The Department of Geodesy and Geoinformatics

Stuttgart University
2002

Preface

Dear friends and colleagues, we are pleased to report some highlights of The Department of Geodesy and Geoinformatics (DoGG), Stuttgart University for 2002. This annual report, introduced in 1993 and now celebrating its 10th anniversary, serves as a helpful compendium for friends, colleagues, and students all over the world. As the years before, the Stuttgart School will contribute to shape the future of satellite and mathematical geodesy, navigation, land surveying and engineering surveys, telematics, photogrammetry, remote sensing, optical inspection, geographic information systems, and most recently Location Based Services in all three branches of university work: research, development and education.

As presented in the years before this compendium gives you an overview on the activities of the four institutes representing The Department of Geodesy and Geoinformatics of Stuttgart University: The Geodetic Institute (Director Prof. E.W. Grafarend), the Institute of Geodetic Applications in Civil Engineering (Director Prof. W. Möhlenbrink), the Institute of Navigation (Director Prof. Dr. A. Kleusberg), and the Institute for Photogrammetry (Director Prof. Dr. D. Fritsch). The institutes are involved in many curricula of Stuttgart University, ran their own curriculum of Geodesy and Geoinformatics, and will (hopefully) start in 2004 with an international MSc Program Geoinformatics Engineering (GeoEngine).

In 2002 the team of professors could grow by Dr. Ralf Reulke, a physicist and former Senior Researcher at DLR, Adlershof/Berlin, who took over the professorship of „Digital Photogrammetric Systems" at the Institute for Photogrammetry (ifp). Dr. Reulke's position results from the negotiations of Dr. Dieter Fritsch, when he took over presidency of Stuttgart University in 2000.

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

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

Dieter Fritsch	Erik W. Grafarend	Wolfgang Keller
Alfred Kleusberg	Wolfgang Möhlenbrink	Ralf Reulke
Detlef Wolf		

Institute for Applications of Geodesy to Engineering

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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	Traffic information
Dr.-Ing. Renate Czommer	Map matching
Dipl.-Ing. Matthias Dünisch (up to 31.3.02)	Geodetic measurements
Dipl.-Ing. Andreas Gläser	Integrated sensors
Dipl.-Ing. Andreas Eichhorn	Deformation analysis
Dipl.-Geogr. Thilo Kaufmann	Digital maps
Dr.-Ing. Heiner Kuhlmann	Surveying engineering
Dipl.-Ing. Katrin Ramm	Vehicle positioning
Dipl.-Ing. Ralph Schollmeyer	Vehicle positioning
Dr.-Ing. Volker Schwieger	Geodetic measurements
Dipl.-Ing. Martin Stark	Information chains
Dipl.-Ing. Thomas Wiltschko	Information quality

Technical Staff

Niklaus Enz
Martin Knihs
Lars Dirk Plate
Doris Reichert

External teaching staff

Dr.-Ing. Ludwig Gekle - Universität Hohenheim
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, engineering geodesy, data processing and traffic information technologies. The institute's daily work is characterised by intensive co-operation with other engineering disciplines, especially with aurospace engineering, civil engineering, traffic engineering and construction management. Co-operations exist with other university institutes as well as with the construction and automobile industry and various traffic services.

In education, the institute is not only responsible for different courses within the curricula of Geodesy and Georelated Computer Science but also for the education in surveying of architects and civil engineers. A special lecture in English is held within the master course Infrastructure Planning. Additionally, first steps towards a virtual learning environment are realised. 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.

The institute's current research and development work focuses on the following:

▷ surveying engineering, vehicle positioning
▷ traffic information techniques
▷ e-learning
▷ formfinding of lightweight structures.

Research Work

The institute's current research work can be summarized by the main topic 'Positioning and controlling moving objects in the digitally described 3D-space'. This research work comprises the following activities:

Surveying engineering, vehicle positioning

This working area comprises design, development and application of multi-sensor-measurement and data processing of static and dynamic information in civil engineering and surveying.

Protection against manipulation of measurement data for final quantity survey

The Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) has conferred a research project to the IAGB for evaluating the manipulation potential in data processes of final quantity survey. The data collected by this survey are substantial for clearing and post-calculation. Since freely programmable measuring systems pushing increasingly into the market, the fear of an increased manipulation potential has been grown up. Therefore, the purpose of this project was to disclose the manipulation potential of such measurement systems that come into operation for clearing. Counteractive measures are indicated in order to prevent manipulation.

Therefore, the whole data flow for the measuring processes by tacheometry, levelling and differential GPS (Real-Time-Kinematic) has been represented and the manipulation potential has been pointed out. Fig. 1 shows this exemplarily for the data flow of tacheometer measurement systems.

It has been stated that no additional manipulation potential exists in relation to electronical measurement systems with external field computer. Only in case of reductions and corrections, an additional manipulation potential exists compared with analogous instruments or electronic instruments with handwritten field books or internal storage. Therefore, test scenarios were created to establish the effect on this values by manipulation. For their evaluation it is decisive which effect the manipulation has on the final result, e.g. the volume of an object. According to the theory of the marginally detectable blunder, a manipulation of an exactly identified value is set into relation to the resulting volume difference. From this derives the critical value for the final result and of which size the marginally detectable blunder should be. So a measuring configuration is derived which can disclose this manipulation.
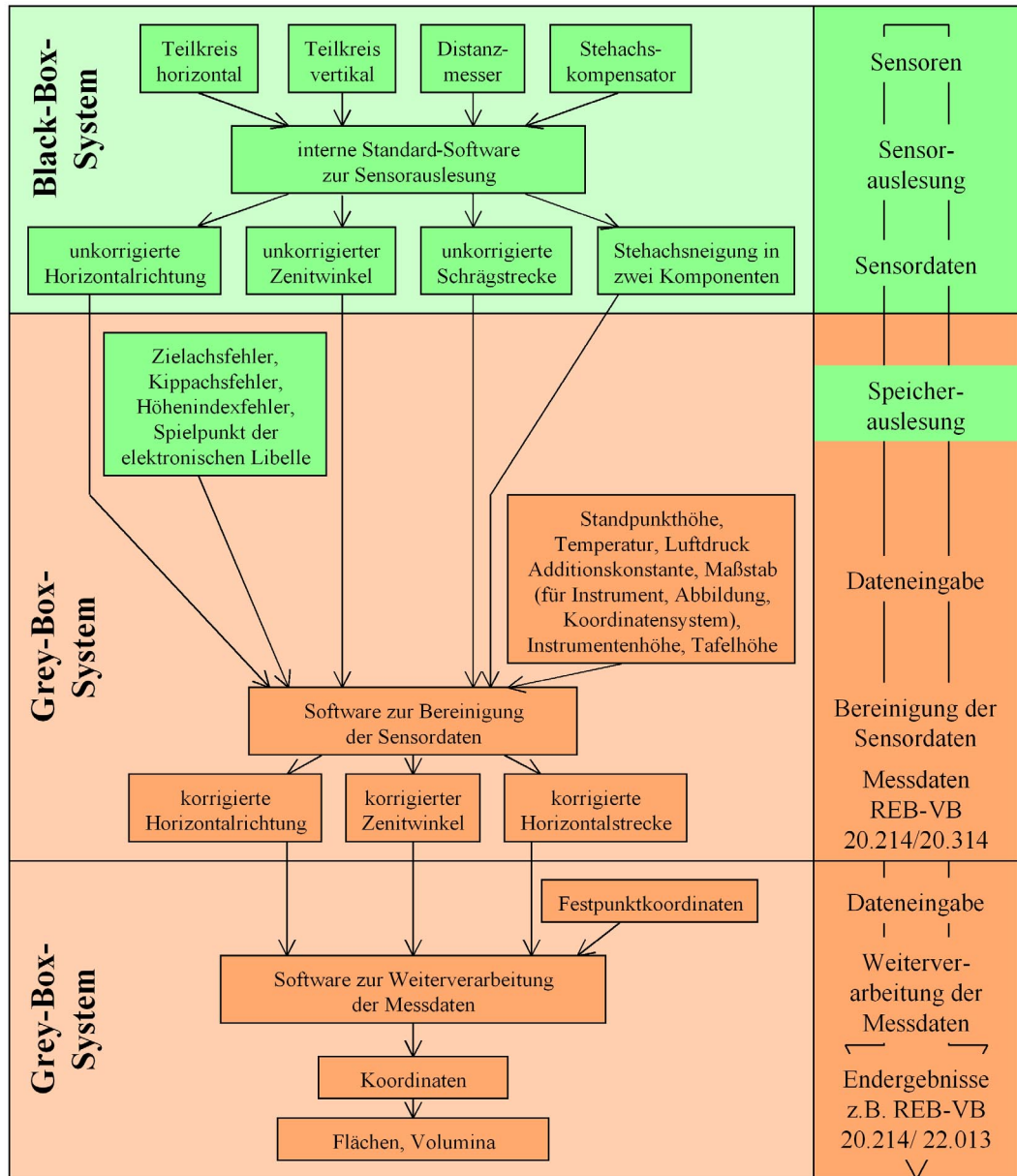
Black-Box-System

Teilkreis horizontal

Teilkreis vertikal

Distanz-messer

Stehachs-kompensator

interne Standard-Software zur Sensorauslesung

unkorrigierte Horizontalrichtung

unkorrigierter Zenitwinkel

unkorrigierte Schrägstrecke

Stehachsneigung in zwei Komponenten

Sensoren

Sensor-auslesung

Sensordaten

Grey-Box-System

Zielachsfehler, Kippachsfehler, Höhenindexfehler, Spielpunkt der elektronischen Libelle

Standpunkthöhe, Temperatur, Luftdruck Additionskonstante, Maßstab (für Instrument, Abbildung, Koordinatensystem), Instrumentenhöhe, Tafelhöhe

Software zur Bereinigung der Sensordaten

korrigierte Horizontalrichtung

korrigierter Zenitwinkel

korrigierte Horizontalstrecke

Speicher-auslesung

Dateneingabe

Bereinigung der Sensordaten

Messdaten REB-VB 20.214/20.314

Grey-Box-System

Festpunktkoordinaten

Software zur Weiterverarbeitung der Messdaten

Koordinaten

Flächen, Volumina

Dateneingabe

Weiterver-arbeitung der Messdaten

Endergebnisse z.B. REB-VB 20.214/ 22.013

Fig. 1: Data flow of a tacheometry measurement system

Kalman-filter for map-independent positioning

An algorithm for map-independent positioning of vehicles was developed supplying the position in realtime by means of an on-board multi sensor system. The proceeding of data acquisition and sensor integration was presented in the annual report 2001. After a quality test of the sensors showing the stochastic observation model, a Kalman-filter was formulated including vehicle position, vehicle speed and orientation as estimated parameters. Thus, failures and errors of the GPS-observations can be compensated. The standard deviation of the positions estimated was about $\sigma_x = \sigma_y = 2$ m.

Additional investigations on the mentioned Kalman-filter were carried out with respect to the integration of additional sensors. Therefore, the unused data of the steering angle sensor from which the change of orientation of the vehicle can be derived were pre-processed and analysed. The possibilities of integration of steering angle sensor into the existing Kalman-filter were tested and veryfied by various modifications.
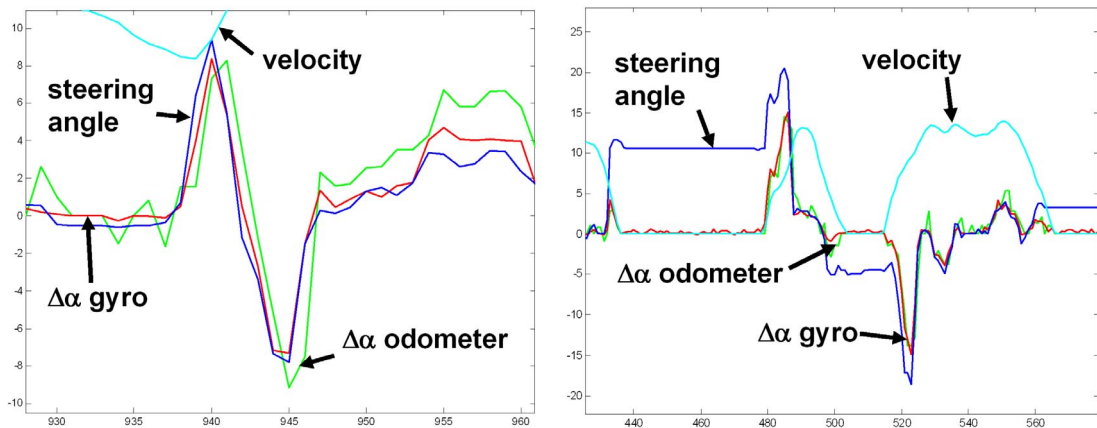

Fig. 2: Characteristics of the steering angle sensors in relation to the change of orientation (from gyro and odometer) and in dependency of the velocity

Positioning for GIS in forestry

Within preliminary examinations to reorganise the geoinformation system for forestry (FoGIS) in Baden-Württemberg, the IAGB contributed with several trial trips testing the positioning methods in forest areas regarding position accuracy and reliability. The spectrum of the sensors comprises several low-cost GPS-receivers as well as precision inertial measurement units (IMU).

A low-cost sensor system suitable for these purposes would assist the tasks of modern forestry such as logistic of woodwork or as documentation of the forest paths. Beyond that, it represents a suitable method to find the own position on the forest paths and to enable further technical applications like way finding, navigation or fleet logistics.

As a first result it could be stated that the used highly precise geodetic receivers have not better receiving characteristics than one frequeny receivers. The comparison of the differently measured tracks shows several situations where low-cost receivers lead to a much better positioning result for the actual guidance than the geodetic receivers. In a further step of evaluation the assigned positioning methods are compared with a reference track measured by a high precision inertial measurement unit (gyro, odometer, correlation-velocity meter).

The expected results will permit a predication concerning applicability of low-cost detection sensors for forestry.

Traffic Information Technology

Within the interdisciplinary field of traffic telematics, the IAGB is contributing 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 to the development of future mobility services and driver assistance systems. A main point is, besides 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.

MOBILIST

The project MOBILIST within the BMBF-program „Mobility in Urban Areas" is the frame for the investigation of expenditures of service companies regarding transaction costs for providing and transmission of information to service customers. The service of an intermodal routing planner was prepared as a demonstrator designed as an internet platform. Hereby the stages of individual and public traffic are coupled in a way that a traveller can dispose of travel information using both traffic systems including the calculation of transfer possibilities. A general geodata basis connecting traffic networks of individual and public traffic in stop overs had to be developed for this purpose.

Within the accompanying research program the IAGB analyses the cost structures regarding the geodata basis and investigates possibilities of Return On Investment (ROI) by means of various prognoses of re-use. First results show that in principle a ROI is only possible in case of at least 1,5 millions of utilisation per year and with a price of 5-10 Eurocent per utilisation. The profitability explicitly was not analysed because a business model was not available within the frame of the MOBILIST demonstrators.
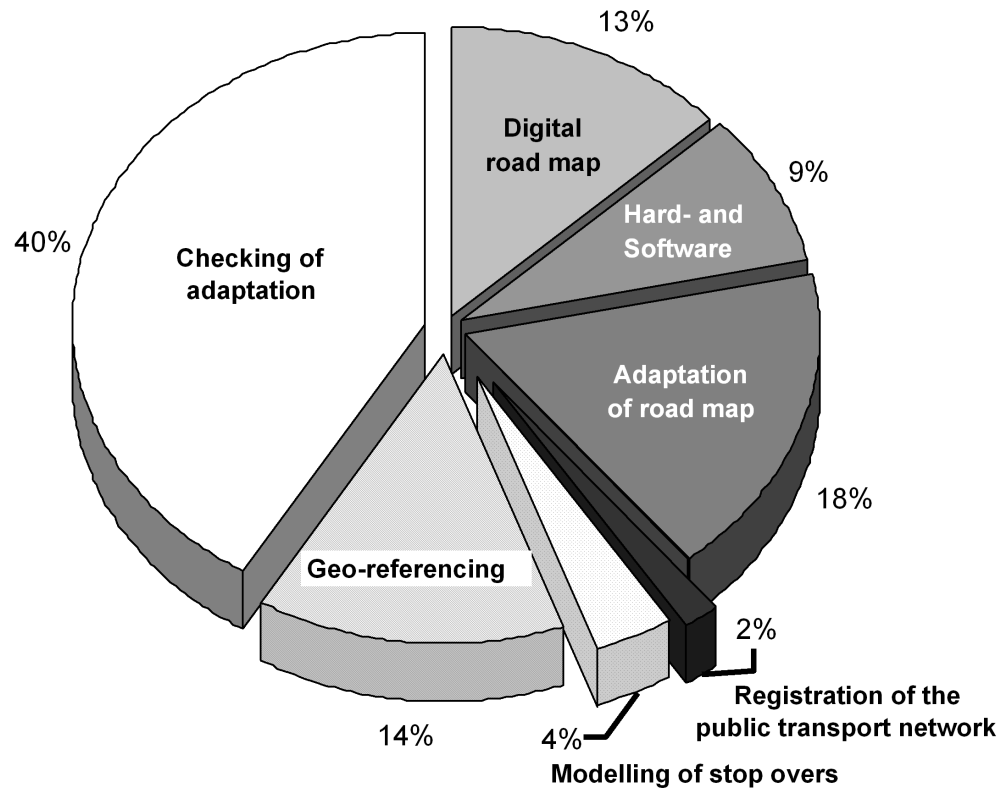
Fig. 3: Example for cost structures of traffic information services

Traffic Flow Analysis in Crossing Areas

Within the frame of the BMBF-project INVENT an analysis of traffic flow in crossing areas was effected ordered by DaimlerChrysler AG. Due to accident data of the police an accident analysis was effected within a representative part of Stuttgart. The microscopic analysis of accidents has the aim to identify traffic situations with highly dangerous potentials. For this analysis 590 accidents documented by the police were registered and analysed.

A further investigation for the work package „Farsighted Active Safety" of INVENT was effected referring to the actual situation of authority data bases concerning crossing information. For this purpose the communal data bases were investigated by means of reference data with specific information on crossings. These information were used in the crossing assistance system in addition to the information from the digital road maps of the navigation systems.

Frequency of Accidents
Stuttgart Ost 2001

- · 1 Accident
- 2-3 Accidents
- 4-5 Accidents
- 6-10 Accidents
- 11-20 Accidents
- > 20 Accidents

0   500m
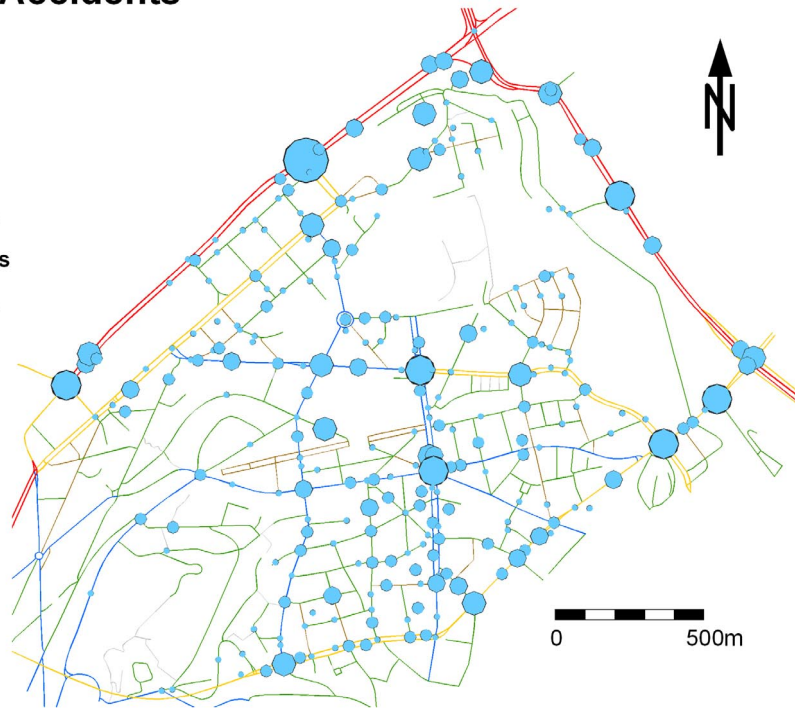
Fig. 4: Frequency of accidents in a part of Stuttgart

Project RUDY

Within the BMBF-Project RUDY (**R**egionale **U**nternehmensübergreifende **DY**namisierung von Fahrplaninformation, Buchung und Betrieb im ÖPNV) two work packages are worked out by the IAGB: incident management und flexible forms of public transport.

A Computerised Operational Control System using geo-data (Geo-COCS) is implemented with the additional functionality of dispatching vehicles with and without respect to a schedule (in co-operation with the Institute of Railway and Transportation Engineering (IEV)). The main subject of the IAGB contribution in the GeoCOCS-centre is providing the geo-data and developing a geo-graphic referenced monitor system for objects of public transport. On-board-part in the vehicles is the determination of position by using a navigation system available on the market, which has the additional functionality to support the driver at the short-term dispatched route. This substitutes the normally used positioning system determining the position relative to the starting point along the projected line.

The following work packages could be finished in 2002:

Functional architecture of a computerised operational control system
The functionality - which is improved or just now available by using geo-data - was identified in the overall functional architecture of a computerised operational control system. The advantage of a GeoRBL using geo-data will be visible looking at the extension of the basic functions like data exchange, visualisation, routing and positioning. Especially the extension of the schedule based operation control by flexible dispatching clearly shows the advantages using geo-data and map based positioning.

Investigation of the metric accuracy of navigation systems
Vehicle techniques equipped in RUDY need a suitable positioning component. Navigation systems available on the market will be used due to their capability to supply with an accurate position in the complete road network and with reference to the digital map. For the decision between two systems on the market, a quality model was worked out defining parameters to assess the information from the positioning component of a navigation system.

Metric accuracy

accuracy	entire number	entire [%]
< 5 m	113	59,20%
< 10 m	174	91,10%
< 15 m	188	98,50%
< 20 m	189	99,00%
< 30 m	191	100,00%

lateral deviation due to matching on wrong road
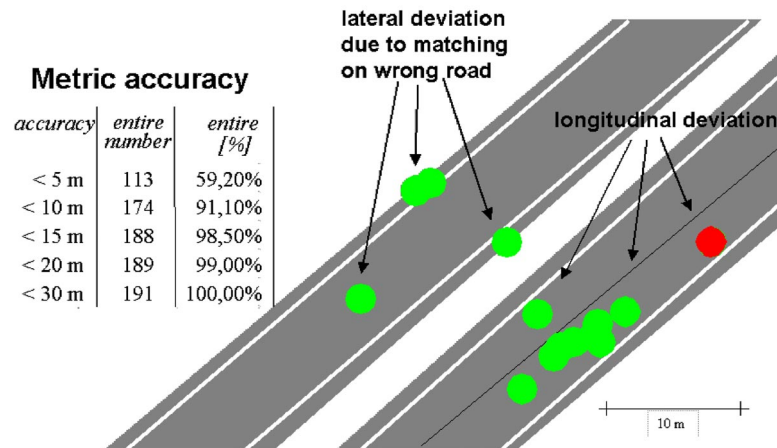
longitudinal deviation

10 m

Fig. 5: Metric accuracy of navigation systems

XML/GML interface for public transport objects
A geo-data interface for public transport objects to extract data from a passenger information system was defined. XML was used in the first step to identify the needed information set from the passenger information system database EFA in cooperation with the company „Mentz Datenverarbeitung". In the following step elements from GML were used to define a geo-data interface which is conform with the Open GIS Consortium specification.
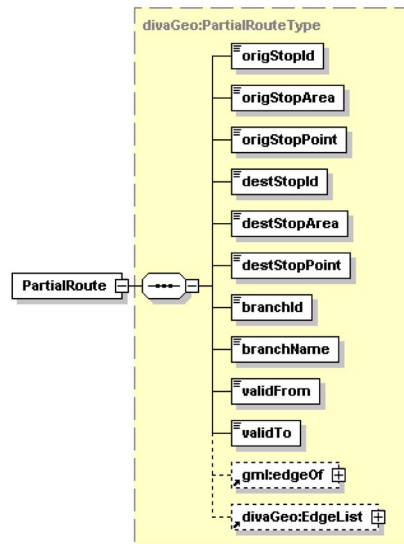
Fig. 6: Elements for the „partial route" between two stop points.

E-learning

GIMOLUS

Within the scope of the BMBF-Project GIMOLUS (GIS- und Modellgestützte Lernmodule für umweltorientierte Studiengänge) an internet-based learning platform is developed. The content of this e-learning system will be the basic knowledge about Geo-information systems and Geo-data acquisition as well as ecologic topics. The project is realized as a cooperation between institutes of the Universities of Stuttgart, Oldenburg, Würzburg und Duisburg.

The IAGB is responsible for the subproject „Data Acquisition and Management" (DAM). The learning moduls „Terrestrial Surveying Methods" and „Mapping" are finished in 2002. The technical realization of the content is done using the meta language XML. The XML documents contain external elements like flash animations, WebGIS applications, graphics and scripts interpretable by the server (e.g. PHP). Based on the results of a media didactical consultation and the evaluation of the prototype moduls, the moduls are revised with the help of students of the master course „Infrastructure Planning".

At present more Data Acquisition learning moduls are in the developing phase. These moduls should complement the education in the study paths „civil engineering", „architecture", „infrastructure planning" and „geodesy and geo-informatics". The content and the included exercises will be relevant for the examinations. The learning moduls should assist education. The bilingual character underlines the universality of the moduls.
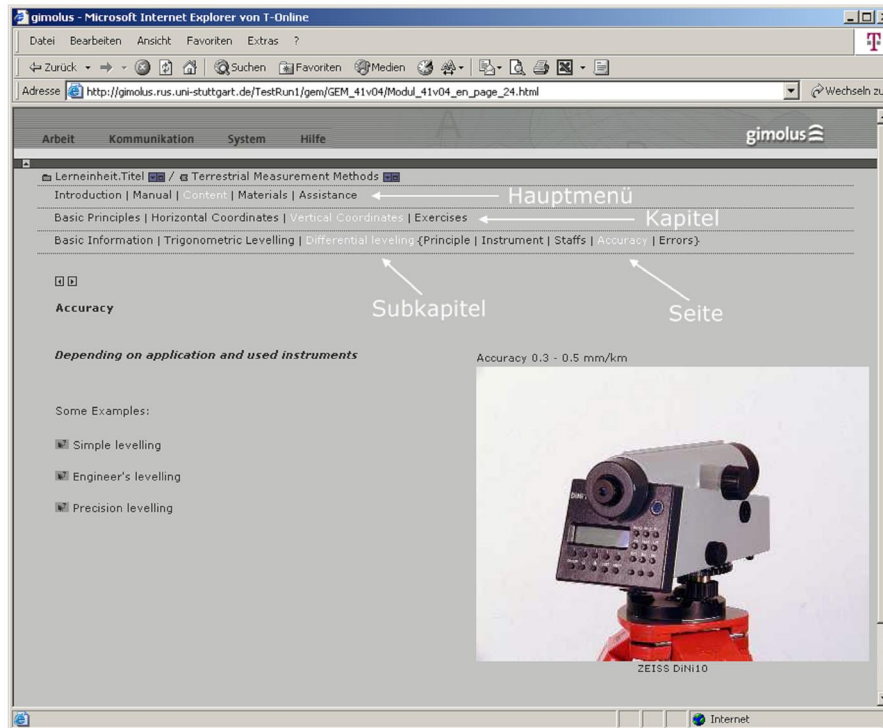
Fig. 7: Navigation structure for the modul terrestrial surveying methods

100-Online

Within this project the possibilities and the limits of new media with respect to realization and integration in education should be determined. Different possibilities to prepare the teaching materials should be tested within the scope of the course „Surveying for civil engineers". Two topics related to surveying instruments (structure of a theodolite and strategy to level a theodolite) and to geodetic computing methods (intersection) subserve as examples. Beside non animated transparencies, that are used like a script, animated transparencies and flash animations are developed for use in teaching and e-learning for private study.

The same techniques were used to represent the design of a route for the courses „Surveying engineering" and „GIS-supported design of routes". The project elucidates the strategy on the basis of the graphical draft of the desired alignment. The project includes the description of the essential alignment elements and the computation of their numerical values.
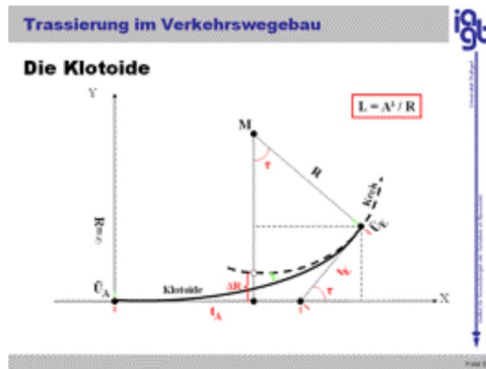
Fig. 8a: Example for a transparency: the clothoid, its geometrical variables and the mathematical relations among these variables
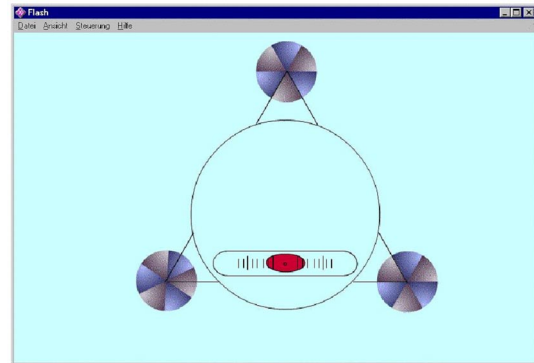
Fig. 8b: Example for a flash animation: illustration of the strategy to level a theodolite

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 were successfully held again. 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, some lectures on the subject „Geometric methods for computer-aided design" were held at the University of Stuttgart.

Special Activity: International Symposium „Networks for Mobility"

The IAGB was deeply involved in the 1st International Symposium „Networks for Mobility" organized by the Centre of Transportation Research under the leadership of Wolfgang Möhlenbrink (speaker) and Ulrich Hangleiter (manager). About 150 scientists and experts from 19 different countries participated. The 75 contributions to the symposium are edited in proceedings.

The contents of the symposium were focussed to three main topics: „Infrastructure and Mobility", „Integrated Traffic Networks" and „Traffic and the Environment". Within this frame, the symposium was a platform to discuss obstacles, opportunities and sustainable solutions which result from physical transportation networks. On the one hand, technical problems from integrated traffic management to car and engine technologies were discussed. On the other hand, political, economic and environmental aspects were taken into account as well as human and social needs. The keywords „integration" and „networking" penetrated all discussions.

Publications 2002

Bettermann, R.: Geodatenbasierte Fahrzeugpositionsbestimmung zur Betriebssteuerung im öffentlichen Verkehr. In: GI-Technologien für Verkehr und Logistik, Jörn Möltgen und Andreas Wytzisk (Hrsg.), Schriftenreihe des Instituts für Geoinformatik, Westfälische Wilhelms-Universität, Münster, 2002.

Bettermann, R.: Traffic Information in Public Transport using High Quality Vehicle Positioning. In: Proceedings of the International Symposium „Networks for Mobility", University of Stuttgart, FOVUS, Stuttgart, 2002.

Kaufmann, Th.; Weippert, H.: Entwicklung von GIS-gestützten interaktiven und multimedialen Lernmodulen zu „Remote Sensing" und „Mapping". In: Strobel, J. et al: Angewandte Geographische Informationsverarbeitung. XIV Beiträge zum AGIT-Symposium 2002, Wichmann-Verlage, S.232-237, Heidelberg, 2002.

Kuhlmann, H.; Gläser, A.: Investigation of new Measurement Techniques for Bridge Monitoring. In: Kahmen, Niemeier, Retscher (Eds.): 2nd Symposium on Geodesy for Geotechnical and Structural Engineering, pp 123-132, Berlin, 2002.

Kuhlmann, H.: Anforderungen an die Geometrie der Festen Fahrbahn für den Hochgeschwindigkeitsverkehr. Symposium Feste Fahrbahn, Berlin, 2002.

Kuhlmann, H.; Heunecke, O.: Auswerteverfahren für Deformationsmessungen aus Sicht der Geodäsie. In: Schriftenreihe DVW, Heft 43 „Interdisziplinäre Messaufgaben im Bauwesen". Verlag Konrad Wittwer, Stuttgart, 2002.

Kuhlmann, H.: Untersuchung von alternativen Messverfahren zur Brückenüberwachung am Beispiel der Kosterwegbrücke. Deutsche Geodätische Kommission, Verlag der Bayerischen Akademie der Wissenschaften, DGK-Reihe B, Heft 311, München 2002.

Linkwitz, K.: „Metrological monitoring of slopes, embankments and retaining walls" (zus. mit Willfried Schwar; Kap. 1.11 in Geotechnical Engineering Handbook, Volume 1:Fundamentals;Ernst @ Sohn/Wiley, Berlin 2002

Linkwitz, K.: „On Some Pecularities of Timber Shells Concerning Formfinding, Manufacturing, Building Physics"; Proceedings of the International IASS Symposium on Lightweight Structures in Civil Engineering, Micro-Publisher Jan B. Obrebski Wydawnictwo Naukowe, ISBN -83-908867-6-6, Warschau 2002

Linkwitz, K.: „Experience from a Course on 'Formfinding and Analysis of Tension Structures' held at the University of Stuttgart for 10 years"; International Journal of SPACE STRUCTURES, Volume 17, No. 2&3 2002; Essex, UK, 2002

Linkwitz, K.: „Computer Aided Design and Manufacture of Timber Roof Shells"; Publications of the Graduate School of Design(GSD), Harvard University, Cambridge, Mass. 2002.

Möhlenbrink, W., Bargende, M., Hangleiter, U., Martin, U. (Eds.): Networks for Mobility - Proceedings of the International Symposium, September 2002, Stuttgart. Stuttgart 2002: FOVUS.

Möhlenbrink, W.: Safety Enhancement for Traffic Management by Vehicle-Infrastructure Coupling. In: Proceedings of the International Symposium „Networks for Mobility", University of Stuttgart, FOVUS, Stuttgart, 2002.

Möhlenbrink, W.; Kuhlmann, H.; Dünisch, M.: Vermessung „Feste Fahrbahn", Verfahren für die Vermessung der Bauart „Feste Fahrbahn". Eisenbahn-Ingenieur-Kalender 2002, Tetzlaff-Verlag, Hamburg, 2002.

Ramm, K.; Bettermann, R.: Positioning method meeting the requirement for flexible management of public transport fleets. 2nd Symposium on Geodesy for Geotechnical and Structural Engineering., S. 464-471, Berlin, 2002.

Wickert, J., Beyerle, G., Hajj, G.A., Schwieger, V., Reigber, C.: GPS radio occultation with CHAMP: Atmospheric profiling utilizing the space-based single difference technique. Geophysical Research Letters, Volume 29, Number 8, 2002.

Stark, M.: Cost factors of combining different spatial databases for future traffic applications. In: Proceedings of the International Symposium „Networks for Mobility", University of Stuttgart, FOVUS, Stuttgart, 2002.

Stark, M.: Cost factor of data acquisition for the ATKIS database for future applications. 2nd Symposium on Geodesy for Geotechnical and Structural Engineering. S. 472-482, Berlin, 2002.

Stark, M.; Kuhlmann, H.: Einsetzbarkeit stiftbedienbarer Feldrechner für den vermessungstechnischen Außendienst. Allgemeine Vermessungsnachrichten AVN, Heft 5/2002, Wichmann, Heidelberg.

Wiltschko, T.; Möhlenbrink, W.: Ein Analyseverfahren zur Bewertung der Informationsqualität in Telematiksystemen. In: Zentrum für Verkehr der Technischen Universität Braunschweig (Hrsg.): Informationssysteme für mobile Anwendungen. Beiträge zum gleichnamigen 2. Braunschweiger Symposium, Oktober 2002, Technische Universität Braunschweig. Berlin: VDE-Verlag, S. 191-209.

Wiltschko, T.: A concept to describe and evaluate the information quality in driver assistance systems. In: Proceedings of the International Symposium „Networks for Mobility", University of Stuttgart, FOVUS, Stuttgart, 2002, S. 184-193.

Diploma Thesis

Buchfink, Michael: Entwicklung einer schnellen Anzeige von Geodaten als Navigationshilfe im großmaßstäbigen Bereich

Jöns, Oliver: Entwicklung eines Fahrzeug-Positionierungsmoduls für Software-basierte Fahrerassistenzsysteme

Krüger, Oliver: Untersuchung der absoluten Positionierungsgenauigkeit des Industrieroboters KUKA KR 15/2

Link, Richard: Erarbeitung von Qualitätsparametern zur quantitativen Beschreibung der Informationsqualität geodätischer Messungen

Weber, Stefan: Zugautonome Ortung mit Map Matching Verfahren

National and International Activities in Scientific and Professional Organisations

Wolfgang Möhlenbrink
Member of Deutsche Geodätische Kommission (DGK)
Member of Deutscher Verein für Vermessungswesen (DVW)
Member of Deutsche Gesellschaft für Ortung und Navigation (DGON)
Member of steering committee „Vermessung" of Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)
Corresponding member of the „Strategic Advisory Group for Telematic Applications for Transport and Related Services"
Member of Deutsche Verkehrswissenschaftliche Gesellschaft (DVWG)
Member of Working Group „Vermessung und Abnahme Feste Fahrbahn" of Deutsche Bahn AG
Coordinator of Working Group „Traffic Guidance and Control" of IAG
Speaker of the directory of Centre of Infrastructure Planning of the University of Stuttgart
Speaker of the Centre of Transportation Research at Stuttgart University (FOVUS)

Ulrich Hangleiter
Member of the International Association of Shell and Spatial Structures (IASS)
Manager of the Centre of Transportation Research at Stuttgart University (FOVUS)

Heiner Kuhlmann
Member of Working Group „Vermessung und Abnahme Feste Fahrbahn" of Deutsche Bahn AG
Member of Working Group „Absteckung und vermessungstechnische Kontrolle" of Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)
Member of Working Group „Ingenieurvermessung" of DVW

Volker Schwieger
>Member of Working Group 3 „Messmethoden und -systeme" of Deutscher Verein für Vermessungswesen (DVW), Head of Sub Working Group „GNSS"
>Member of Working Group „Geodäsie" of Normenausschuss Bauwesen of DIN
>Member of Working Group „Ausgleichungsrechnung und Statistik" of Normenausschuss Bauwesen of DIN, Head of Sub Working Group „Auswertung kontinuierlicher Messreihen"

Education - Lecture / Practice / Training / Seminar

Surveying I, II for Civil Engineers (Möhlenbrink / Stark)	3/1/3/0
Surveying for Architects (Möhlenbrink / Wiltschko)	2/0/1/0
Data Acquisition and Management for Infrastructure Planning (Schwieger)	2/0/0/0
Fundamentals to Surveying for Geodesists (Schwieger)	3/2/0/0
Information Studies for Geodesists II (Wiltschko)	2/2/0/0
Adjustment Theory and Statistics I, II. III (Kuhlmann)	5/3/0/0
Surveying I, II for Geodesists (Kuhlmann)	3/2/0/0
Field Practica in Surveying (Kuhlmann)	10 days
Special Tasks in Surveying (Kuhlmann)	2/1/0/0
Cadastral Survey (Bettermann)	1/1/0/0
Field Practica in Cadastral Survey (Bettermann)	4 days
Surveying Engineering I, II, III (Kuhlmann / Eichhorn)	4/3/0/0
Structural Analysis for Geodesists (Hangleiter)	2/0/0/0
GIS-Supported Design of Road Tracks (Bettermann)	2/0/0/0
Digital and Thematic Cartography (Bettermann)	1/2/0/0
Analytical Formfinding of Lightweight Structures (Linkwitz)	2/0/0/0
Geodetic Seminar I, II (Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink)	0/0/0/4
Land Consolidation I (Mayer)	3/0/0/0

Institute of Geodesy

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Dipl.-Ing. Gerrit AUSTEN	Gravity Field Modeling GRACE/CHAMP
M.Sc. Joseph AWANGE (until 31.1.)	
Dipl.-Ing. Oliver BAUR (since 17.5.)	Satellite Gravity Gradiometry
Dipl.-Ing. Karla BÖLLING	Geoid determination
Dipl.-Ing. M.Sc. Jianqing CAI	Deformation Analysis, Mathematical Statistics
Dipl.-Ing. Gunter FINN	Geoid determination
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Dipl.-Ing. Petar MARINKOVIĆ	Statistical Aspects of Satellite Geodesy
Dipl.-Ing. Stephan NAGEL	Earth Rotation and Gravity Field Modeling
Ph.D. Pavel NOVÁK (since 1.2.)	Gravity Field Modeling GRACE
Dipl.-Ing. Tilo REUBELT (since 1.6.)	Gravity Field Modeling CHAMP
Dipl.-Ing. Verena SEUFER (until 31.12.)	
M.Sc. Mohammad A. SHARIFI (since 11.3.)	Gravity Field Modeling GRACE

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Dipl.-Ing. (FH) Konrad RÖSCH (until 31.5.)
Dipl.-Ing. (FH) Ron SCHLESINGER (since 7.6.)

Guests

Sima ADHYA (London, England) 8.-12.7.
Prof. Dr. Alireza A. ARDALAN (Tehran, Iran) 9.9.-21.9.
David BÉTAILLE (London, England) 8.-12.7.
Mirjam BILKER (Masala, Finnland) 28.10.-8.11.
Dr. Andrzej BORKOWSKI (Wrozlaw, Polen) 8.10.-19.10.
Prof. Yi CHEN (Shanghai, China) 1.9.-31.12.
Prof. Dr. Paul CROSS (London, England) 8.-12.7
M. Sc. Younis FATHY (Mosul, Irak) 1.10.-19.12.
Prof. Dr. D. GHITAU (Bukarest, Rumänien) 15.10.-14.11.
Prof. Dr. P. HOLOTA (Prag, Tschechische Republik) 4.11.-4.12.
Prof. Dr. Juhani KAKKURI (Helsinki, Finnland) 9.-11.1.
Prof. Dr. Yuki KUROISHI (Tokio, Japan) 1.1.-28.2.
Prof. Dr. Lintao LIU (Wuhan, China) 1.3.-31.12.
Prof. Dr. Zdenek MARTINEC (Prag, Tschechische Republik) 15.-18.1., 21.11.-22.11.
Prof. Dr. Sjamsir MIRA (Bandung, Indonesien) 18.11.-25.11.
Prof. Dr. mult. Helmut MORITZ (Graz, Österreich) 8.12.-15.12.
M.Sc. Mahdi MOTAGH (Tehran, Iran) 1.6.-30.9.
Prof. Dr. Markku POUTANEN (Masala, Finnland) 28.10.-1.11.
Prof. Dr. Peter VARGA (Budapest, Ungarn) 21.11.-5.1.
Prof. Lianbi YAO (Shanghai, China) 22.4.-31.12.
Dr. Marek ZIEBART (London, England) 8.-12.7.

Additional Lecturers

Dr.-Ing. Johannes ENGELS, Stuttgart
Dipl.-Ing. Gerhard HAUG, Stadtplanungs- und Stadtmessungsamt, Esslingen/Neckar
Dr.-Ing. Burghard RICHTER, Deutsches Geodätisches Forschungsinstitut, München
Präsident Dipl.-Ing. Hansjörg SCHÖNHERR, Landesvermessungsamt Baden-Württemberg, Stuttgart

Research

Ocean circulation from CHAMP data

Present orbit models for altimeter satellites and models for the stationary sea-surface topography have considerable errors in the length-scale 1000 - 4000 km. Gravity field models derived from CHAMP orbit observations will improve the knowledge about the gravity field in exactly this spectral band. Based on the improved gravity field new orbits for the altimeter satellites could be computed. Since orbit computation is a very complex task, a technology for incremental orbit improvement exclusively due to changes in the gravity field model was developed. With the help of the incremental orbit improvement technique a radial orbit accuracy of 1cm for a complete repeat cycle of the ERS1/2 satellite could be achieved.

A reprocessing of the ERS1/2 altimeter data based on the improved orbits will be the next step. The final step of the DFG-sponsored project will be the assimilation of the CHAMP-improved geoid model and of the reprocessed altimeter sea-surface heights into the ocean circulation model LSG of the Alfred-Wegener-Institute (AWI) in Bremerhaven.
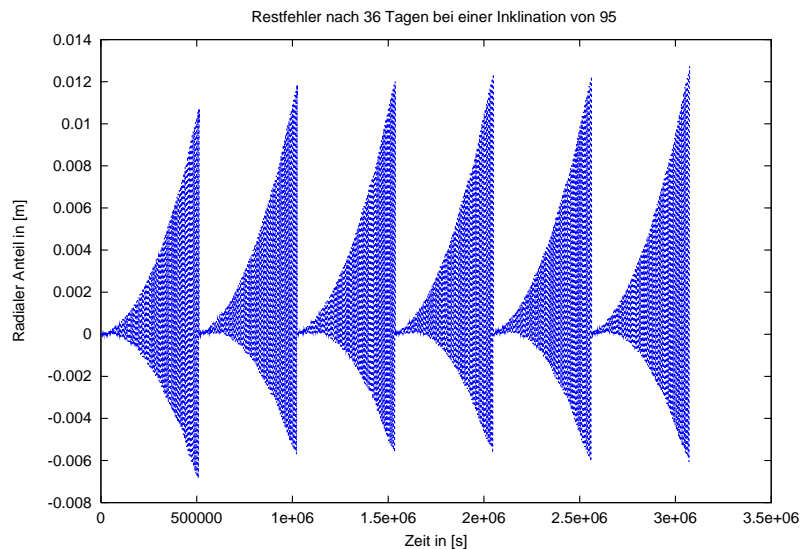
The GRACE processor for a spherical harmonic analysis of temporal variations of geopotential

The GRACE (Gravity Recovery and Climate Experiment) mission consists of two low-orbiting satellites equipped with GPS receivers and very accurate inter-satellite ranging system. These sensors provide data that can be mapped into the geopotential, namely geocentric positions and velocities of the two satellites and an inter-satellite range and range-rate. The unknown geopotential can be solved in terms of its spherical/ellipsoidal harmonic coefficients using the so-called space gravity spectroscopy developed at the Stuttgart University. Due to the relatively long duration of the GRACE mission (five years), temporal variations of the low-degree spherical/ellipsoidal harmonic coefficients are expected to be also recoverable.

During the first year of the GRACE project, an algorithm for determination of the spherical harmonic coefficients of the geopotential from the GRACE observables started to be developed as well as its computer realization. The mathematical model is based on the Newtonian equation that links gravitational acceleration with the corresponding gravitational potential. For the GRACE mission, one such an equation can be written for each of the two satellites using satellites' accelerations derived from a time series of satellites' positions by numerical differentiation. Since the Newtonian equation is strictly valid only in the inertial frame of reference and the GPS observations are related to the Earth-fixed coordinate system (GRS80), corresponding transformations must be defined and applied in the case of real data processing. Moreover, the inter-satellite range can also be treated as a time series that yields after differentiation differences of the two satellites' accelerations, i.e. differences of gradients of the geopotential at the locations of the two satellites. These three equations result in an over-determined system of linear equations (for a truncated spherical harmonic series of the geopotential) with unknown spherical harmonic coefficients.

Alternatively, the pair of the two GRACE satellites can be seen as a one-directional gradiometer with the satellites representing two proof-masses. Expanding the geopotential at the barycentre of the satellites and knowing the spatial orientation of the inter-satellite vector, a complete gradiometric tensor can theoretically be determined. This approach leads to the concept intended for another satellite mission GOCE and offers additional constraints for determination of the unknown coefficients. The approach to be taken for the real data analysis must still be investigated and tested including the most efficient combination of different observables and models.

Several modules of the future software package for processing the GRACE data were developed and tested. A module for transformation between the quasi-inertial frame of reference (frame with space-fixed primary directions but a moving origin) and the Earth-fixed frame was coded and tested independently using MATLAB, Fortran and C compilers. The most effective and accurate algorithm is intended to be moved to a parallel platform for processing of real data. A module for numerical differentiation was developed using two independent approaches: Newton's interpolation formula and Savitzki-Golay's algorithm. The Newton formula was tested extensively using noise-free and noisy data and its applicability for differentiation of data with positively-correlated noise was verified. The latter approach must still be tested using data with a realistic approximation of observation noise.

Concerning the system of linear equations, the model for the satellites' accelerations was successfully tested using both simulated and actual data (CHAMP data were used as replacement for currently unavailable GRACE data). The model for the inter-satellite range was tested for the simulated data only (there is no alternative in any already active satellite). Two independent algorithms showed the availability of recovering the signal from simulated observations.

Simultaneously with the gravity field recovery from the satellite data, a research on gravity field variations was conducted. Namely the effect of deglaciation was studied due to its dominant magnitude among secular effects. The local effect caused by deglaciation of Fennoscandia was computed using a five-layer visco-elastic model of the upper mantle. The results are consulted with the experts in this field.

Space Gravity Spectroscopy: homogeneous and isotropic three-dimensional functions (Taylor-Karman structure, spatial autoregressive processes)

As soon as a space gravity spectroscopy was successfully performed, for instance by means of semi-continuous ephemeris of LEO - GPS tracked satellites, the problem of data validation appeared. It is for this purpose that a stochastic model for the homogeneous and isotropic analysis of measurements, obtained as „directly" measured values in LEO satellite missions (CHAMP, GRACE, GOCE), is studied. An isotropic analysis is represented by the homogeneous distribution of measured values and the statistical properties of the model are calculated. In particular, a correlation structure function is defined by the rank-n tensor (Taylor-Karman tensor) for the ensemble average of a set of incremental differences in measured components. Specifically, Taylor-Karman correlation tensor is calculated with the assumption that the analyzed random function is of a „potential type". The special class of homogeneous and isotropic correlation functions is introduced. In addition, matching the longitudinal, lateral and mixed components, the structural components of the correlation tensor, with experimental results is performed. The lateral, longitudinal and mixed components of the n-rank correlation tensors are then model predictions.

Space Gravity Spectroscopy: Review of difference interpolation processes in LEO satellite orbit analysis

Techniques for analysis of a LEO satellite orbit are reviewed, namely by interpolation algorithms with interpolants based on rational difference processes, for instance Newton's and Schoenberg's B-Splines interpolation techniques. Theoretical and analytical aspects of these methods are analyzed with a special emphasis on the application in space gravity spectroscopy by means of the inertial vector computation at the LEO satellite mass centre from position differences.

SGG - Satellite Gravity Gradiometry

During the last few years enormous improvements and progress in the estimation of the gravitational field (gravity field, respectively) of the Earth by satellite born methods have been achieved. Nevertheless, the requirements of a model for the Earth's gravitational field could not yet be fulfilled. Only an accuracy of the geoid of about 1cm, combined with the estimation of gravity anomalies with an accuracy of 1mgal, both with respect to a spatial resolution of about 80km (half wavelength, corresponding to a harmonic expansion up to degree/order 250), can lay the foundation for recognizing and therefore possibly counteracting global problems and phenomena (modelling of disturbing forces, estimation of the dynamic ocean topography, unification of height systems, estimation of heat transport in the world oceans, see level changes etc.).

The principle of architecture of the ESA satellite mission GOCE (Gravity Field and Steady-State Ocean Circulation Earth Explorer) will for the first time meet the requirements mentioned above. Anticipated for the year 2006, the satellite will collect very precise data on the Earth's gravitational field from a height of about 250km above the Earth's surface within a time interval of two times six months. For the first time - next to the established kinematic orbit analyses (Satellite-to-Satellite Tracking in the high-low mode (SST-hl), for the analysis of the long scale part of the Earth's gravitational field), which so far provides excellent results with respect to the satellite missions CHAMP (Challenging Mini-satellite Payload for Geophysical Research and Application) and GRACE (Gravity Recovery and Climate Experiment) - a gradiometer will be operating as Earth gravitational field sensor (Satellite Gravity Gradiometry (SGG), for the analysis of the short and middle scale part of the Earth's gravitational field). According to the figure, due to the arrangement of six accelerometers (three-dimensional gradiometer), the changes of gravitational accelerations (gravitational gradients) can be estimated with an accuracy up to 3mE ($1E = 1$Eötvös $= 10^{-9}s^{-2}$). By combining six three-dimensional accelerometers, nine components become apparent, which are summarized in the so-called MARUSSI-EÖTVÖS tensor (or gravitational tensor).
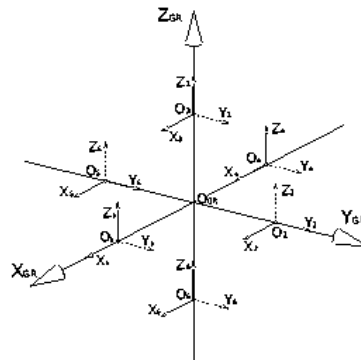

Three-dimensional gradiometer

Of course, the estimation of the coefficients of the Earth's gravitational field by combining SST/SGG raw data requires a multitude of partial stages. With respect to SST analysis, the approved GREGORY-NEWTON interpolation is used for the calculation of accelerations out of kinematic orbit information provided by GPS measurements. Via the transformation of the accelerations of the satellite into an orthonormal coordinate system ($e_\lambda, e_\varphi, e_u$) defined by an Earth reference figure (sphere, ellipsoid), the first set of observation equations is given. In the same way, the transformation of the gravitational tensor can be accomplished. Of course, gravitational (tides, effects of third bodies etc.) as well as non-gravitational (air drag, solar radiation etc.) disturbing influences have to be considered in the data.

This can be done by reducing the influences with a priori models, or alternatively by modelling the influences in the range of analysis. At last, a linear least square adjustment (GAUß-MARKOV) will provide the desired parameters of the Earth's gravitational field. Thereby, stabilization methods for the inversion of the normal equation system as well as a kind of collocation of both observation types (SST, SGG) will be important items.

Gravity field determination from kinematic LEO-ephemeris

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. The procedure is as follows: First, the accelerations acting on the satellite are computed by means of the second order functional of Newton interpolation from quasi-inertial GPS tracked LEO ephemeris. Second, the Newton interpolated accelerations are reduced from disturbing accelerations. Third, the reduced accelerations are balanced by the quasi inertial vector of gravitational field intensity. A Cartesian representation of the gradient is applied. The Cartesian gradient is obtained by means of Chain rule from the spherical gradient in order to apply the efficient recurrence relations of the spherical derivatives. The resulting overdetermined system of equations is solved by means of the special linear GAUß-MARKOV Modell. Numerical instabilities are diminished via regularisation of type TIKHONOV-PHILLIPS, especially the regularisation matrix is based upon Kaula's rule. Detailed simulations exhibit that the interpolation error of the determined accelerations is smaller than $3*10^{-9}$m/s^2 and thus a determination of the long and medium wavelength coefficients with an accuracy of 10^{-14} is possible (corresponding to a geoid error in the sub-mm level). As soon as realistic measurement errors are introduced in the orbits, the accuracy of the coefficients decreases to 10^{-9} - 10^{-10} which means a geoid error of 1 - 2 dm up to degree/order 30/30.
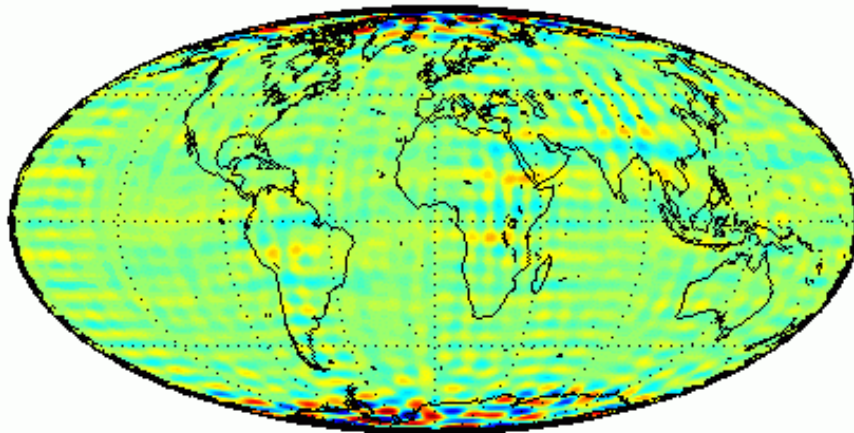
Difference of the recovered potential (in m^2/s^2) from a 11-days CHAMP-kinematic orbit and the GRIM5_**C**1 - model up to degree/order 30/30 on the surface of a reference sphere with R = 6371 km (dynamic orbits)
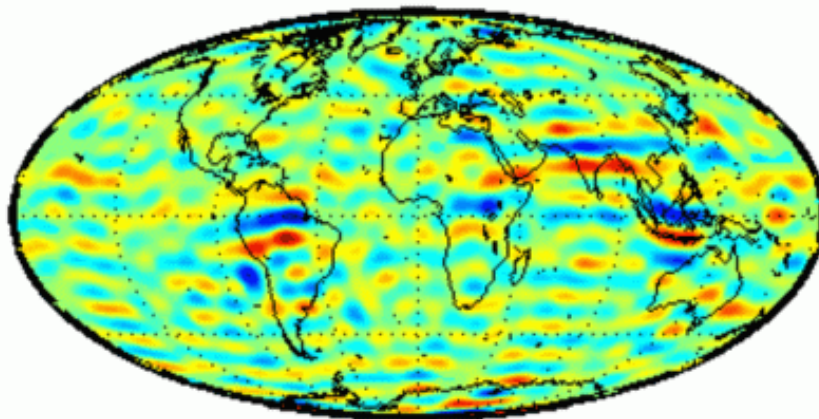

Difference of the recovered potential (in m^2/s^2) from a 45-days CHAMP-Rapid Science Orbit and the GRIM5_**C**1 - model up to degree/order 50/50 on the surface of a reference sphere with R = 6371 km (kinematic orbits)

First analyses of preliminary real CHAMP orbits (dynamic and kinematic - see figures -, accuracy of 10 cm) illustrate by comparisons to existing models, that already from short arcs (1 month or less) a geoid accuracy of 1 - 3dm can be achieved. This means, that an analysis of the whole CHAMP mission should lead to a geoid error of a few cm and thus shall improve the long-wavelength parts of existing models. An enhancement is additionally expected from an increasing accuracy of kinematic orbits.

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 analyzed. The purpose of this project is high-precision multiscale modelling of the geoid starting from functionals of the gravitational potential at points in the outer space. These functionals can be zero order derivatives: Dirichlet boundary value problem; first order derivatives: horizontal and vertical boundary value problems and second order derivatives: gradiometric boundary value problems. These functionals are expressed by *ellipsoidal* scalar-valued, vector valued or respectively tensor valued harmonics.

After removing the reference potential field and reducing the topographic masses outside the reference equipotential surface the downward continuation is performed. The downward continuation written as linear differential equations of first and second kind results in an ill-posed problem. The weighted HAPS inverse (Tykhonov - Philips Regularization, minimal prediction errors included) connects the boundary functionals of the measurements with the disturbing potential on the international reference ellipsoid. Using the ellipsoidal version of Brun's formula the ellipsoidal disturbing potential is converted to geoidal undulations with respect to the international reference ellipsoid.
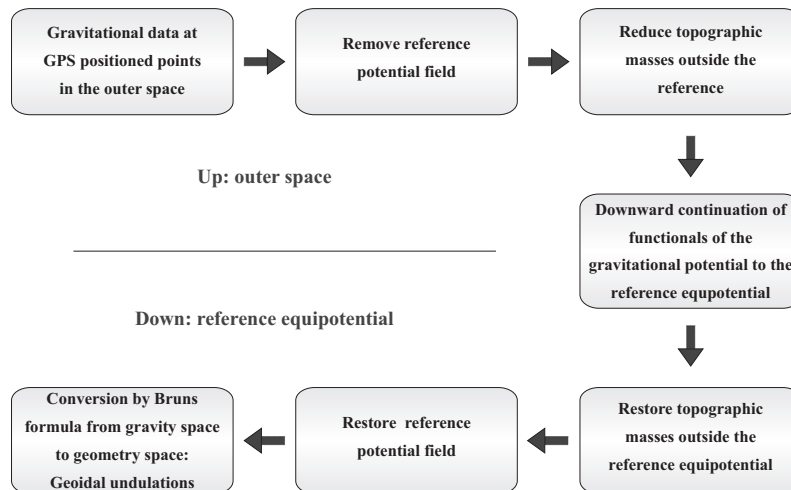
Wavelet Application in Geodesy and Geodynamics

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 taylored to this special wavelet were developed.

skeleton
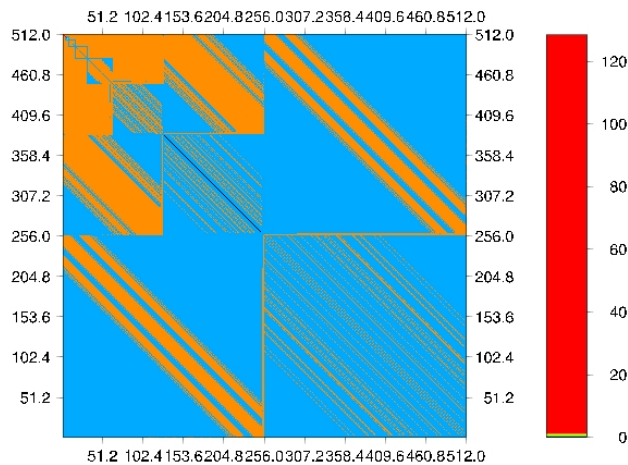
▷ 2. Operator compression. Weak singularities are a typical feature of kernels of geodetic integral formulas. Using wavelets for their discretization thanks to the localization property of wavelets a very sparse matrix structure can be obtained. Then sparse matrix techniques can be applied for a numerically 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.
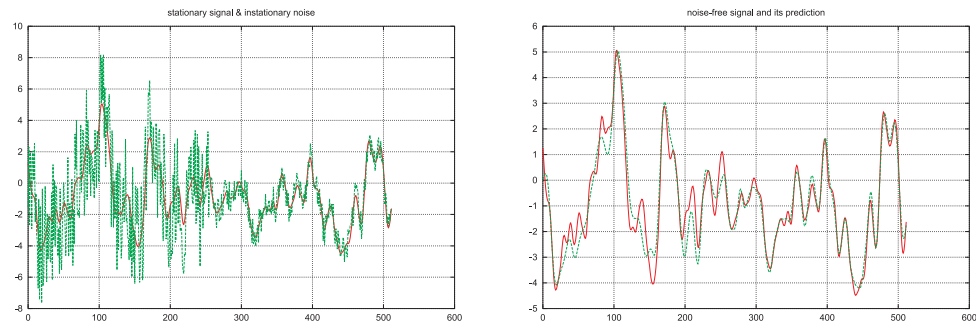
The international cooperation in the field of wavelet application was organized in the framework of the *IAG Special Study Group 4.187*. One important outcome of this cooperation is a wavelet package for the most common wavelet algorithms both in a command-line driven C version as in a platform independent JAVA version. Both versions can be downloaded from the *SSG 4.178 homepage* http://www.uni-stuttgart.de/iag.
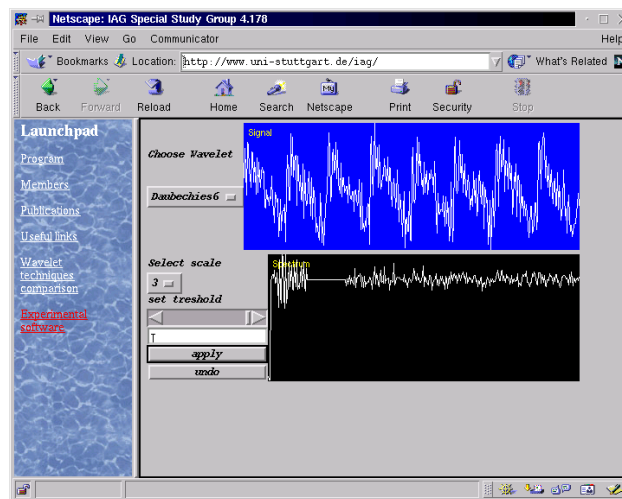
Hypothesis tests and sampling statistics of the eigenvalues and eigendirections of a random tensor of type deformation tensor

The eigenspace components of random tensors, namely of type deformation tensor, (principal components, principal directions) are of focal interest in geodesy, geophysics and geology. They play an important role in interpreting the geodetic phenomena like earthquakes (seismic deformations), plate motions and plate deformations among others. To develop the proper statistical inference for the eigenspace components of a symmetric deformation tensor is the main purpose of our research project. On the assumption that a strain tensor has been directly measured or derived from other observations, such a three-dimensional, symmetric random tensor of second order is a random tensor T which we assume to be a realization from the tensor-valued Gauss normal distribution over $\Re^{3\times3}$ with independently, identically distributed (i.i.d.) tensor-valued observations, but with identical off-diagonal elements. We have proven that the vectorized random tensor y = vech T $\in \Re^{6\times1}$ has a BLUUE estimate $\hat{\mu}_y \in \Re^{6\times1}$ which is multivariate normal, $\hat{\mu}_y \sim \mathcal{N}_6(\mu, N^{-1}\Sigma_y; \hat{\mu}_y)$, where N is the number of full tensor observations and $\Sigma_y = D\{$vech T$\}$ the variance-covariance matrix of vech Y (read vec half). The BIQUUE sample variance-covariance matrix $\hat{\Sigma}_y$ is Wishart distributed $\hat{\Sigma}_y \sim \mathcal{W}_6(N-1, (N-1)^{-1}\Sigma_y; \hat{\Sigma}_y)$. Since the *eigenspace synthesis* of a symmetric random tensor is nonlinear in terms of the tensor-valued observations, the respective parameters have to be estimated within a special nonlinear multivariate *Gauss-Markov* model. We have derived its linearized counterpart for sampling the eigenspace synthesis parameters from the originally nonlinear observation equations. The Σ-BLUUE of eigenspace components and their variance-covariance matrix estimate of type BIQUUE are developed. The test statistics such as *Hotelling's* T^2 and *likelihood ratio statistics* are generated. Hypothesis tests for the random tensor sample means as well as its one variance component are used in the case study of validating a given random strain rate tensor.

Astro-Geodetic 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 analyzed. A new theory is developed for high-resolution geoid computation based on vertical deflections. Its algorithmic version can be described as following: (i) Remove the effect of a reference potential field of very high degree/order at the point of measurement (POM), in particular GPS positioned, either on the Earth's surface or in its external space. 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 to degree/order 360/360. (ii) Remove the effect of the centrifugal potential at POM. (iii) Remove the gravitational field of topographic masses („terrain effect") in a zone of influence of radius r, depending on the highest degree of the harmonic expansion. The third remove step aims at generating a harmonic gravitational field outside the International Reference Ellipsoid (IRE). (iv) The residual vertical deflections are downward continued to the IRE by means

of the inverse solution of the ellipsoidal Dirichlet Boundary Value Problem based upon the modified ellipsoidal Abel-Poisson kernel. As a discretized integral equation of the first kind, downward continuation is Tykhonov-Philipps regularized by an optimal choice of the regularization factor. (v) Restore the effect of the reference field at the corresponding point to POM on the IRE. (vi) Restore the centrifugal potential and (vii) the gravitational field of topographic masses („terrain effect") at the same point. (viii) Convert the gravity potential on the IRE to geoidal undulations by means of the Ellipsoidal Bruns Formula.

Analysis and Modeling of the periodic change of the parameters of polar motion and gravity

In the numerical part, based on the work of J. Vondrák, Prague, and the work of the International Earth Rotation Service (IERS), we analysed and compared long time series of polar motion and nutation. Beside the Fourier- and Wavelet-Analysis, new methods of analysis have been applied. These new methods allows us a more consistent analysis of the time series. They include a priori correlations between simultaneous coordinates and an optimized weighting function. We also determined the linear drift and decadal variations of the pole. We investigated the Chandler and the annual wobble. Finally, the parameters of the Chandler wobble and the annual wobble were repeatedly determined by a sliding window analysis, and their variability was analysed by wavelet transformation.

The analysis of the time series of nutation was still a difficult task. Only a few coefficients of nutation could be collected, but we were able to significantly detect the Free Core Nutation (FCN). The theoretical part is based on a former project, in which the Liouville perturbation theory of the Euler angular momentum equation of the Earth considered as a deformable body leads to a first order inhomogeneous system of integro-differential equations which is classified in terms of system theory. With respect to a viscoelastic Earth model of homogeneous spherical shells the spectrum of the Liouville operator is analyzed. Following a proposal by M. Schneider (1999) the first order system is differentiated to a second order system and alternatively classified as a second order inhomogeneous system of integro-differentiated equations. Its interpretation is that the characteristic equations of polar motion represent an excited, coupled, damped, approximately elliptic oscillator, while the characteristic equation of length-of-day variation documents an excited, damped non-periodic motion. Solutions are presented both in the Laplace as well as in the Fourier domain. Open problems are within the solution analysis in the dynamical wavelet domain and the fractal domain. Through the combination of both, numerics and theory, it was possible for the first time to define the function of excitation and the inelastic part.

Deformation, sea-level and gravity changes: indicators of processes in the system solid earth-cryosphere-ocean

According to previous studies, lateral variations of the lithosphere thickness and the mantle viscosity have significant influence on the mode of the glacial-isostatic adjustment following the disappear-ance of the last Pleistocene ice-sheets. In order to adapt the modelling capacities to

this situation, a new numerical algorithm for computing load-induced deformations of a 3-D viscoelastic earth model was developed. First tests for an axisymmetric model consisting of an ice sheet over a continental lithosphere of enhanced thickness showed that interpretations based on a 1-D earth model underesti-mate the lithosphere thickness beneath central Fennoscandia by about 50 per cent.

A second study was concerned with the implementation of the sea-level equation when coupled with a 3-D viscoelastic earth model. This equation takes into account the vertical ground motion and the geoid change when calculating the relative sea-level change. As an example, the influence of glacial-isostatic adjustment on tide-gauge measurements was investigated. For simulating the impact of the melting of the Pleistocene and present ice masses, an extension of the Pleistocene ice model ICE-3G was developed and the vertical motion as well as the geoid change were predicted by numerical solu-tion of the sea-level equation. A preliminary interpretation for selected tide-gauge stations in Fen-noscandia suggests that an absolute sea-level rise of about 1 mm/a contributes to the secular relative sea-level change measured at these stations.

The topic of a further study was the prediction of temporal gravity variations due to glacial-isostatic adjustment and recent changes of the Greenland and Antarctic ice sheets. Up to degree 40, the pre-dictions are well above the noise level expected for the gravity data of the GRACE satellite mission (Figure 1: Present-day geoid change).

A different aspect was the storage of information relevant to glacial-isostasy in a data bank. The archive includes data on relative sea-level change based on more than 10 000 age-dated samples from shorelines formed during the last 10 000 years. To better quantify the present-day land uplift in Can-ada, permanent GPS stations were installed in cooperation with the Canadian Geodetic Survey at Baie Comeau, Baker Lake, Dartmouth, Kuujjurrapik, Pickle Lake and Val d'Or. These stations have produced data since the beginning of 2002.

List of Publications

ARDALAN A and GRAFAREND E (2002): High Resolution Regional Geoid Computation. In: M.G. Sideris (Ed.): Gravity, Geoid and Geodynamics 2000. International Association of Geodesy Symposia 123 (2002) 301-310

ARDALAN A, GRAFAREND E and IHDE J (2002): Molodensky potential telluroid based on a minimum-distance map. Case study: the quasi-geoid of East Germany in the World Geodetic Datum 2000. Journal of Geodesy 76 (2002) 127-138

ARDALAN A, GRAFAREND E and KAKKURI J (2002): National height datum, the Gauß-Listing geoid level value w0 and its time variation (Baltic Sea Level Project: epochs 1990.8, 1993.8, 1997.4). Journal of Geodesy 76 (2002) 1-28

AUSTEN G, GRAFAREND E and REUBELT T (2002): Analysis of the Earth's gravitational field from semi-continuous ephemerides of a low Earth orbiting GPS-tracked satellite of type Champ, Grace or Goce. In: J. Adam and K.P. Schwarz (Eds): Vistas for Geodesy in the New Millenium, pp. 309-315, Springer Verlag, Berlin-Heidelberg 2002

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AWANGE J and GRAFAREND E (2002): Nonlinear adjustment of GPS observations of type pseudo-ranges. GPS Solutions 5 (2002) 80-93

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BÀNYAI L, PAPP G, VARGA P and WOLF D (2002): Preface. Acta Geod. Geophys. Hung. 37 (2002) 1

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GRAFAREND E (2002): Sensitive control of high-speed-railway tracks, Part I: Local representation of the clothoid. Allgemeine Vermessungsnachrichten 109 (2002) 61-70. Part II: Minimal distance mapping of a point close to the clothoid. Allgemeine Vermessungsnachrichten 109 (2002) 85-94

GRAFAREND E and ARDALAN A (2002): Time evolution of a World Geodetic Datum. In: J. Adam and K.P. Schwarz (Eds): Vistas for Geodesy in the New Millenium, pp. 114-123, Springer Verlag, Berlin-Heidelberg 2002

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GRAFAREND E und SCHWARZE VS (2002): Das Global Positioning System. Physik Journal 1 (2002) 39-44

HÄHNLE J and GRAFAREND E (2002): Erstellung eines digitalen Höhenmodells (DHM) mit Dreiecks-Bézier-Flächen. Zeitschrift für Vermessungswesen 127 (2002) 193-199

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NOVÁK P (2002): The use of airborne gravimetry for precise geoid determination. Geodetic and Cartographic Horizon 5 (2002) 85-94.

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NOVÁK P and HECK B (2002): Downward continuation and geoid determination based on band-limited airborne gravity data. Journal of Geodesy 76 (2002): 269-278. SCHÄFER C and GRAFAREND E (2002): On the determination of gravitational information from GPS-tracked satellite missions. Artificial Satellites, J. Planetary Geodesy 37 (2002) 31-49

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Doctoral Theses

None

Diploma Theses

BAUR O (2002): Ozeangezeitenlösungen aus Bahnstörungen erdnaher Satelliten (Ocean Tides Solutions from Orbit Perturbations of near Earth Satellites)

FINN G (2002): Lokale und globale Darstellung von Lotabweichungen bezüglich des Internationalen Referenzellipsoides (Local and Global Representation of Vertical Deflections with Respect to the International Reference Ellipsoid)

WENGERT M (2002): Wavelet Toolbox in Java

Study Works

> FINN G (2001): Ellipsoidal Harmonic Vertical Deflections
>
> FINN G (2001): ABDAM: Design and Implementation of Software for Ashtech Z-12 GPS-Receiver
>
> JÄGER A (2002): ERS-1 Cross-Over-Adjustment über dem Mittelmeerraum (ERS-1 Cross-Over-Adjustment over the Mediterranean Region)
>
> KLAPP M (2002): Analyse der Datumtransformation von Kugel- und Sphäroidalfunktionen zur Darstellung des terrestrischen Schwerefeldes (Analysis of the datum transformation of spherical and spheroidal function for the representation of the gravity field of the Earth)
>
> WILD F (2001): Tests an der geschlossenen Lösung des „Twin P4P-Problems": Dreidimensionaler Vorwärts- und Rückwärtsschnitt (Tests on the closed solution of the twin P4P problem: Threedimensional intersection and resection)

Lectures at other universities and at conferences

> AUSTEN G, REUBELT T and GRAFAREND E: Space Gravity Spectroscopy - Determination of the Earth's Gravity field by means of Newton interpolated LEO ephemeris - Case study: CHAMP Rapid Science Orbit. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich (Posterpräsentation)
>
> BAUR O: GOCE-GRAND AP4 Statusbericht (Bestimmung einer GPS-Schwerefeldlösung aus kinematischen GOCE-Bahndaten (kartesischer Ansatz) in Kollokation mit GOCE-Gradiometerdaten). GOCE-GRAND Projekttreffen, Bonn, 21. November 2002
>
> BÖLLING K: Forward computation of tensor valued spherical and ellipsoidal harmonics representing the Eötvös tensor (gravity gradients). 3rd Meeting of the International Gravity and Geoid Commission, 26.-30. August 2002, Thessaloniki, Griechenland
>
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>
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>
> BÜRGER S, JACOBY WR and WOLF D: Current glacial isostasy in SE Iceland. ICDP/ODP Workshop, Potsdam. 07.06.02
>
> BÜRGER S, JACOBY WR and WOLF D: Current glacial isostasy in SE Iceland. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002
>
> CAI J and GRAFAREND E: Optimal α for Tykhonov-Phillips regularization by the A-optimal design. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

CAI J and GRAFAREND E: The statistical inference of eigenspace components of a symmetric random tensor of type strain rate. Annual Conference of the International Association for Mathematical Geology, Berlin, 15.-20. September 2002

CAI J and GRAFAREND E: The statistical inference of eigenspace components of a three-dimensional, symmetric random tensor of type strain rate. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

CAI J, GRAFAREND E and SCHAFFRIN B: The A-optimal regularization parameter in uniform Tykhonov-Phillips regularization - α-weighted BLE. V Hotine-Marussi Symposium on Mathematical Geodesy, Matera, Italy, 17.-21. Juni 2002

FINN G: Ellipsoidal Vertical Deflections: Regional, Continental, Global Maps of the Horizontal Derivative of the Incremental Gravity Potential. V Hotine-Marussi Symposium, Space Geodesy Institute, Matera, Italien, 17.-22. Juni 2002

FINN G: Ellipsoidal Vertical Deflections: Regional, Continental, Global Maps of the Horizontal Derivative of the Incremental Gravity Potential. Annual Conference of the International Association for Mathematical Geology, Berlin, 15.-20. September 2002

FINN G: The Modeling of the Ellipsoidal Gravitational Terrain Effect, Case Study: Ellipsoidal Vertical Deflections. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

GRAFAREND E: W_0 und $\dot{W}_0$ Geoid, Randwertaufgaben, Quasi-Geoid - Datum und Datumvariation -. Arbeitskreis der Deutschen Geodätischen Kommission „Theoretische Geodäsie", Universität Bonn, 9. Juli 2002

GRAFAREND E: A closed form representation of Somigliana Pizzetti gravity. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

GRAFAREND E: Deformationsanalyse von ITRF-Satellitennetzen im europäischen Raum: Flächendilatation, Flächenscherung und spektakuläre Krümmungsänderungen. Geodätisches Kolloquium SS2002 im Studiengang Geodäsie, Rheinische Friedrich-Wilhelms-Universität, 13. Juni 2002, Bonn

GRAFAREND E: El Niño-La Niña – ein Katastrophenalarm. Spektakuläre geodätische Ergebnisse zum Anstieg des Meeresspiegels und zur Plattentektonik. Universität Stuttgart, Matinée, 7. Juli 2002

GRAFAREND E: Ellipsoidal harmonic vertical deflections: global and regional modelling of the horizontal derivative of the terrestrial gravity field. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

GRAFAREND E: Fixed effects, random effects and the mixed model: new results of geodetic estimation and prediction theory. V. Hotine-Marussi Symposium, Space Geodesy Institute, Matera, Italien, 17.-22. Juni 2002

GRAFAREND E: Fixed effects, random effects, and the mixed model: the new world of geodetic estimation and prediction theory (including the power Gauß-Jacobi Algorithm). Weikko A. Heiskanen Symposium in Geodesy: 50 years of Geodetic Science at The Ohio State University, 1.-4. Oktober 2002

GRAFAREND E: From „free air" and „*Bouguer* anomaly" to EGM/SEGEN „gravity anomalies": test computations of ellipsoidal harmonic gravity disturbances. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

GRAFAREND E: Geodätisches Weltdatum 2000, Datumtransformation und hochgenaue GPS-LPS Positionierung. Geodätisches Kolloquium SS2002 Fachbereich Vermessungswesen, Universität Dessau / Hochschule Anhalt, 27. Juni 2002, Dessau

GRAFAREND E: Gibt es eine Erdkugel, existiert eine Bjerhammar Sphäre? Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

GRAFAREND E: Globale Positionierungssysteme: Relativistische Aspekte. Physikalisches Kolloquium, Universität Stuttgart, 17. Dezember 2002

GRAFAREND E: Harmonic analysis of the Earth's gravitational field from ephemerides of Low Earth Orbiting (LEO), GPS tracked satellites; Case study: CHAMP. Finnish Geodetic Institute, Masala / Helsinki / Finland, 18. September 2002

GRAFAREND E: Harmonic maps. V. Hotine-Marussi Symposium, Space Geodesy Institute, Matera, Italien, 17.-22. Juni 2002

GRAFAREND E: On the A-optimal design of the regularization parameter in uniform Tykhonov-Phillips regularization - α weighted BLE. V. Hotine-Marussi Symposium, Space Geodesy Institute, Matera, Italien, 17.-22. Juni 2002

GRAFAREND E: System dynamics of polar motion and length-of-day variation. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

GRAFAREND E: The temporal variation of the terrestrial gravity field: the generalized MacCullagh formula. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

GREVE R, KLEMANN V and WOLF D: Ice flow and isostasy of the north polar layered deposits of Mars. DFG-Kolloquium über Mars und die terrestrischen Planeten, Münster. 09.04.02.

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HAGEDOORN J, MARTINEC Z and WOLF D: On the implementation of the sea-level equation in the spectral finite-element domain. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

HAGEDOORN J, MARTINEC Z and WOLF D: Implementing the sea-level equation in the spec-tral finite-element domain: the influence of different ocean models in glacial-isostatic adjustment, 3rd Meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece, Book of Abstracts, p. 108. 30.08.02.

HINTZSCHE M: Neue Standards - Markttransparenz durch Gutachterausschüsse. INTERGEO 2002, 17. Oktober 2002, Frankfurt am Main

KLEMANN V and WOLF D: On the construction of shoreline diagrams and the inference of the earth's relaxation-time spectrum. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

KLEMANN V, WOLF D and WU P: Compressible viscoelasticity: stability of solutions for homogeneous plane earth models. 62. Jahrestagung der DGG, Hannover, Tagungskalender. 05.03.02.

KLEMANN V, WOLF D: Global relative sea-level data based on raised strandlines, 2nd SEAL Prog-ress Meeting, Potsdam. 20.02.02.

MARINKOVIĆ P:Space Gravity Spectroscopy: a review of difference interpolation processes in LEO satellite orbit analysis. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

MARINKOVIĆ P: Space Gravity Spectroscopy: homogeneous and isotropic three-dimensional functions (Taylor-Karman structure, spatial autoregressive processes). Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

MARINKOVIĆ P: Space Gravity Spectroscopy: Variance-covariance transformation from pseudo-observations (Cartesian coordinate ephemeris) to gravity field parameters (spherical or ellipsoidal harmonics) based upon Taylor-Karman structured criterion matrices. First CHAMP Science Meeting, 22.-25. Januar 2002, GFZ Potsdam

MARINKOVIĆ P: Variance-covariance transformation in space gravity spectroscopy, the benefits of Taylor-Karman structured criterion matrices; case study: CHAMP. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

MARTINEC Z and WOLF D: Gravitational signatures of Pleistocene and recent glacial changes. DFG Round-Table Discussion on Mass Transports and Mass Anomalies of the System Earth: Integrated Analysis of Satellite Observations, Bonn. 23.09.02.

MARTINEC Z and WOLF D: Gravitational-viscoelastic relaxation of a spherical earth with a cratonic lithosphere. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

MARTINEC Z and WOLF D: Inverting the Fennoscandian land uplift in terms of a 2D viscosity structure with a cratonic lithospheric root. 27th General Assembly of the EGS, Nice, France, Geophys. Res. Abstr., Vol. 4, Session SE1.05. 24.04.02.

MARTINEC Z and WOLF D: Significance of 2-D viscosity structure in global isostatic adjustment, 2nd SEAL Progress Meeting, Potsdam. 20.02.02.

MARTINEZ Z and WOLF D: Inverting the Fennoscandian relaxation-time spectrum in terms of a 2D viscosity structure with a cratonic lithosphere. 2002 Fall Meeting of the AGU, San Francisco, California. 09.12.02.

NOVÁK P (2002): Airborne gravimetry and its application in geodesy. Presented at the University of Karlsruhe, May 2002.

NOVÁK P (2002): Stable algorithm for determination of the gravimetric geoid. Presented at the Astronomical Institute of the Czech Academy of Sciences, Prague, June 2002.

NOVÁK P and GRAFAREND E (2002): The Gauß-Listing geoid: Stokes-Helmert's approach and beyond. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

NOVÁK P and HECK B (2002): Stable downward continuation of airborne gravity. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

NOVÁK P, ŠIMEK J and KOSTELECKÝ J (2002): A detailed gravimetric quasi-geoid model VUGTK 2002 for Central Europe. 3rd Meeting of the International Gravity and Geoid Commission, 26.-30. August 2002, Thessaloniki, Griechenland

NOVÁK P, ŠIMEK J and KOSTELECKÝ J (2002): On the homogenization of a quasigeoid model for GPS heighting - a case study Central Europe. 27. Generalversammlung der European Geophysical Society, 22.-28. April 2002, Nice, Frankreich

REUBELT T, AUSTEN G and GRAFAREND E: Ellipsoidal Space Gravity Spectroscopy. First CHAMP Science Meeting, 22.-25. Januar 2002, GFZ Potsdam (Posterpräsentation)

REUBELT T: Ellipsoidal Space Gravity Spectroscopy - Räumliche ellipsoidisch-harmonische Schwerefeldbestimmung mit GPS getrackten Ephemeriden niedrigfliegender Satelliten - Fallstudie: CHAMP-Rapid Science Orbits (RSO). Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

REUBELT T: Space gravity spectroscopy: Determination of the Earth's Gravity field by means of interpolated LEO ephemeris - first results from CHAMP Rapid Science and Kinematic orbit. 3rd Meeting of the International Gravity and Geoid Commission, 26.-30. August 2002, Thessaloniki, Griechenland

WOLF D and HAGEDOORN J: Pleistocene and Recent deglaciation in Svalbard: implications for tide-gauge, GPS and VLBI measurements, Workshop of the IASC Working Group on Arctic Glaciology, Obergurgl, Austria. 29.01.02.

WOLF D, FLEMING K and MARTINEC Z: A reinterpretation of the Fennoscandian relaxation-time spectrum for a viscoelastic lithosphere. 3rd Meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece, Book of Abstracts, p. 107. : , 30.08.02.

WOLF D, HAGEDOORN J and MARTINEC Z: A new time-domain method of implementing the sea-level equation in glacial-isostatic adjustment. 2002 Fall Meeting of the AGU, San Francisco, California. 09.12.02.

YAO L and GRAFAREND E: Sensibilitätsanalyse von Hochgeschwindigkeitstrassen. Geodätische Woche 2002, Frankfurt/Main 15.-17. Oktober 2002

Guest Lectures and Lectures on special occasions

> M. BILKER (Finnish Geodetic Institute, Masala, Finland): Comparison of geoid models over Fennoscandia (29.10.)

> Prof. Dr. D. GHITAU (Universität „Dunărea de Jos" Galati): Eine Bestimmung der Mikroplattenbewegung um das Vrancea-Gebiet mittels GPS-Messungen (5. oder 7.11.)

> Prof. Dr. E. GRAFAREND (Geodätisches Institut, Universität Stuttgart): Fixed effects, random effects and the mixed model: new results of geodetic estimation and prediction theory (12.12.)

> Prof. Dr. J. KUSCHE (Department of Physical, Geometrical and Space Geodesy, Delft Institute for Earth Oriented Space Research (DEOS), Niederlande): Geodetic inverse problems: case study satellite gradiometry (7.2.)

> Prof. Dr. Z. MARTINEC (Department of Geophysics, Charles University, Praha, Tschechische Republik / Geoforschungszentrum Potsdam, Division 1: Kinematics and Dynamics of the Earth): Effects of lateral changes in lithospheric thickness on post-glacial rebound modelling (17.1.)

> Prof. Dr. Z. MARTINEC (Department of Geophysics, Charles University, Praha, Tschechische Republik / Geoforschungszentrum Potsdam, Division 1: Kinematics and Dynamics of the Earth): Spherical harmonic analysis of regularly distributed data on a sphere with a uniform or a non-uniform distribution of data uncertainties (21.11.)

> Prof. Dr. H. MORITZ (TU Graz):Prediction, Stability and Chaos in Geodesy and Geophysics (12.12.)

> Prof. Dr. M. POUTANEN (Finnish Geodetic Institute, Masala, Finland): GPS time series (29.10.)

Activities in National and International Organizations

> ENGELS J:
> Member Special Study Group 4.189 (IAG): „Dynamic theories of deformation and gravity fields"

> FINN G:
> Managing Board „Studentenwerk Stuttgart e. V."
> Member „Nutzerbeirat des Zentrums für Sprachausbildung"
> Member „Fakultätsrat der Fakultät Bauingenieur- und Vermessungswesen"
> Member „Erweiterter Fakultätsrats der Fakultät Bauingenieur- und Vermessungswesen"
> Member „Strukturkommission der Fakultät Bauingenieur- und Vermessungswesen"
> Vice member „Senatsausschuß Struktur"
> Vice member „Senatsausschuß Höchstleistungsrechenzentrum Stuttgart"

Vice member „Senatsausschuß Bibliothek“
Chairman „FachschaftsvertreterInnenversammlung (FaVeVe)“

GRAFAREND E W:
Member Examining Board „Studiengang Geodäsie und Geoinformatik“
External Examiner, University South East London, UK
External Examiner, University of Nairobi, Nairobi, Kenya
Member German Geodetic Commission at the Bavarian Academy of Science
Member German Physical Society
Member German Geophysical Society
Member Gauß-Society e.V.
Chairman Scientific Committee German Geodetic Research Institute
Member „Deutscher Verein für Vermessungswesen“
Member „Deutscher Markscheideverein“
Member „Auswahlausschuss Alexander-von-Humboldt-Stiftung“
President of the Special Commission Section IV (IAG), SC1: Mathematical and Physical Foundations of Geodesy“
Chairman Study Group 4.195 (IAG) „Fractals“
Member Special Commission (IAG), SC3: „Fundamental Constants (SCFC)“
Member Special Study Group 5.147 (IAG): „Studies of the Baltic Sea“
Member Special Study Group 2.109 (IAG) „Application of Space VLBI in the Field of Astro-metry and Geodynamics“
Member Royal Astronomical Society
Member American Geophysical Union
Member Bernoulli Society
Member Flat Earth Society

GRAFAREND E W, KELLER W:
Members „Promotionsausschuss“
Members „Erweiterter Fakultätsrat der Fakultät für Bauingenieur- und Vermessungswe-sen“
Members „Studienkommission Geodäsie und Geoinformatik“

HINTZSCHE M:
Member Research Group „Bodenordnung und Bodenwirtschaft der Deutschen Geodätis-chen Kommission (DGK)“
Member „Gesellschaft für Immobilienwirtschaftliche Forschung (gif)“
President 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 German Mathematical Society
President Special Study Group 4.187 (IAG) „Wavelets in Geodesy and Geodynamic"
Member Society of Industrial and Applied Mathematics

NOVÁK P:
Associated member of the IAG. Special Study Group 3.167 Regional Land and Marine Geoid Modelling
Granting Agency of the Czech Republic research grant application reviewer
Reviewer for Journal of Geodesy
Reviewer for Bollettino di Geofisica Teorica ed Applicata

WOLF D:
External Examiner, Freie Universität Berlin
Member Special Commission (IAG)SC1: „Mathematical and Physical Foundations of Geodesy"
Member Commission 14 (IAG): „Crustal Deformation"
Member Special Study Group 4.189 (IAG) „Dynamic Theories of Deformation and Gravity Fields"
Member Canadian Geophysical Union
Member American Geophysical Union
Member European Geophysical Society
Fellow International Association of Geodesy
Member German Geophysical Society

Education - Lecture/Practice/Training/Seminar

Applied Graph Theory (Grafarend)	2/1/0/0
Adjustment and Statistics III (Grafarend)	2/1/0/0
Differential Geometry for Geodesists (Grafarend)	2/1/0/0
Geodetic Astronomy I,II (Richter)	2/2/0/0
Geodetic Coordinate Systems (Keller)	1/1/0/0
Geodetic Seminar I,II (Fritsch/Grafarend/Keller/Kleusberg/Möhlenbrink/Wolf)	0/0/0/4
Gravimetry and Earth Tides (Grafarend)	2/1/0/0

Introduction to Geodesy I,II (Grafarend)	2/1/0/0
Map Projections (Grafarend, Krumm)	2/1/0/0
Mathematical Geodesy I,II (Grafarend, Krumm)	2/2/0/0
Numerical Methods in Geodesy (Keller)	1/1/0/0
Physical Geodesy I,II (Engels, Grafarend)	3/2/0/0
Physical Geodesy III,IV (Keller)	4/2/0/0
Potential Theory and Special Functions (Keller)	2/1/0/0
Lab Satellite Geodesy I,II (Keller)	0/0/1/0
Lab Geodesy/Geodetic Astronomy (Grafarend/Richter)	0/0/1/0
Real-Estate Cadastre I,II (Schönherr)	4/0/0/0
Real-Estate/ Property Valuation I,II (Hintzsche)	2/1/0/0
Satellite Geodesy I,II (Keller)	2/2/0/0
Stochastic Processes for Geodesists (Keller)	2/1/0/0
Geodetic Reference Systems (Ardalan)	2/2/0/0
Geodynamics I: Theoretical Foundations (Wolf)	2/0/0/0
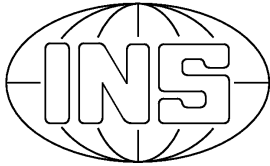
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Secretary: Helga Mehrbrodt
Emeritus: Prof. em. Dr.-Ing. Ph. Hartl

Staff

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Dipl.-Ing. Felix B u t s c h	Navigation Systems
Dipl.-Ing. Denise D e t t m e r i n g	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. Jürgen S c h m i d t	Interferometry
Dr.-Ing. Aloysius W e h r	Laser Systems
Dipl.-Ing. Karl W ö r z	Interferometry
Dipl.-Ing. (FH) Martin T h o m a s	Laser Systems
MSC(IP) José Marcelo Z á r a t e Encalada	Remote Sensing

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
Dipl.-Ing. (FH) Dieter S c h w e i z e r
Technician Edmund K ö n i g
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

MSC Imam M u d i t a

External teaching staff

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

Integrity of Satellite Navigation in Airborne Applications

The DLR (Deutsches Zentrum für Luft- und Raumfahrt) project entitled ISAN (Integrity of Satellite Navigation) investigates the use of GPS or GNSS in all phases of flight especially during approach and landing. The ISAN project involves through participation of a number of collaborating German research institutions and private companies. The Institute of Navigation contributing in studies related to signal multipath and electromagnetic signal interference.

Signal Multipath and Electromagnetic Interference

In high precision applications of satellite navigation systems, a number of common measurement error sources is eliminated or greatly reduced by applying differential corrections provided by a reference station. One of the most severe remaining influences is then the signal multipath effect that corrupts the GPS and GLONASS signals in almost all surroundings, especially in the vicinity

of conducting material. Reflections of the GPS or GLONASS signals from nearby conducting objects can affect the signal at the user location and the ground reference station. New algorithms and software tools are developed and evaluated in order to reduce signal multipath effects.

When satellite navigation systems are used for air navigation, the threat of the reliability, integrity and precision by interfering signal is a very important concern. Within the ISAN (Integrity for Satellite Navigation) project the INS conducts laboratory tests of interference resistance of GPS and GLONASS receivers and field measurements near airports and other possibly electromagnetically contaminated sites.

The INS cooperates with the Deutsche Flugsicherung GmbH (DFS, German Air Navigation Services) in development and deployment of a GNSS Interference Monitoring System (GIMOS). GNSS interference monitoring means to observe signals that could be able to degrade the quality of GPS and GLONASS signals. For this purpose, all signals within the frequency range of GPS and GLONASS are received and their signal properties are evaluated in regular time intervals (e.g. once per second). The goal is to assess the impact on the satellite navigation signal and to gain information about the source of the interference signals.

Integrity of Satellite Navigation Data and Differential GPS Data in Land Applications

Real-time positioning of land vehicles can be usually done by integrated systems consisting of satellite navigation systems, dead-reckoning, and mapmatching. As the accuracy and integrity of these systems is often insufficient for high performance applications, the employment of differential satellite navigation has become an important technology.

One project of the INS is to analyse the availability, accuracy and integrity of the satellite navigation systems and the differential correction data in different environments. Especially in urban canyons, the satellite signals can be shaded or disturbed in such a way that optimal receiver quality can not be guaranteed. In order to give a detailed overview about the performance of differential satellite navigation in different situations, a complete evaluation of the situation will be provided.

Integrity of Satellite Navigation in Airborne Applications

The DLR (Deutsches Zentrum für Luft- und Raumfahrt) project entitled ISAN II (Integrity of Satellite Navigation) investigates the use of GPS or GNSS in all phases of flight especially during approach and landing. The ISAN II project involves a number of collaborating German research institutions and private companies. The Institute of Navigation is continuing to make a contribution in studies related to signal multipath and electromagnetic signal interference, especially for the new signals in space (SIS).

Signal Multipath and Electromagnetic Interference

In high precision applications of satellite navigation systems, a number of common measurement error sources is eliminated or greatly reduced by applying differential corrections provided by a reference station. One of the most severe remaining influences is then the signal multipath effect that corrupts the satellite signals in almost all surroundings, especially in the vicinity of conducting material. Reflections of the satellite signals from nearby conducting objects can affect the signal at the user location and the ground reference station. A simulation toolbox is developed to analyze the multipath mitigation methods for the new GPS and Galileo signals. And further simulation s are going to be applied to analyze the hard- and software methods used to reduce interference errors.

Integrated positioning and orientation for airborne Laser scanning

For years the integration of GPS and INS has ranked among the standard techniques in navigation. Kalman filters are predominantly used for the purpose of this integration. They allow the estimation of positions and sensor errors in real time; in these systems the GPS-receiver serves as supporting sensor for the primary INS observations.

For several years now the results of such measuring systems have not only been applied in navigation, but also have provided a very precise position and orientation required by airborne geodetic data recording equipment (geo-referencing of remote sensing measurements). This application has also been utilised at the Institute of Navigation, which has conducted flights with a in-house-developed Laser scanner for several years.

For these applications it is not important to get the results in real time; the precise trajectory is produced in the post processing mode instead. Furthermore, unlike in navigation applications, the accuracy of the orientation angle determination plays a very important role. For tthe case of Laser scanner measurements, they are needed to determine the Laser view angle pattern to be able to correct measured distances.

At the Institute of Navigation the software packages of the company Applanix (POSPac3.0/POSAV1.3) are used for calculating the position and orientation of the scanner. With these programs the trajectory can be produced both in real time and in post processing mode; GPS and IMU data are integrated through a loosely coupled Kalman filter. The main difference between the real time and the post-processed solution consists in the use of GPS carrier phase data instead of pseudo-range observations for the computation of the GPS solution, and of following up the forward Kalman filter run by a backward smoother.

Researchers at the INS are also developing a new Data integration strategy, which takes into account that in post-processing mode the complete GPS and IMU data sets. This new algorithm is supposed to replace the Kalman filter by a least squares estimation in which the observations are represented by the GPS position solutions and the unknowns are the initial values for positions, velocity and orientation angles, and the error parameters of the INS. This way the GPS

observations play no longer just the part of a supporting sensor. The importance ot the IMU measurements is reduced instead; they serve primarily for interpolation the positions - both in data gaps and between two GPS epochs - and the very precise determination of the sensor orientation parameters. This reversal in the priority can be justified by the fact that airborne kinematic GPS positioning accuracy has been dramatically increased over the last years and that therefore the positions of the flight trajectory are determined almost exclusively by this system. See also figure 1 where the position components from the integrated trajectory differs max. 2 cm from those of the GPS trajectory.
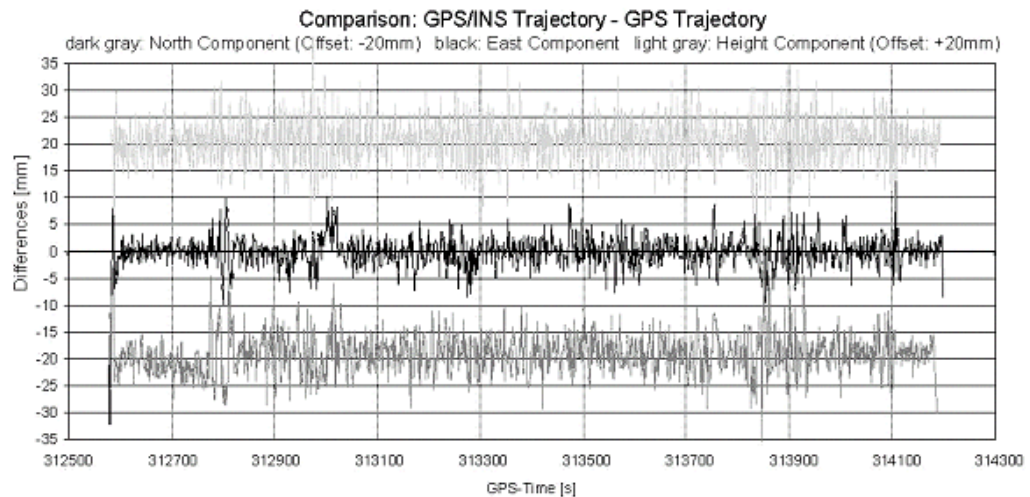
Figure 1

Sensitivity analysis with respect to calibration parameters of airborne ScaLARS laserscanner

For the purpose of sensitivity analysis the opto-mechanical system of the laserscanner is parted into following components: transmitting optics for focusing the intensity modulated laser beam, rotating laser mirror for deflection of measuring beam towards the terrain surface and receiving optics for focusing the reflected radiation. The optical path can be defined as stable due to rugged and torsion-resistant mechanical suspension. The reflection of the incoming laser beam at the deflection unit are described by the mirror rotation α_M around the motors axis, the tilt angle $\beta_M=45°$ of the motor axis and a reeling movement of the mirror of $\gamma_M=7°$. For wider laser strips a $\gamma_M=10°$ mirror can be used alternatively. Due to expected tolerances as a result of mechanical manufacturing and final assembly of the deflection unit, this angles must be calibrated very proper. Recorded angular displacements of the drive motor during runtime are superposed by the offset error $\Delta\alpha_M$ which must be determined additionally (encoder-offset).
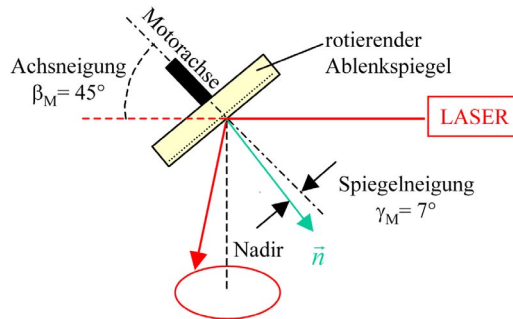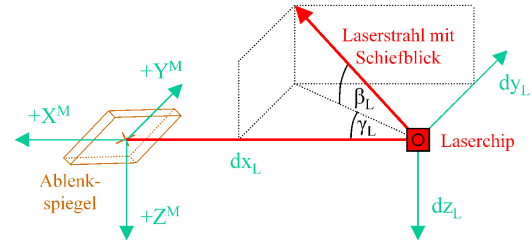
Fig. 1: Deflection unit and tilt angles

Fig. 2: Assembly of laser optics with respect to deflection unit and emitted laser beam

The laser chip, the optical system for focusing and the suspension at the mounting system is also subject to mechanical tolerances. Thus, the laser beam hits normally not exact axial the mirror as figured in Fig. 1 but rather hits aslope the mirror surface as figured in Fig. 2. This effect can be described by two angles β_L and γ_L and must also be determined in the context of internal calibration. Inadequate information about the internal calibration is also a accuracy limiting factor as inaccurate boresight angles and both have a direct influence of the geocoding of laser data. Figure 3 and 4 shows the necessary 1σ accuracy requirements for the internal calibration parameters β_L, γ_L, $\Delta\alpha_m$, β_M, γ_M and the boresight angles in terms of roll, pitch and heading direction $\delta\omega$, $\delta\varphi$, $\delta\kappa$.
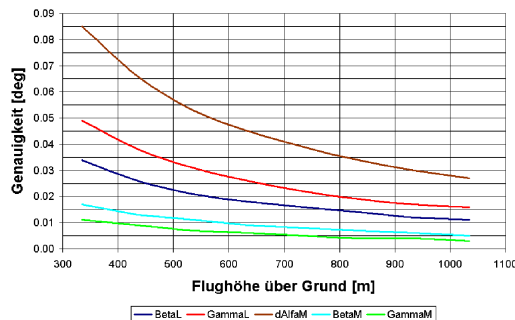

Fig. 3: Needful accuracy with respect to emitted laser beam and mirror angles
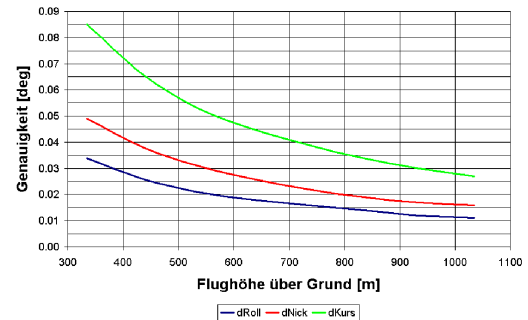

Fig. 4: Needful accuracy with respect to boresight angles

The deterministic computation based on a simulated aircraft flight each with constant flight altitudes above ground, planar terrain, an altitude accuracy of 0.10 m and a position accuracy of 0.25 m maximum with respect to terrain coordinates. All plotted curves show a flight altitude dependent, nonlinear influence with reference to the accuracy of geocoded terrain coordinates. The more flight altitude the more accuracy need with respect to calibration parameter is necessary at a constant accuracy level of terrain coordinates. Both angles β_L and γ_L have to be known with an accuracy of better than 0.018° and 0.024° for a flight altitude of 700 m and higher. At the same flight altitude the mirror angles $\Delta\alpha_M$, β_M and γ_M have to be determined with an accuracy of better than 0.041°, 0.009° and 0.006°. The accuracy curves of the boresight angles show that they have to be determined better than 0.017° and 0.024° for roll and pitch and better than 0.041° for heading direction for a flight altitude of 700 m. Without the essential knowledge about the internal calibration and boresight angles, the geocoded terrain coordinates and derived products like digital landscape models will be superposed by systematic and nonsystematic effects.

Scanning Laser Altimeter (ScaLARS)

A joint laser scanning surveying campaign was carried out together with the company ILV (Ingenieurbüro für Luftbildauswertung und Vermessung) and Fachhhochschule Sachsen-Anhalt, Dessau. The covered area comprised different landscapes as e.g. urban areas, forests, open land, and recultivated brown coal surface mining areas in the Federal States of Germany Saxony, Saxony-Anhalt, Brandenburg and Thuringia. By gathering very precise data over selected calibration areas, it was possible to improve the calibration procedure of the scanning laser altimeter system. This resulted in more precise calibration values and led to stable and more accurate elevation data. Figure 1 shows the derived digital elevation model (DEM) of surface mining area Peres.
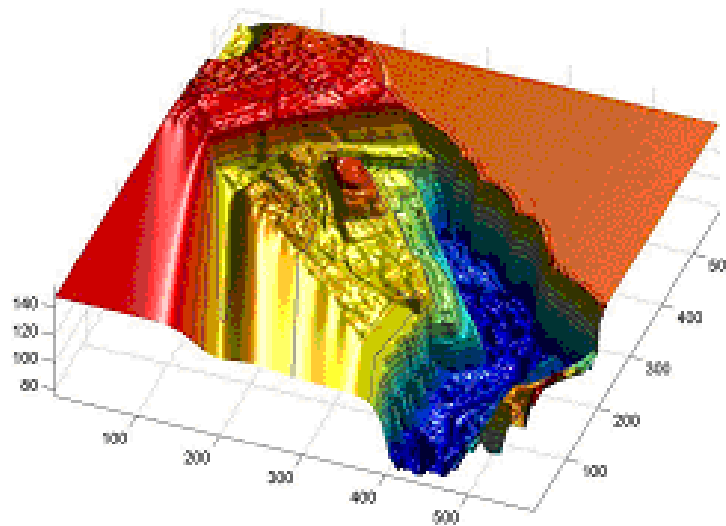
Fig. 1: Surface Mining Area Peres

Near Range Applications

In the working field of scanner applications in near ranges new interactive software tools were developed to improve the merging process of independent laser range images in order to describe solids. The software was first applied on the body of camera which will be installed on light weight airplane carrying out low cost surveying. A stable and precise mounting for the camera is required. Therefore the front part and the sides were digitize with a laser scanner. Figure 2 shows the measurement configuration. 23 independent laser images were digitized and merged (s. figure 3). Each laser image comprises 400x400 pixels. In dependence on the actual view only 40,000 to 65,000 pixels per image could be used. This means after merging, the surface of the camera body is described by about 1.13 million quadruples (Cartesian coordinates plus intensity). The final measurement result is shown in figure 4

Now, this data set will be applied for manufacturing a negative form, which will be used to mount firmly the camera with a well defined orientation in the airplane.
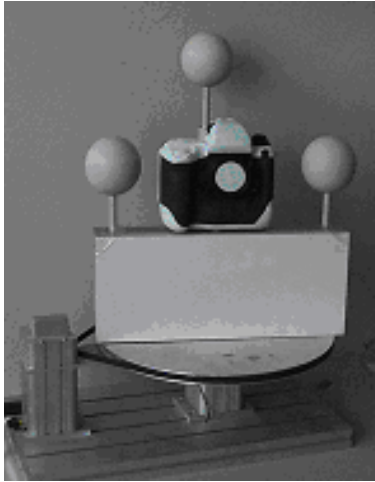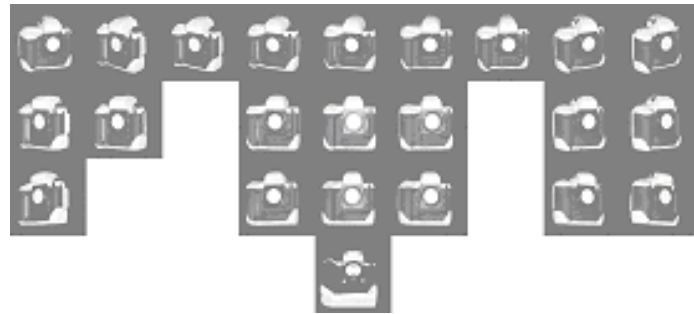
Fig. 2: Measurement Setup

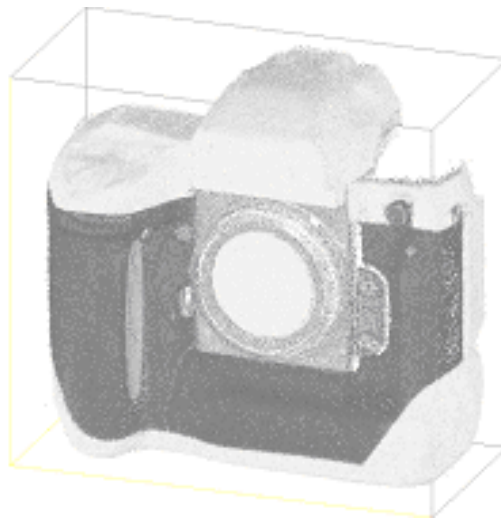Fig. 3: Used Laser Scanner Images

Fig. 4

Remote sensing - SRTM-DEM ACCURACY FOR DIFFERENT SURFACE COVER TYPES

The Shuttle Radar Topographic Mission (SRTM) flown in February 2000 was the first Single Pass SAR Interferometry (SPSI) Mission operated from space. The mission provided worldwide topography information between +60 and -58 degrees latitude. Only limited digital topographic maps with varying resolution and datum were available before the SRTM Mission. Two SAR-Interferometry Systems (X-Band and C-Band) have been used during the SRTM-Mission to establish the consistent global SRTM digital elevation model.

After the instrument calibration phase the Institute of Navigation participated in the validation process for the SRTM height data using a large set of different data including a high precise Laser DGM, an official DEM of LVA, an ERS-INSAR-DEM and digital TK-10 map data.

Our Laser height reference model covered an area of about 1300 square kilometers in the western part of Thüringen and the isle of Borkum. The pixel size of the Laser DGM is 5 m x 5 m and it only consists of *ground points*. „no ground" points (buildings, trees) have been carefully eliminated. It could be shown that the vertical accuracy of the Laser DGM is always better than 0.5 m and typically 0.2 m in open areas.

We also calculated an ERS-DEM, applying our own Interferometry Software Package to ERS-Tandem data. We used ERS-data of both, ascending and descending passes to overcome the problems with shadow and overlay areas in mountainous regions. Areas of missing or unstable phase information (shadow, overlay) could be removed by this method. As a result, the accuracy and reliability of the ERS-height model could be improved significantly.

In a further step a classification of the earth cover has been performed on the basis of additional optical remote sensing data and ERS-intensity and coherence data to test the accuracy of the height values for different surface types. Laser-intensity data and digital information of topographical maps were used to assist and control the classification process.

A Geoinformation System has been established for the Thüringen test area by implementation of the Laser DGM, the ERS-DEM, the official DEM of the LVA Thüringen and digital information from 77 maps of the type TK 10. We used the INS PCI Image Processing System, where the individual data have been resampled to 25 m resolution image files geocoded in WGS84 UTM coordinates and in Bessel Gauß Krüger coordinates.

The accuracy of the SRTM-data was analysed by comparing the SRTM-data with the Laser DGM for different surface types. This was also done for the official DEM of the LVA Thüringen, the ERS-height data and the height information from the TK 10.

The accuracy of the SRTM-height data varies from 4.3 m for open areas to 7.9 m for forest. For the open areas the SRTM accuracy is even better than the existing digital elevation models of the geodetic authorities (LVA Thüringen).
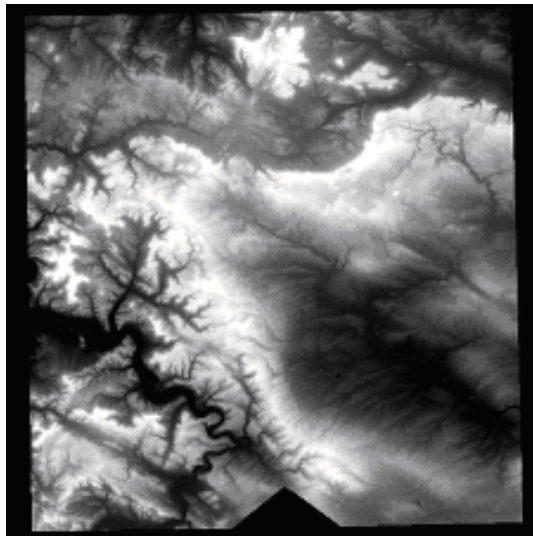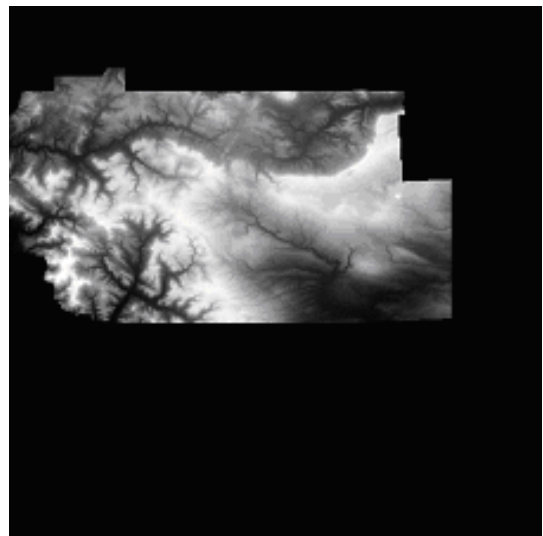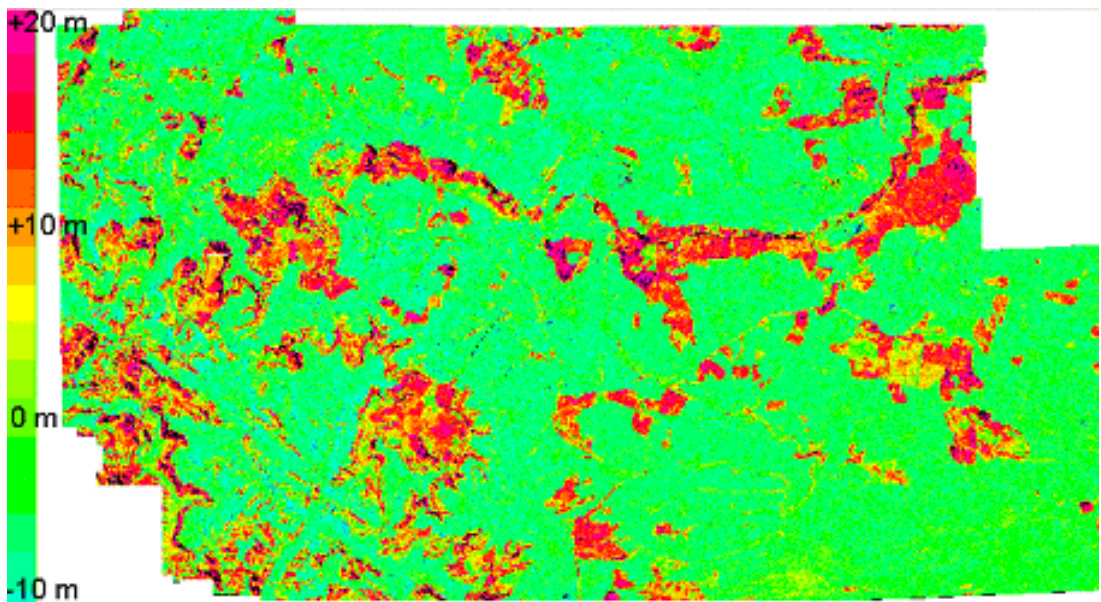
*SRTM Height Model*   *Laser Height Model*

Height Differences between SRTM-DHM and Laser Reference DHM

Mapping material damages due to air pollutants

The research project „Mapping material damages due to air pollutants" (BMU/UBA FE-NO. 201 43 205) is funded by Federal Environmental Agency (UBA). A major goal of the project is to produce maps showing the effects of air pollutants on the deterioration of materials. The research project is part of the research activities within the „International Co-operative Programme on Effects on Materials, including Historic and Cultural Monuments" (ICP Materials). Within ICP Materials the scientific basics of the dose-response-relationships between air pollutants and climate on the one hand and the deterioration of materials on the other hand is established.

The mapping activities are based upon the results of an 8 years materials exposure programme. At 39 test sites in Europe and the Northern America specimen of materials often used to build monuments and buildings are exposed to climate and air pollutant conditions. From the results of the 8 years materials exposure programme dose-response-functions have been derived. These dose-response-functions describe the relationship between climate and air pollutants on the one hand and corrosion rates on the other hand quantitatively. Using the dose-response-functions actual corrosion rates of the materials can be calculated and mapped. The maps indicate the deterioration rate of the materials under actual climate and air pollutant conditions.
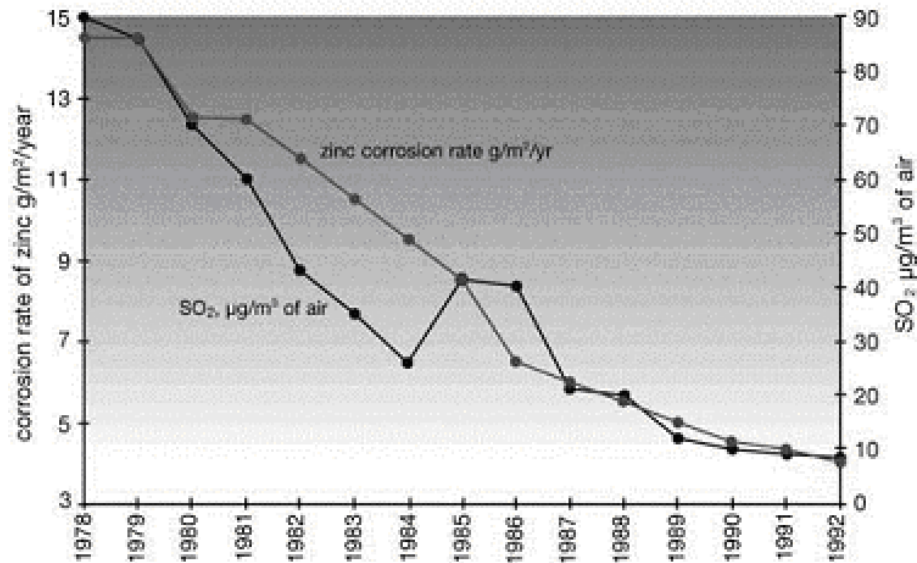

1(Source: Knotkova D and Porter F 1994 Longer life of galvanized steel due to reduced sulphur dioxide pollution in Europe, Ed. proc. Intergalva 94, p GD 8/1-8/20 pub. EGGA, London)

Correlation of air concentration of SO$_2$ and corrosion rates of zinc

Mapping of ecosystem specific long-term trends in deposition loads and concentrations of air pollutants in Germany and their comparison with Critical Loads and Critical Levels

The research project „Mapping of ecosystem specific long-term trends in deposition loads and concentrations of air pollutants in Germany and their comparison with Critical Loads and Critical Levels" (BMU/UBA FE-NO. 299 42 210) is funded by Federal Environmental Agency (UBA). The aim of the project is to support the German Federal Environmental Agency in calculation and verification of national data to be implemented in European scale Critical Loads and Levels maps. Special interest is put on the detection of long term trends in deposition loads and concentration of air pollutants in Germany. The results of this research project are gained by working in close co-operation with „Gesellschaft für Ökosystemanalyse und Umweltdatenmanagement mbH" (ÖKO-DATA GmbH) located in Strausberg, Netherlands Organization for Applied Scientific Research (TNO), Appeldoorn, The Netherlands and Netherlands Energy Research Foundation (ECN), Petten, The Netherlands.

Within the project national maps of concentration levels and deposition loads are generated. Maps of deposition loads are used to calculate Critical Loads exceedances in Germany. The calculation of the maps is based upon measurement network data, additional model estimates and high resolution land use maps. Differences of yearly air pollutant input to several ecosystems on the local scale can be identified and exceedances of Critical Levels and Critical Loads within different regions in Germany can be determined.
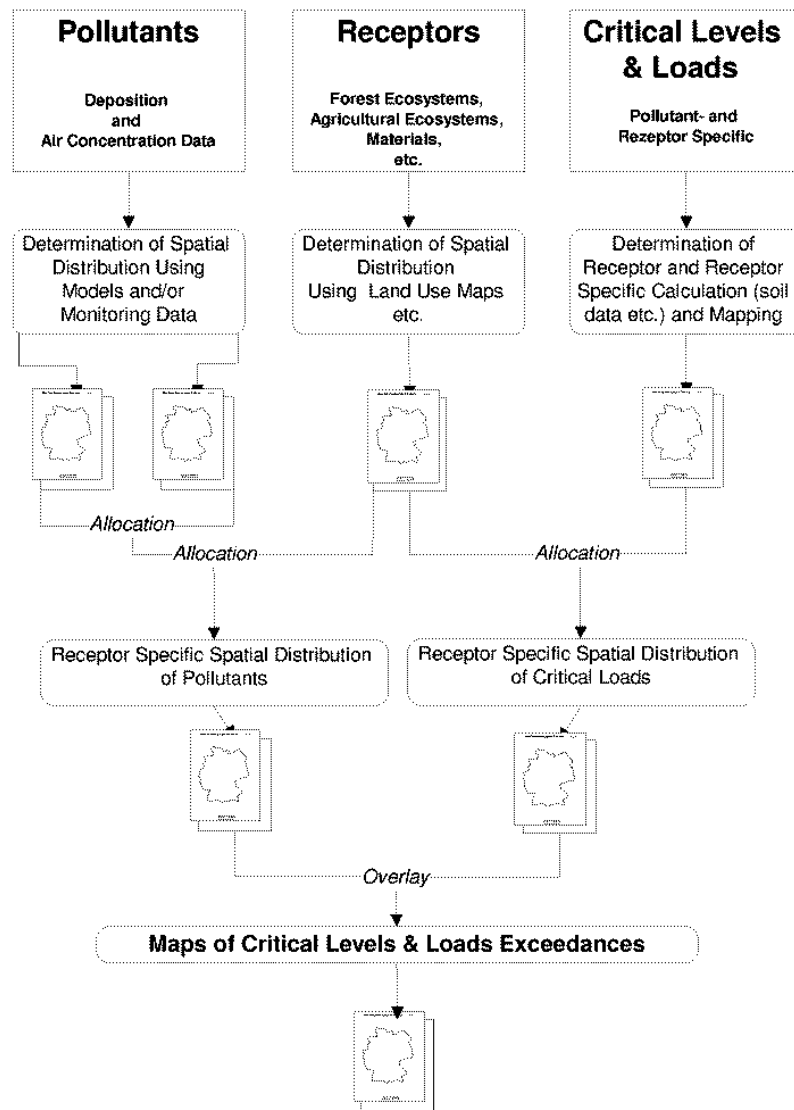
Principles of mapping Critical Loads & Levels exceedances in Germany

Publications 2002

Gauger, Th.: Flächendeckende Kartierung der Gesamtdeposition von Stickstoff in Deutschland. In: Franko, U. (Hrsg.): Stickstoff - ein Nährstoff aus dem Gleichgewicht. Ergebnisse aus dem Workshop „N-Deposition in Agrarökosystemen" vom 02.-03. Mai 2002. UFZ-Bericht 16/2002. Umweltforschungszentrum Leipzig-Halle GmbH.

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Anshelm, F.: Mapping actual corrosion rates in Germany.- UN ECE Convention on Long-range Transboundary Air Pollution. 12th CCE Wokshop on Mapping Critical Loads and Levels. 14 - 17 April 2002, Sorrento, Italy.

Anshelm, F.: Kritische Belastungsgrenzen für Materialien. Koordinierungstreffen der deutschen NFCs der UN ECE ICP's. 30-31 July 2002. Neuschönau, Germany.

Anshelm, F.: Kartierung ökosystembezogener Langzeittrends atmosphärischer Stoffeinträge und Luftschadstoffkonzentrationen in Deutschland und deren Vergleich mit Critical Loads und Critical Levels - Luftschadstoffkonzentrationen und Überschreitung von Critical Levels, Abschlussveranstaltung zum Forschungsvorhaben (BMU/UBA 299 42 210) „Mapping of ecosystem specific long-term trends in deposition and concentrations of air pollutants in Germany and their comparison with Critical Loads and Critical Levels". 10-11 June 2002. Berlin,Germany.

Gauger, Th.: Progress made mapping deposition loads in Germany. Expert Panel on Deposition meeting. 19th June 2002. Fontainebleau, France.

Schiele, O., Kleusberg, A., Horn, A.: A Comparison of Two Integrated Airborne Positioning and Orientation Systems. Prodceedings of the 9th Saint Petersburg International Conference on Integrated Navigation Systems. 27.-29. May, 2002 St. Petersburg/Russia.

Diploma Theses

Kicherer, S.: „Radarleistungsuntersuchung"

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 (Schöller, 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 (Schöller)	3/1/0/0
Practical Course in Navigation (Schöller)	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 (Schöller)	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 Programming in Remote Sensing (Liebig)	2/0/0/0

Institute for Photogrammetry

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Dr.-Ing. Norbert Haala	Multisensor Photogrammetry
Dipl.-Ing.(FH) Werner Schneider	Digital Photogrammetry Lab
Dipl.-Geogr. Timo Balz	Photogrammetry and Remote Sensing

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Dipl.-Ing. Jan-Martin Bofinger	GIS and CAFM
Dipl.-Inform. Martin Kada	3D-Visualisation
Dipl.-Geogr. Steffen Volz	Location Based Services
Dipl.-Geogr. Heike Weippert	eLearning

Optical Inspection

Head: Dipl.-Inform. Jan Böhm	Spatial Segmentation and Object Recognition
Dipl.-Ing. Jürgen Hefele	Optical Inspection

Sensor Integration

|	
Head: Dr.-Ing. Michael Cramer	GPS/INS-Integration
Dipl.-Ing.(FH) Markus Englich	Sensor Labaratory
Dipl.-Ing. Dirk Stallmann	Aerial Triangulation
Dipl.-Ing. Darko Klinec	Pedestrial Navigation

External teaching staff

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Research Projects

Photogrammetry and Remote Sensing

Urban Landscapes

A number of projects on the collection of virtual city models were realized based on a software tool for automatic collection of 3D building models. Within the approach the 3D reconstruction of urban scenes is enabled by the combination of dense height data from airborne laser scanning and ground plans of buildings provided by an existing 2D GIS or map data. For realistic visualization aerial and terrestrial images are additionally mapped against the faces of the reconstructed buildings. Figure 1 shows a data set of the city of Parma, which was collected by this approach.
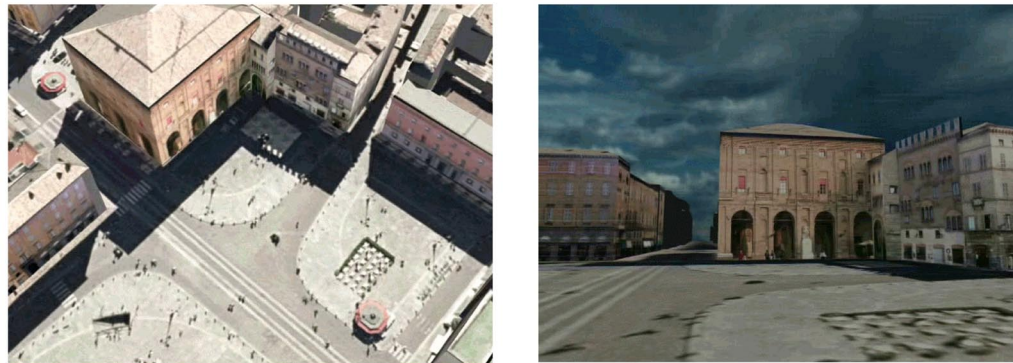
Fig. 1: 3D model of the city of Parma

Additionally, the real-time visualization of urban landscapes was exemplary realized for a city model of Stuttgart. For this purpose the geometry of more than 36,000 buildings covering an area of 25 km^2 was already available from an existing data set provided by the Stadtmessungsamt Stuttgart. In order to enable a realistic visualization, approximately 5000 terrestrial images were used to generate facade texture for more than 500 buildings in the main pedestrian area of the city.

The efficiency of this process could be improved considerably by the application of a self-developed semi-automatic tool for texture mapping. Figure 2 gives an overview of the complete model, figure 3 depicts the degree of realism and amount of image texture available for the inner city. By the application of LOD selection and management and the use of impostors, real-time performance could nearly be achieved for the visualization of this data set on a standard PC.

*Fig. 2: 3D building model of Stuttgart (overview).*

Fig. 3: 3D building model of Stuttgart (detail).

Cylindrical Panoramic Cameras

In a joint project between German Aerospace Center (DLR), University of Auckland and Stuttgart University the design and application of cylindrical panoramic cameras was investigated. Basically such a camera is characterized by rotating linear sensors collecting one image column at a time. Extremely high numbers of pixels per line allow capturing of super-high resolution panoramic images. These can be used for stereo visualisation and stereo reconstruction.

The single-line panoramic camera may rotate part of, or full 360°. This colour camera produces images having 10,200 pixels, and a full 360° image has 55,000 columns for f = 60 mm which results in a single image of size 3.3 gigabytes. The radiometric dynamics is 14 bits and the signal to noise ratio is in the range of 8 bits. The acquisition time depends from the illumination conditions and is about 4 minutes. The whole equipment is portable and is working with a typical car battery. Figure 4 shows a stereo viewable 360° panoramic image of the Tamaki campus.
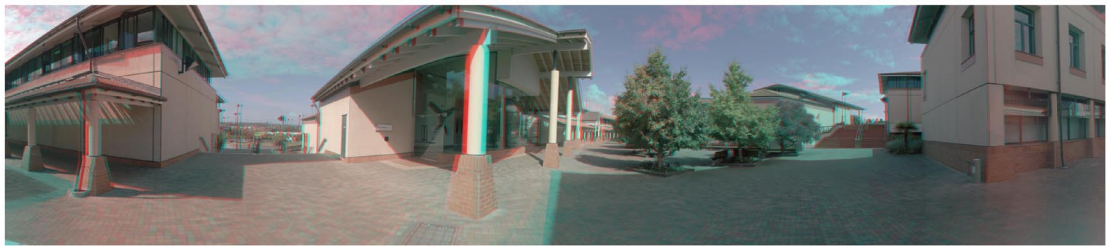
Fig. 4: Panoramic image of Tamaki campus.

Sensor Network for Road Traffic Observation

This project is related with an integrated observation system for dynamic control of roads and traffic based on computer vision approaches. The system will be developed from the German Aerospace Center (DLR) together with other institutes and companies. Vision sensors with computational and real-time capabilities collect relevant traffic data. Efficient algorithms for robust and fast image processing extract objects, like motor vehicles and non-motorized traffic. This system will work at day and night on stable platforms for observation of traffic junctions and on airborne platforms.

An important aspect is the fusion of the data from different sensors. Sensor fusion is an approach to overcome problems with uncertainties, errors and incomplete information from single sensor measurements. Sensor data can be redundant (e.g. same sensor from the same position) or complementary (e.g. different sensors types and different positions). Image matching and registration as a part of the data fusion is a procedure that determines the best spatial fit between two or more images acquired at the same time and depicting the same scene, by identical or different sensors.

Figure 5 shows an example of data fusion concept. At the same time colour images and infrared images are collected. The left figure shows a typical RGB image, which is merged with an affine transformed IR-image (right). Additional thermal features are shown, which can be used for object detection on day and night.

Fig. 5: Data fusion concept.

Geographic Information Systems

Integration of heterogeneous geodata within an open architecture for location-based applications

Within the last few years, a new kind of applications has evolved: location-based services are on their way to become one of the killer applications within the field of information technology. They can be defined as applications which know the positions of their users and provide information and services accordingly on a mobile computer device. Thus, the main criterion for selecting information is the spatial context around the user's location.

At the University of Stuttgart, a research project called NEXUS has been initiated to develop an open and global platform supporting all possible types of mobile, location-based information systems. In order to realize this approach, two crucial prerequisites have to be fulfilled: First of all, different data providers have to be able to integrate their data into a generic data model provided by NEXUS. For this reason, a schema integration takes place that maps the object classes of existing data models onto the classes of the NEXUS Data Schema. Secondly, corresponding object instances stored in the NEXUS format must be matched. Thus, adjoining or overlapping data sets can be merged in order to derive one complete, geometrically and semantically enriched spatial representation meeting the needs of different location-based applications. Therefore, appropriate conflation algorithms have to be developed.

Concerning the mapping of existing data models onto the object classes of the NEXUS Data Schema, it is important to preserve the original properties of features as far as possible. First of all, a suitable amount of object classes has to be defined within the data model of the platform for each specific domain, e.g. road traffic, settlements, etc. Thereupon the relations between them and the corresponding object classes of the existing data models must be determined, i.e. a catalogue including mapping rules has to be set up. This task has been performed on the basis of road data from different suppliers (ATKIS and GDF). In figure 6, the object classes of the NEXUS Data Schema for the road traffic domain are illustrated in UML.
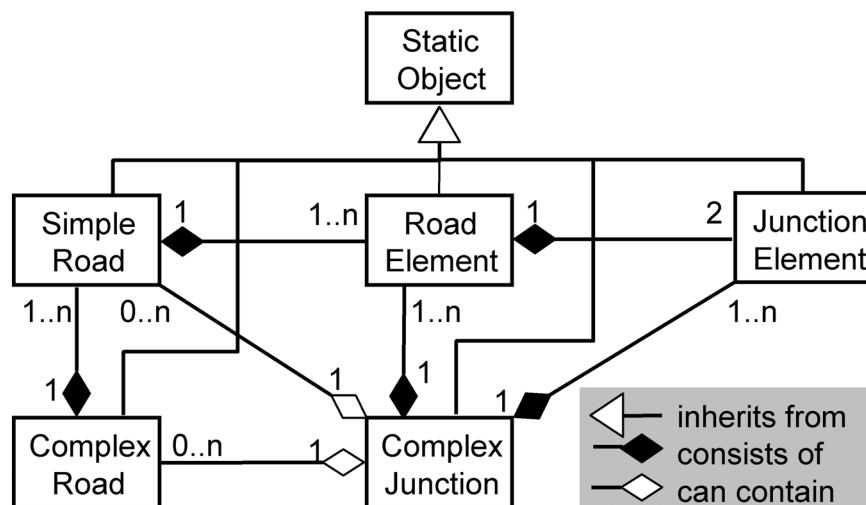

Fig. 6: UML representation of road objects within the NEXUS Data Schema.

If the schema integration has been done, data sets of the original formats like GDF or ATKIS can be converted into an XML-based data exchange language called AWML that is based on the NEXUS Data Schema. Thus, data sets stemming from proprietary formats can be combined within the NEXUS infrastructure.

But, in order to realize a co-processing of heterogeneous spatial data from different origin, it is not only necessary to integrate them in the NEXUS Data Schema. Rather, multiple digital representations of one and the same real world object have to be identified to enable the conflation of adjoining or overlapping spatial data sets. Then, further services like navigation or map production can operate on the conflated data (see figure 7).
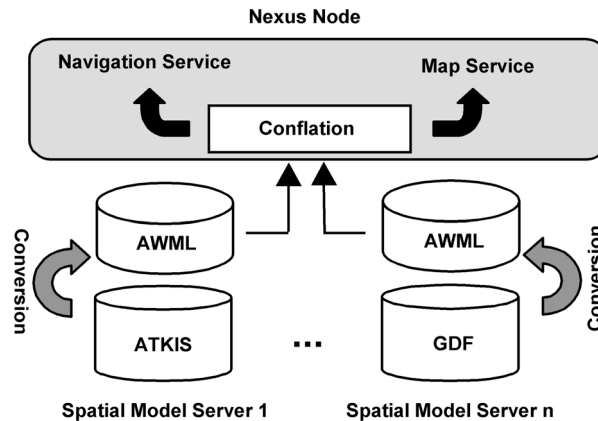
Fig. 7: The role of conflation within the NEXUS platform.

Generally, a conflation process is the more successful, the less discrepancies between two spatial representations in terms of scale and data model exist. In NEXUS, not only data with a high degree of similarity must be matched, but also correspondencies between strongly differing objects must be detected.

Beyond schema integration three more steps have to be carried out for the conflation of heterogeneous data in NEXUS:

▷ Analysis of meta data: Each AWML document contains meta information about its data. For example, the coordinate system, the data origin, the spatial extent, etc. are specified in the header section. This information can be exploited to determine, which operations have to be carried out in the conflation process, e.g. if a coordinate transformation has to be done.

▷ Determination of the conflation category: The conflation category is defined by the type of query the user performs. Either, any data of two AWML files are conflated in overlapping areas to generate one semantically enriched file or two AWML files are merged at their boundaries to receive one coherent data set.

▷ Matching of object instances: Using semantic, geometrical and topological indicators, object instances are compared in order to determine their degree of similarity. The matching process generally involves many conflicts which not only come up due to different data models or scales, but also because of different times of acquisition or erroneous data capturing. Therefore, in some cases a matching process is ambiguous or does not yield any result at all. Sophisticated algorithms capable of solving difficult matching conflicts are currently being developed within the project.

Generalisation of 3D building models

The development of tools for the efficient collection of 3D city models has been a topic of intense research for the past years. In addition to Digital Height Models and 3D data representing streets and urban vegetation, building models are the most important part thereof. Originally, simulations for the propagation of electromagnetic waves used for the planning of antenna locations were the major application areas for 3D building models. Meanwhile visualisation in the context of three-dimensional car navigation systems, virtual tourism information systems or city and building planning has become the key market for that type of data. One important development-driving force for the application of 3D city models is e.g. the widespread use of mobile devices for the provision of location based services. Features like personal navigation or telepointing, i.e. the provision of spatial information by pointing to regions of interest directly on the display, presume a realistic visualisation of the 3D urban environment on these mobile devices. Due to the limited amount of computational power and small size of the displays on the one hand and the huge amount of data contained within a 3D city model on the other hand, the amount of information to be handled, stored and presented has to be reduced efficiently. Thus, the generalisation of the 3D building models becomes a topic of major interest.

A generalisation process basically presumes the elimination of unnecessary details, whereas features, which are important for the visual impression, have to be kept. Especially for man-made-objects like buildings, symmetries are of major importance. For this reason, during the process of generalisation the preservation of regular structures and symmetries like parallel edges, perpendicular intersections or planar roof faces have to be guaranteed.

Our approach derives a coarse model from a highly detailed, polygonal building model by first detecting symmetries between the faces such as coplanarity, parallelism and orthogonality. This is done using explicit rules that compare the normal vector and the distances of the faces. The symmetries are then globalised over the model thru inductive and deductive reasoning. Such an approach is useful when dealing with inaccuracies, which almost always occur during the measurement of building models. Once the symmetries have been detected, the building model is iteratively simplified performing the following three steps: simplification, pre-processing and optimisation. During the simplification step, features like extrusion are detected and removed by the use of edge-collapse and edge-foreshortening operations. The pre-processing step then converts the remaining symmetries of the building into a set of constraints that are used in the final optimisation step. The conversion of symmetries can not always be done in an unambiguous way. To resolve conflicts between competing constraints and to improve the processing time of the following optimisation process, the pre-processing algorithm uses a graph-based strategy. The result is a weighted subset of all constraints which are then used to derive the final shape of the building model in the optimisation step. The optimisation then finds a new position for every vertex in the model by using least squares adjustment in order to fulfil all constraints.

The following screenshots show part of the building model of the New Castle of Stuttgart as it was collected from stereo imagery and an existing outline from the public Automated Real Estate Map. Figure 8 shows the original model whereas figure 9 shows the result of the generalisation process. As it is visible, parallelism and rectangularity have been preserved for the remaining faces. Using textured models, as it is depicted in figure 10 and figure 11, this amount of detail is sufficient for visualisation in most cases.
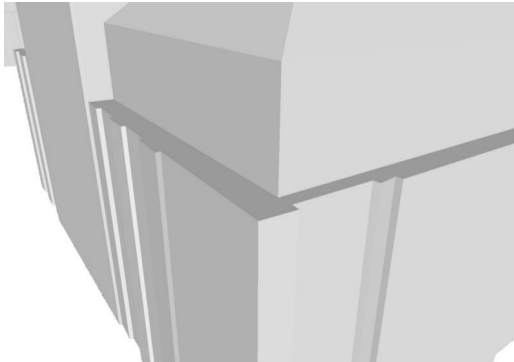
Fig. 8: Original building model
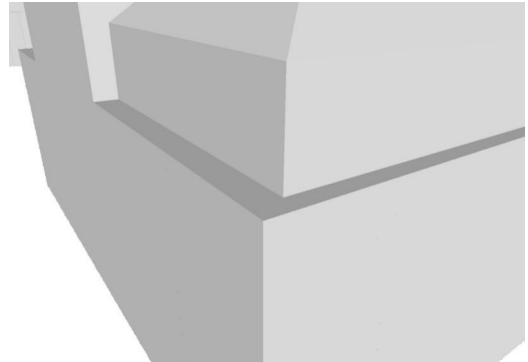
Fig. 9: Simplified building model

Fig. 10: Original model (textured)

Fig. 11: Simplified model (textured)

Sensor integration

GPS/inertial technology in operational use

Within the last years one main focus of the research work was laid on the evaluation of commercial GPS/inertial systems in airborne photogrammetric environments. Since these systems provide the fully exterior orientation elements, positioning and attitude information throughout the whole flight mission, the georeferencing of any kind of sensor data is solved directly. In the ideal case no additional ground control has to be provided for sensor orientation.

From several well controlled test flights the maximum accuracy potential of high quality GPS/inertial systems was proven and some limitations were shown. Nonetheless, all these results are based on especially designed test flights, performed in well controlled environments, with relatively smooth airborne flight conditions. The processing itself typically is done by experts (sometimes by the system manufacturers itself) and enough time is spent for a very careful and extensive data evaluation. The question now is, whether these accuracy from performance tests is transferable to production environments?

To estimate the quality of direct georeferencing in operational use parts of the data from a large production project have been analysed. This project was flown by the HansaLuftbild Air Survey company (Münster/Germany). Within the overall project more than 9000 images were collected with a standard aerial camera during several mission days within an almost two months time period in the beginning of 2001. Parallel to image recording direct exterior orientation elements are provided from the GPS/inertial AEROcontrol-IId (IGI, Kreuztal/Germany) system. Since the overall system installation remained unchanged within almost the whole flight period, investigations on GPS/inertial long term behaviour and accuracy reproducibility in operational airborne projects are possible. One example is given in figure 12.

The figure depicts the mean attitude variation for 8 mission flight days. The values are obtained from comparison of directly observed GPS/inertial attitudes to the estimated values from classical aerial triangulation at a certain number of images from a special calibration test field close to the mission areas. As it can be seen from the figure the quality of GPS/inertial attitude determination is quite consistent, where the mean accuracy (STD) is ∼0.005grad. These results are fairly close to the accuracy obtained from well designed performance test flights. Nonetheless, the κ-angle performs worse, the mean accuracy (STD) over all mission days is 0.013grad. At least for two flight days (Feb 18, Feb 19) significant larger variations can be seen. The main reason for such effects is due to the non-optimal estimation of the internal inertial error behaviour within the GPS/inertial data integration process of these specific flight days, indicating that the accuracy potential is not fully reached within this processing conditions. Although non-optimal data processing deteriorates the quality of direct georeferencing such effects are relatively small to other error sources occurring in practical projects typically. In this particular case for example severe problems with coordinates of ground control points and the definition and transformation of coordinate systems itself were present.

Nonetheless, although the maximum quality of GPS/inertial positioning and attitude determination could not be fully reproduced in this operational environment, the directly observed orientation elements were essential for the later processing of the large image blocks. Without the additional information provided from GPS/inertial the successful triangulation of the image blocks would not have been possible, indicating the relevance of this technology for efficient data processing especially in production environments.
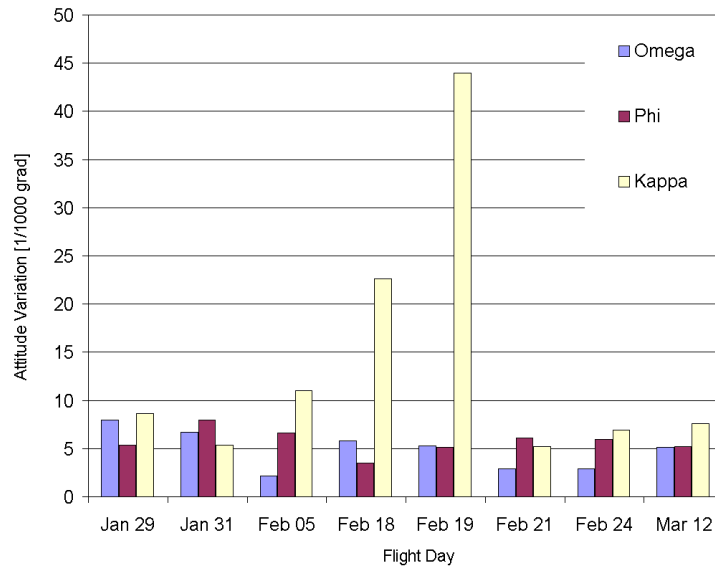

Fig. 12: Mean GPS/inertial attitude quality at different operational flight missions days.

Evaluation of BIRD satellite image data

The BIRD (Bi-spectral InfraRed Detection) satellite mission is a so-called „small satellite" project headed by the Institute of Space Sensor Technology and Planetary Exploration at German Aerospace Centre (DLR) Berlin. The satellite was launched together with two other satellites with the Indian Polar Satellite Launch Vehicle PLSV-C3 rocket at October 22, 2001. The primary goal of this satellite mission is the detection and quantitative analysis of thermal processes on the earth surface, namely forest fires, burning coal seams or volcanic activities. Hence the BIRD satellite carries different imaging sensors operating at visible and infrared wavelengths. Among these, the Medium Wave Infrared Sensor (MWIR, 3.4-4.2 μm) and the Long Wave Infrared Sensor (LWIR, 8.5-9.3 μm) provide images with a ground resolution of 370m. WAOSS-B (Wide Angle Optoelectronic Stereo Scanner), in contrast, is a 3-line CCD stereo camera recording the visible and near infrared spectral range, which maps the Earth at a pixel size of 180m from a 560km altitude. Some more technical specifications on the imaging sensors are given in table 1.

	WAOSS-B	**HSRS**
Spectral range	VIS[a]: 600-670nm NIR[b]: 840-900nm	MWIR: 3.4-4.2μm LWIR: 8.5-9.3μm
Focal length	21.65mm	46.39mm
Field of view	50deg	19deg
Pixel size	7μm x 7μm	30μm x 30μm
Number of pixel	2880	2 x 512 (staggerd)
Resolution	11 bit	14 bit
Ground pixel size	185m	370m
Swath width	533km	190km

a . . . forward and backward channel, b . . . nadir channel

Table 1: Imaging sensors specifications on BIRD satellite.

The ifp is involved in the georeferencing task and the co-registration of the different imaging sensors. Besides the traditional approach of satellite image orientation based on ground control and orbit models the information from additional navigation sensors (i.e. star sensors, ring laser gyros) is considered in the orientation process, to obtain the most flexible and accurate orientation procedure.

The potential of this mission was already shown several times, i.e. the IR sensors were used to detect the large bush fires in Australia end of 2002. Finally, a quite impressive example should be given (© DLR, www.dlr.de/bird). In order to verify the potential of the night-time fire detection a small test fire with approximately 2m x 2m ground size was lighted north of the Ammersee close to Munich. The fire is shown in the right half of figure 13. The corresponding part of the MWIR BIRD satellite image is depicted in the left part of figure 13. Although the ground pixel size is much larger than the effective size of the fire, the hot spot is clearly visible north of the Ammersee.
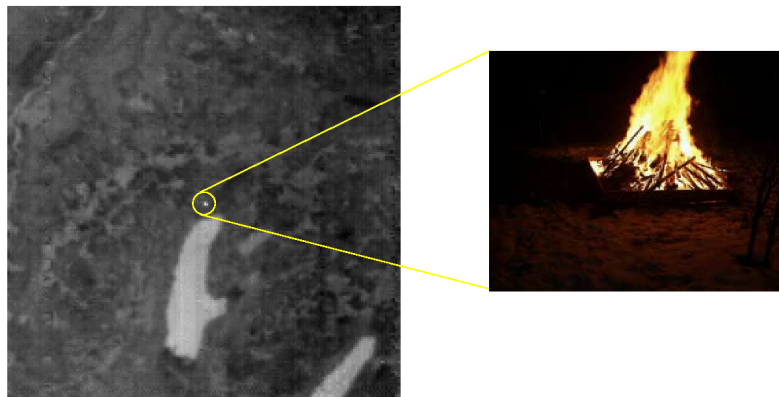
Fig. 13: On ground verification of BIRD night-time fire detection (Ammersee area, Munich)
(© DLR Institute of Space Sensor Technology and Planetary Exploration, www.dlr.de/bird)

NEXUS demonstrator program for location based applications

The NEXUS concept focuses on the development of a global platform supporting different kinds of location based applications. It is intended to facilitate access to services and information by means of the infrastructure. NEXUS aims at the development of such a generic platform, comprising a scalable system architecture, which specifies basic services, open protocols and open data exchange formats needed for location based services.

As an additional pre-requisite real-time positioning information for the individual user is necessary continously, where the accuracy requirements are very high for some applications. Since this location information has to be provided without any gaps, i.e. as well as in outdoor as in indoor environments a complex combination of different positioning techniques, so-called hybrid positioning is essential. Some of the different sensor types which are integrated in this approach are given in figure 14.
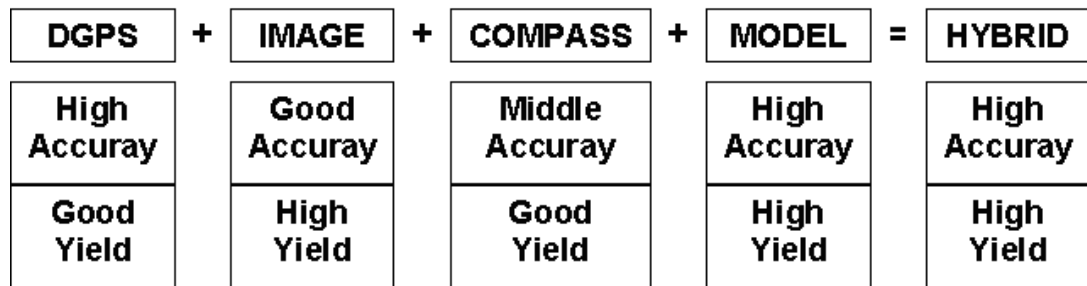

| DGPS | + | IMAGE | + | COMPASS | + | MODEL | = | HYBRID |

| High Accuray | Good Accuray | Middle Accuray | High Accuray | High Accuray |
| Good Yield | High Yield | Good Yield | High Yield | High Yield |

Fig. 14: Hybrid positioning techniques.

Especially the demanding task of indoor navigation requires additional sensors to supplement other technologies, i.e. GPS cannot be used in indoor environments directly. In this case infrared (IR) signals, ultrasonic- or radio based systems assist the navigation process. Furthermore, the so-called hand-shaking - i.e. the transfer between outdoor and indoor navigation - is of particular interest and appropriate interfaces have to be developed.

Within the last months parts of a demonstrator program has been implemented with the new feature of indoor navigation capability. For a certain building floors and rooms are equipped with IR beacons, transmitting unique IDs. From the received IR signals the aspired position information, necessary for navigation or access on location based information, is provided from the indoor module. The basic principle is given in figure 15.
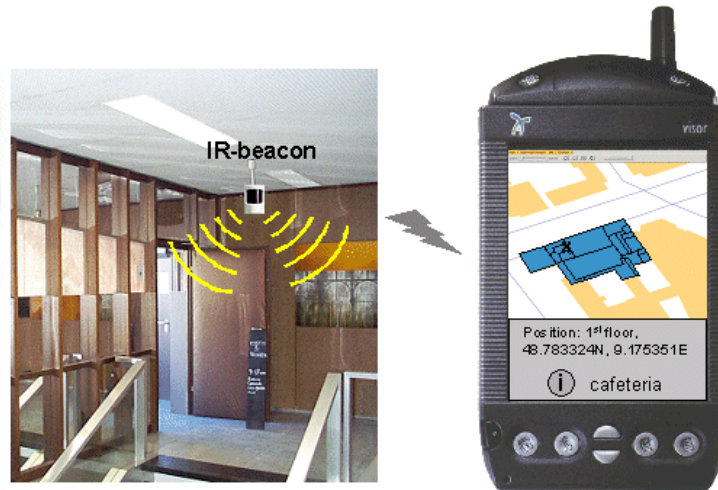
Fig. 15: Principle of indoor positioning.

Besides research work a comprehensive proposal describing future research topics and long-term perspectives was submitted to the Deutsche Forschungsgemeinschaft (DFG, German Research Council) to establish the new Sonderforschungsbereich 627 (SFB 627, Special Research Group). The inauguration evaluation, carried out by representatives of the DFG and a number of independent scientific experts, took place very successfully and since beginning of 2003 the SFB 627 is running as the successor of the successful former NEXUS research group.

Optical Inspection

Appearance-based building detection

We have developed a method for automated appearance-based detection of buildings in terrestrial images. The problem is stated as follows: From an image with a given approximated exterior orientation and a three-dimensional CAD Model of the building, detect the exact location of the building in the image. The method we have developed uses the combination of an imaging device and hardware to approximately measure the exterior orientation. The project is a combination of our work on close-range photogrammetry and virtual city models.

In the view class representation scheme for appearance-based object recognition the space of possible viewpoints is partitioned into view classes. The view classes are arranged in a graph known as the aspect graph (see figure 16). Each node represents a single view class, each arc represents the transition from one viewpoint to another. The methods used to compute the view classes of an object can be very complex and the aspect graph of a non-trivial shape is quite large. In the subsequent matching process the input data has to be compared to a multitude of nodes.

In our framework we make use of the knowledge of an approximated exterior orientation. This translates to a single point in the space of possible viewpoints. Therefore we are not required to compute the full aspect graph. If the viewpoint is known only to a very low accuracy it is sufficient to compute a small part of the aspect graph in the neighborhood of the approximated viewpoint. Our experience shows that for our application it is usually sufficient to reduce the graph to a single node. This single node does not need to be stored beforehand but can be computed on-the-fly. The matching process is restricted to only one instance further reducing computational costs.
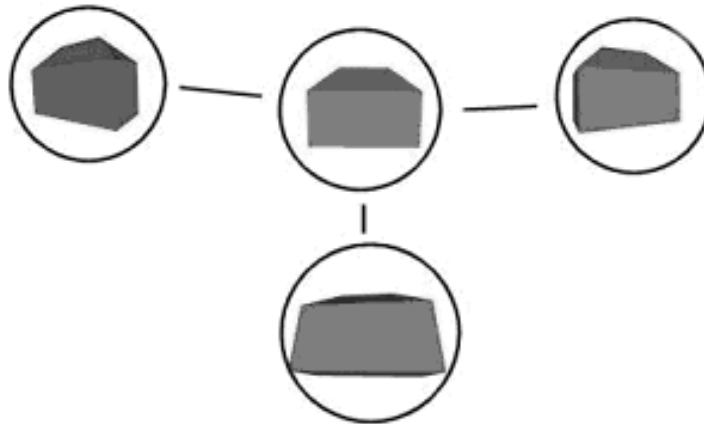
Fig. 16: Part of an aspect graph of a simple building.

To achieve a robust detection we chose to detect the overall shape of the building in the image rather than extracting single features. The intent was, that the overall shape is more robust against clutter of the scene, partial occlusion by trees, cars, pedestrians and other negative influences onto the scene. The silhouette of a building is a good representation for its overall shape. From an existing CAD database the CAD model of the building is rendered for a given view according to the calibration data of the camera. The virtual view of the building is used to extract the silhouette of the building (see figure 17). This representation is then detected in the scene.

Fig. 17: CAD model of a building rendered for a given exterior orientation and the extracted silhouette to the right.

Two examples for the recognition of buildings using our approach are given with the opera house and with a museum in figure 18. The figure shows the initial approximation on the left and the results after matching on the right. In both examples perfect matches were obtained. This is the case even though one can clearly see the problems, which are encountered in realistic situations. For the opera house a tree is obstructing the view partly occluding the building. A shadow is cast across the facade generating additional gradients. The statues on the roof are not represented in the model. Still the algorithm is able to detect the overall shape of the building, demonstrating the robustness of our approach.

Fig. 18: CAD model of a building rendered for a given exterior orientation
and the extracted silhouette to the right.

The method we have developed can be used in augmented reality or pedestrian navigation systems. As an example it could be applied to the presentation of name labels or additional alphanumeric data appearing to be attached to a side of a building. In addition to the visualization of these virtual signposts, more specialized applications could aim at the display of information based on "X-ray vision" in order to present features normally not visible for the user. Typical objects of inter-

est are features hidden behind the facades of a building like the location of rooms or information on infrastructure like the position of power-lines. The integration of augmented reality into a tourist information system is another application for this kind of technique. The so-called telepointing capability is an important feature in implementing an intuitive user interface for location based services .

Demonstrating the principle of a Laser Triangulation Sensor

The projects aim was to design an affordable laser triangulation sensor for demonstration and education purposes. The system is comprised of two off-the-shelf web-cams and a laser-line (see figure 19). The systems design uses two cameras allowing for a photogrammetric calibration of the stereo configuration. The laser line is only used to establish correspondences.

Fig. 19: (a) Laser triangulation sensor built from two web cameras.
(b) The sensor and the visible laser beam on a test object.

The appropriate software components have been developed to perform the image processing tasks and compute the spatial relations. The image acquisition is based on Microsoft's DirectX API. Using this multi-purpose API allows us to integrate almost any imaging hardware and thus gives us a wide choice of cameras. Since the main purpose of the system is educational the software has been structured into small modules. To keep the implementation effort for the user to a minimum the system has been based on the HALCON image processing environment. The user is able to change the individual steps of processing and can explore the effects on performance and accuracy.

In order to compensate for the inaccuracies of low-cost web cameras one has to perform intensive system calibration. Using the standard close-range camera model by Brown, it is possible to remove the strong pin cushion distortions typically encountered when using simple plastic lenses. The setup has been calibrated and tested in various configurations (see figure 20). The system has been shown to work at an accuracy of 1 mm in object space.

Fig 20: (a) Left view of the camera on the test object. (b) Right view. (c) 3D shape of the step object.

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Diploma Theses

Peter Kapusy: Gebäudelokalisierung aus terrestrischen Aufnahmen mittels Silhouetten Matching. Supervisor: Jan Böhm.

Martin Schneck: Analyse von Lastverteilungen im tesion - Telekommunikationsnetz unter Nutzung von GIS - Daten. Supervisor: Volker Walter, Daniel Schnermann (tesion).

Michal Beck: Realisierung eines Geoinformationssystems - Visualisierung und Analysefunktionalität mit einer 3D Engine. Supervisor: Martin Kada.

Franziska Wild: Direkte Verfahren als Alternative zur linearisierten Kollinearitätsgleichung . Supervisor: Jan Böhm.

Steffen Firchau: Optimisation of Virtual Environments - Use of Proxy Geometries for Collision Detection. Supervisor: Norbert Haala.

René Pfeiffer: Modellierung und Implementierung eines 3D-Campusinformationssystems mit GPS-Koordinierung. Supervisor: Martin Kada, Volker Walter.

Study Theses

Martin Götzelmann: Realisierung einer Feldkalibrierung von Inertialen Messsensoren. Supervisor: Michael Cramer.

Mathias Schneider: Einfluss von GPS/INS; Orientierungselementen auf die automatische AT. Supervisor: Josef Braun, Michael Cramer.

Ansgar Jäger: Einfluss fehlerhafter Orientierungselemente in der DGM-Generierung. Supervisor: Michael Cramer.

Eugen Steinbrenner: MapPoint (Microsoft) und GeoMedia Professional (Intergraph) - Eigenschaften, Funktionen, Unterschiede. Supervisor: Jan-Martin Bofinger.

Doctoral Theses Supervisor Dieter Fritsch

Heiner Hild: Automatische Georeferenzierung von Fernerkundungsdaten.

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Activities in National and International Organizations

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Adjustment theory and Statistical Inference I,II,III (Fritsch)	5/3/0/0
Aerotriangulation and Stereo Plotting (Cramer)	1/1/0/0
Cartography (Haala)	1/1/0/0
Civil Law (Schwantag)	2/1/0/0
Close Range Photogrammetry (Böhm)	1/1/0/0
Digital Elevation Models (Haala, Englich)	1/1/0/0
Digital Image Processing (Haala)	1/1/0/0
Geodetic Seminar I, II (Fritsch, Grafarend, Keller, Kleusberg, Möhlenbrink, Reulke)	0/0/0/4
Geographic Information Systems I,II,III (Fritsch, Walter)	5/1/0/0
Geographic Information Systems for Infrastructure Planning and WAREM (Walter)	2/1/0/0
Geographic Information Systems for Environmental Monitoring (Walter)	2/1/0/0
Geometry and Graphical Representation (Cramer)	1/1/0/0
Introduction to Photogrammetry (Cramer)	1/1/0/0
Image Processing and Pattern Recognition I,II (Haala)	4/1/0/0
Image Acquisition and Mono Plotting (Reulke, Cramer)	2/1/0/0
Practical Training in GIS (Bofinger, Hefele, Kada, Volz, Walter, Weippert)	0/0/4/0
Practical Training in Digital Image Processing (Haala)	0/0/4/0
Programming in C++ (Böhm, Kada)	1/1/0/0
Signal Processing for Geodesists (Fritsch, Böhm)	2/1/0/0
Urban Planning (Schäfer)	2/1/0/0