAR data collected at North Theater, Jerash.

References 2004

- Alshawabkeh, Y. and Haala, N.: Integration of Digital Photogrammetry and Laser Scanning for Heritage Documentation. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Balz, T.: Automated CAD Model Based Geo-Referencing for High-Resolution SAR Data Fusion in Urban Environments. In: Proceedings of the 5th European Conference on Synthetic Aperture Radar, 427 - 430.
- Balz, T.: SAR Simulation Based Change Detection with High-resolution SAR Images in Urban Environments. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Balz, T.: Event-Driven Change-Detection in Urban Environments Using SAR. Proceedings of the Map ASIA Conference 2004, 4 pages (on CD).
- Böhm, J.: Multi-Image Fusion for Occlusion-Free Façade Texturing. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Cramer, M.: The EuroSDR network on digital camera calibration. In: EuroSDR newsletter, No. 1, 2004, 19 - 20.
- Cramer, M.: Performance of medium format digital sensor systems. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Cramer, M.: EuroSDR network on digital camera calibration. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Cramer, M.: A European network on digital camera calibration. PE&RS Photogrammetric Engineering and Remote Sensing, December, 2004.

- Cramer, M.: Positions- und Lagemesssysteme. In: R. Sandau (ed): Digitale Luftbildkamera - Ein Handbuch für die Praxis. Herbert Wichmann Verlag, Karlsruhe, will be published in 2005.
- Fritsch, D. and Kada, M.: Visualisation using Game Engines. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 5 pages (on CD).
- Grejner-Brzezinska, D., Li, R., Haala, N. and Toth, C.: From Mobile Mapping to Telegeoinformatics: Paradigm Shift in Geospatial Data Acquisition, Processing and Management. PE&RS Vol. 70(2), 197 - 210.
- Gülch, E. and Cramer, M.: Kalibrierung von digitalen Luftbildkameras. ZfV Zeitschrift für Geodäsie, Geoinformation und Landmanagement, Heft 5, Jahrgang 2004, 129. Jahrgang, 289 - 297.
- Haala, N.: On The Refinement of Urban Models by Terrestrial Data Collection. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Haala, N., Reulke, R., Thies, M. and Aschoff, T.: Combination of Terrestrial Laser Scanning with High Resolution Panoramic Images for Investigations in Forest Applications and Tree Species. In: Proceedings of the Panoramic Photogrammetry Workshop, IAPRS, Vol. 34, Part 5/W16, 6 pages (on CD).
- Haala, N. and Kada, M.: Generation and application of virtual landscape models for location-based services. In: Stefanidis, A. and Nittel, S. (eds.), GeoSensor Networks CRC Press, 167 - 178.
- Haala, N.: Laserscanning zur dreidimensionalen Erfassung von Stadtgebieten. In: Coors, V. and Zipf, A. (eds): 3D-Geoinformationssysteme. Wichmann Verlag, 26 - 38.
- Kada, M.: Hardware-Based Texture Extraction for Building Facades. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Kada, M., Haala, N., Maier, S. and Fritsch, D.: Integration of Street Networks and LIDAR for Modelling and Visualisation of Terrain Data. In: Proceedings of the Asian Conference on Remote Sensing, ACRS 2004, 6 pages (on CD).
- Klinec, D.: A model based approach for orientation in urban environments. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Reulke, R., Becker, S. and Haala, N.: Determination and Improvement of Spatial Resolution of the CCD Line-Scanner System ADS40. In: Proceedings of Image and Vision Computing '04 (on CD).
- Reulke, R. and Haala, N.: Tree Species Recognition with Fuzzy Texture Parameters. In: Proceedings of the IWCIA, Tenth International Workshop on Combinatorial Image Analysis (on CD).
- Reulke, R., Tempelmann, U., Stallmann, D., Cramer, M. and Haala, N.: Improvement of Spatial Resolution with Staggered Arrays as used in the Airborne Optical Sensor Leica ADS40.

- In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 4 pages (on CD).
- Volz, S. and Walter, V.: Linking Different Geospatial Databases by Explicit Relations. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Istanbul, Turkey, 6 pages (on CD).
- Walter, V.: Object-wise Classification of Remote Sensing Data for Change Detection. In: C. Heipke, K. Pakzad and F. Willrich (eds): Integration of geodata and imagery for automated refinement and update of spatial databases, ISPRS Journal of Photogrammetry & Remote Sensing, Vol. 58, 225 - 238.
- Walter, V.: GIS-Architekturen. In: Möser, Müller, Schlemmer and Werner (eds): Handbuch Ingenieurgeodäsie - Raumbezogene Informationssysteme, Wichmann Verlag, Heidelberg, 58 - 76.
- Walter, V.: Object-based Evaluation of LIDAR and multispectral data for automatic change detection in GIS databases. In: Proceedings of the XXth Congress of the ISPRS, Vol. 35, Part B, Istanbul, Turkey, 6 pages (on CD).
- Walter, V. and Weippert, H.: GIS und Fernerkundung. In: Mark Müller and Giselher Kaule (eds): E-Learning mit GIS- und Modellanwendungen - Ergebnisse des Projektes GIMOLUS. Wichmann Verlag, Heidelberg, 169 - 182.

Diploma Theses

- Parvesh Kumari: Extraktion of planar surfaces from 3D point clouds for building reconstruction. Supervisor: Lohani, B. and Haala, N.
- Eugen Steinbrenner: Internetbasierte interaktive Lernmodule zur hierarchischen Datenstrukturierung und zur Linienglättung. Supervisor: Walter, V.
- Christian Thamm: Optische Formerfassung von Objekten mit spiegelnden Oberflächen. Supervisor: Böhm, J.
- Sara Schuhmacher: Entwicklung eines automatischen Bildzuordnungsverfahrens für die dreidimensionale Rekonstruktion von menschlichen Körperteilen. Supervisor: Böhm, J.
- Susanne Becker: Auflösungsverbesserungen von panchromatischen ADS40-Daten. Supervisor: Reulke, R.

Study Theses

- Steffen Lindenthal: Untersuchungen zum Aufbau eines Filters zur Warnung bei unbeabsichtigtem Fahrspurwechsel. Supervisor: Haala, N.
- Jan Hörschelmann: Direkte Georeferenzierung - Potenzial der AEROoffice Software (Version 5.0). Supervisor: Cramer, M.
- Daniel Wilhelm: Messungen im Windkanal mittels Nahbereichsphotogrammetrie. Supervisor: Böhm, J.

Activities in National and International Organizations

Dieter Fritsch

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 (Fritsch)	2/1/0/0
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 Photogrammetric Systems (Reulke)	2/0/0/0
Digital Signal Processing (Fritsch, Böhm)	2/1/0/0
Geodetic Seminar I, II (Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink, Reulke)	0/0/0/4
Geoinformatics I,II,III (Fritsch, Walter)	6/2/0/0
Geometry and Graphical Representation (Cramer)	1/1/0/0
Introduction into Civil Law (Schwantag)	2/1/0/0
Introductory Readings to Photogrammetry (Cramer)	1/1/0/0
Image Processing and Pattern Recognition I,II (Haala, Reulke, Balz)	4/1/0/0
Image Acquisition and Monoplotting (Reulke, Cramer)	2/1/0/0
Practical Training in GIS (Walter, Volz)	0/0/4/0
Practical Training in Digital Image Processing (Haala)	0/0/4/0
Programming in C/C++ (Böhm, Kada)	1/1/0/0
Urban Planning I, II (Schäfer)	1/2/0/0