The Department of Geodesy and Geoinformatics

Stuttgart University

2011

editing and layout:
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Dear friends and colleagues,

It is our great pleasure to present to you this annual report on the 2011[1] activities and academic highlights of the Department of Geodesy & Geoinformatics of the University of Stuttgart. The Department consists of the four institutes:

- ▷ Institute of Geodesy (GIS),
- ▷ Institute of Photogrammetry (ifp),
- ▷ Institute of Navigation (INS),
- ▷ Institute of Engineering Geodesy (IIGS),

and is part of the Faculty of Aerospace Engineering and Geodesy.

Research

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

Teaching

Our BSc programme *Geodesy & Geoinformatics* is currently in its third year of operation. We were able to welcome close to 50 new BSc students in Winter Term 2011/2012. The very first batch of BSc graduates is expected to finish in Summer 2012. Accordingly the development of our MSc programme of the same name is being finalized. The Diploma programme is slowly being phased out. Total enrolment, in both the BSc and the Diploma programmes, is stable at about 125 students. In 2011 we have graduated 12 Diploma students. Please visit our website *www.geodaesie.uni-stuttgart.de* for additional information on the programmes.

In its 6th year of existence, our international MSc programme *Geomatics Engineering* (GEOENGINE) has a solid enrolment of 22 students. We attract the GEOENGINE student population from such diverse countries as China, Romania, Palestine, Iraq, Iran, Pakistan, Nigeria, Chile and Colombia. Please visit *www.geoengine.uni-stuttgart.de* for more information.

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

Beyond the transition from the old Diploma programme into the BSc/MSc-system we also put much effort into a general overhaul of the GeoEngine programme. The University of Stuttgart is aiming at a so-called system accreditation. This process necessitated an adaptation of GeoEngine to conform to the general university's guidelines for MSc programmes. In fact, we stood very much in the spotlight as the accreditation agency selected GeoEngine as one of only three programmes out of the whole range at the University of Stuttgart to be scrutinized for quality processes. Key elements of our redesign are a change from 3 to 4 semesters, a better spread of credit points over the semesters and the opportunity for more elective courses. The accreditation process will continue into 2012. In the mean time we are confident that we can offer a very attractive GeoEngine programme also to future students.

Awards and scholarships

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

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

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

Below is the list of the recipients of the 2011 awards and scholarships. The criterion for all prizes is academic performance; for some prizes GPA-based, for other prizes based on thesis work. Congratulations to all recipients! We take particular pride that for the second time on row one of our students, Ms. Kan Wang, received the Diploma Thesis Award from the Friends of the University, an award for which she stood in direct competition with theses from the Aerospace Engineering Programme.

Award	Recipient	Sponsor	Programme
Karl-Ramsayer Preis	Kan Wang	Department of Geodesy & Geoinformatics	Geodesy & Geoinformatics
Harbert-Buchpreis	Kan Wang	DVW	Geodesy & Geoinformatics
Diploma/MSc Thesis Award	Ali Khosravani	F2GeoS	GEOENGINE
Vordiplompreis F2GeoS	Jiawei Yang	F2GeoS	Geodesy & Geoinformatics
MS Photogrammetry / Vexcel Imaging Scholarship	Xu Wang	MS Photogrammetry / Vexcel Imaging	GEOENGINE
IGI Scholarship	Jun Chen	IGI mbH	GEOENGINE
matching funds	Wenjian Qin Jun Chen Hamid Gharibi	DAAD	GEOENGINE
Diploma Thesis Award	Kan Wang	Friends of the University of Stuttgart	All university, one per faculty

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Head of Institute

Prof. Dr.-Ing. habil. Volker Schwieger

Secretary

Elke Rawe

Emeritus

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

Scientific Staff

Bara Al-Mistarehi, M.Sc. (since 01.10.2011)	Construction Process
Dipl.-Ing. Alexander Beetz	Sensor Integration
Shenghua Chen, M.Sc.	Kinematic Positioning
Dipl.-Ing. Jacek Frank (until 30.01.2011)	Quality Assurance
Dipl.-Ing. Ralf Laufer (until 28.02.2011)	Quality Assurance
Xiaojing Lin, M.Sc. (since 01.10.2011)	Kinematic Positioning
Dr.-Ing. Martin Metzner	Akad. Oberrat
Dipl.-Ing. Annette Scheider	Engineering Geodesy
Rainer Schützle, M.Sc.	Information Quality
Dipl.-Ing. Jürgen Schweitzer	Construction Process
Dipl.-Ing. Li Zhang	Kinematic Positioning
Dipl.-Ing. Bimin Zheng	Engineering Geodesy
Zhenzhong Su, M.Sc. (until March 2011)	Sensor Integration

Technical Staff

Martin Knihs
Lars Plate
Doris Reichert
Mathias Stange

External teaching staff

Dipl.-Ing. Thomas Meyer - Landratsamt Ludwigsburg - Fachbereich Vermessung

General View

The Institute of Engineering Geodesy (IIGS) is directed by Prof. Dr.-Ing. habil. Volker Schwieger. It is part of the faculty 6 „Aerospace Engineering and Geodesy“ within the University of Stuttgart. After having accepted the chair of a Professor for „Engineering Geodesy and Geodetic Measurements“ in the year 2010, Prof. Schwieger became a full member of the German Geodetic Commission (Deutsche Geodätische Kommission - DGK) at the 69th annual meeting of the DGK which was held from 23rd to 25th November 2011 in Munich. Furthermore, Prof. Schwieger is a member of the section „Engineering Geodesy“ within the DGK. He is head of the DVW working group 3 „Measurement Techniques and Systems“ and chairman of the FIG working group 5.4 „Kinematic Measurements“.

In addition to being a member of faculty 6, Prof. Schwieger is co-opted on to the faculty 2 „Civil and Environmental Engineering“. Furthermore, IIGS is involved in the Center for Transportation Research of the University of Stuttgart (FOVUS). Prof. Schwieger presently acts as speaker of FOVUS. So, IIGS actively continues the close collaboration with all institutes of the transportation field, especially with those belonging to faculty 2.

The institute’s main tasks in education focus on geodetic and industrial measurement techniques, kinematic positioning and multi-sensor systems, statistics and error theory, engineering geodesy and monitoring, GIS-based data acquisition, and transport telematics. Here, the institute is responsible for the above-mentioned fields within the curricula of „Geodesy and Geoinformatics“ (currently Diploma and Bachelor courses of study) as well as for „GEOENGINE“ (Master for Geomatics Engineering in English language). In addition, IIGS provides several courses in German language for the curricula of „Civil Engineering“ (Bachelor and Master) and „Technique and Economy of Real Estate“ (Bachelor). To integrate the content of teaching into the master courses of „Aerospace Engineering“ is presently also one of the main activities. Furthermore, several lectures are given in English to students within the master course „Infrastructure Planning“. Finally, eLearning modules are applied in different curricula. Also during the year 2011, teaching was characterized by the conversion of courses from Diploma to Bachelor and Master degree. This is going to continue within the next years.

The current research and project work of the institute is expressed in the course contents, thus always presenting the actual state-of-the-art to the students. As a benefit of this, student research projects and theses are often effected in close cooperation with the industry. The main research focuses on kinematic and static point positioning, analysis of engineering surveying processes and construction processes, machine guidance, monitoring, transport and aviation telematics, process and quality modelling. The daily work is characterized by intensive co-operation with other engineering disciplines, especially with traffic engineering, civil engineering, and aerospace engineering.

Research and Development

Center for Transportation Research University of Stuttgart (FOVUS)

Since 2011, Prof. Volker Schwieger took over the position as the speaker of the Center for Transportation Research from Prof. Ullrich Martin of the Institute of Railway and Transportation Sciences. In this regard, also the FOVUS office was moved to the Institute of Engineering Geodesy. Mr. Rainer Schützle took over as the new FOVUS manager. Main tasks in 2011 were the preparation of the international symposium „Networks for Mobility“ that will be held in 2012 at the University of Stuttgart. Furthermore, the transportation-related study programs have been re-organized. In this context, the new program „Transportation Engineering“ has been established. In addition, joint research proposals related to transportation and mobility have been formulated. All these actions within FOVUS have been coordinated by the IIGS.

Project EQuiP: Simulation of the Geometric Quality Assurance Process

The project EQuiP (Efficiency Optimization and Quality Control of Engineering Geodesy Processes in Civil Engineering), which is funded by the german research foundation (DFG) deals with the efficiency orientated integration of engineering geodesy processes in construction processes in due consideration of measures of quality insurance. In this context, the Institute of Engineering Geodesy (IIGS) is responsible for the quality assurance.

In the first part of the project (2009-2010) a quality model is developed. It consists of characteristics and parameters, which deliver a complete description of the geometric quality of a high-rise building. In the second part of the project, exemplified a simulation study for engineering geodesy processes is done, on the base of the quality model.

The simulation of an engineering geodesy process was performed, using the Monte Carlo method (MCM), which is a numerical method to solve mathematical problems, using the modeling of random variables. It also models deterministic and stochastic components and propagates random variables through a process or a system. A large number of scattered observations are generated computer-based in a „virtual experiment“, whose impact on the outcome is determined.

The MCM is an intuitive method, which considers the non-linearity of the functional model. It provides an easy way to consider different probability density functions of the input parameters (compare Fig. 1). Certain quality parameters can thus be propagated through different processes.

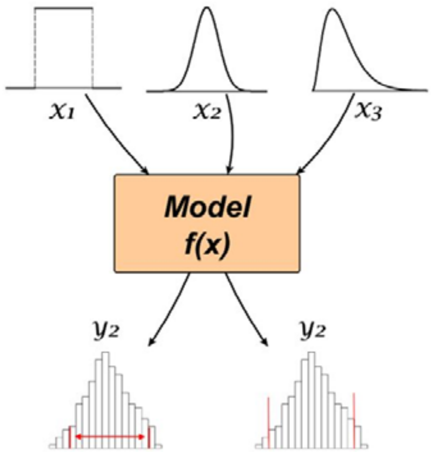

Fig. 1: Principle of Monte Carlo method

Exemplary two engineering geodesy processes (stationing and stake out) are presented in Table 1. Here the parameter „covariance matrix“ or „standard deviation“ is propagated.

Process	Parameter	
<u>Stationing</u>	*Input:*	*standard deviation of the control points* *standard deviation of the observations*
	Output:	***covariance matrix station point*** *condition density*
<u>Stake out</u>	*Input:*	***covariance matrix station point*** *standard deviation of the observations*
	Output:	*covariance matrix stake out points* *condition density stake out points* ***tolerance of the building component***

Table 1: Engineering geodesy processes with input and output parameters

A result is among others the tolerance of a building component which is defined by the stake out points.

So, in the planning phase, the impact of certain influencing factors (measurement configuration, building dimensions ...) is determined on the final result.

Project QuCon: Real Time Quality Control System for Residential Houses Construction Processes

The EU-project QuCon „Development of a Real Time Quality Support System for the Houses Construction Industry" was finalized successfully in 2011. Within this project, a real time quality assurance tool/software (compare Fig. 2), which is suitable for residential houses construction processes, was developed and then evaluated and improved by the experts and potential users.

Fig. 2: Screenshot of the Software

Using the software, the process and product quality can be documented, accessed and monitored in real time. The user can have an overview of the current project state through the so-called „real time quality index". In this way, the reasonable decision and remediation can be carried out, so that the quality of the construction process can be improved and assured in real time.

The project results, the software and the user guidance as well as the user manual were finalized and delivered to all the project partners. For the dissemination of the project results, an information event was held in Cyprus and several papers and presentations were published and made by all the project partners on a national and international level.

iMobility Working Group on Digital Maps (DMWG)

In succession of the EU-funded ROSATTE project (Road Safety Attribute Exchange Infrastructure in Europe), which was finalized at the end of 2010, a working group within the iMobility Forum was founded in 2011. This working group mainly consists of national road authorities, commercial map vendors, service providers and research institutions that already have been involved in ROSATTE. It is aimed to increase the number of road authorities from other EU member states. The working group itself has a steering function and aims to prepare the implementation of the data exchange infrastructure that was developed within ROSATTE across Europe. This is mainly the preparation of the legal structure of the ROSATTE implementation platform (RIP) that is to be built as a self-contained organization and to conduct preparative studies. The eMaPS project consortium (eSafety Digital Maps Public Private Partnership Support Action) has been assigned with the practical realization of these tasks. This project is funded by the European Commission and mainly consists of DMWG members.

Although the IIGS is neither a member of DMWG nor of eMaPS, it stays in close cooperation with these consortia. As in ROSATTE, the IIGS is mainly involved in the quality management and location referencing tasks.

Databases for Traffic Road Data Acquisition

Within the research about traffic state acquisition, the IIGS focused on the databases for traffic road data acquisition in 2011. Two principally data sources for generation of traffic information are collected and stored with suitable data structure. These includes the digital road map and cellular phone data.

In the first case (digital road map), the research work chose the Geographic Data File (GDF) as the standards of digital road map, concerning its worldwide acceptance in the field of research and industry. According to the data model described in GDF standards, the database build and stores the digital road map in terms of features, attribute and relationships and geometry. Especially the attributes are important which influence the traffic information collection, like direction of traffic flow, functional road class, intersection type, junction type, and national road class, and so on.

Another part of the databases include the mobile phone data. The data related to this, include a static and a dynamic part. The static part, like signal strength maps, best server plots and antenna positions maps, and other information of mobile phone network, deals with the infrastructure information about cellular phone network. The dynamic data will be transferred from the so called A- or the A-bis interface of the mobile phone network. They contain the information of the mobile devices in the network.

Fig. 3 totally formulates the data structure in database for traffic information acquisition.

Concerning the query function of the database, the work mainly focus on the basic traffic information queries, including positioning of vehicles, vehicles' trajectories, traffic incident detection and traffic volume detection and traffic flow. All of these query function of the database will consider the positioning interesting object and the time slot. The trajectory of one identified road user (cellular phone user) during one period is calculated by exploiting the handover records in A data. Intersection between the digital road map and best sever plots were stored to optimize the spatial query by decreasing the query space significantly.

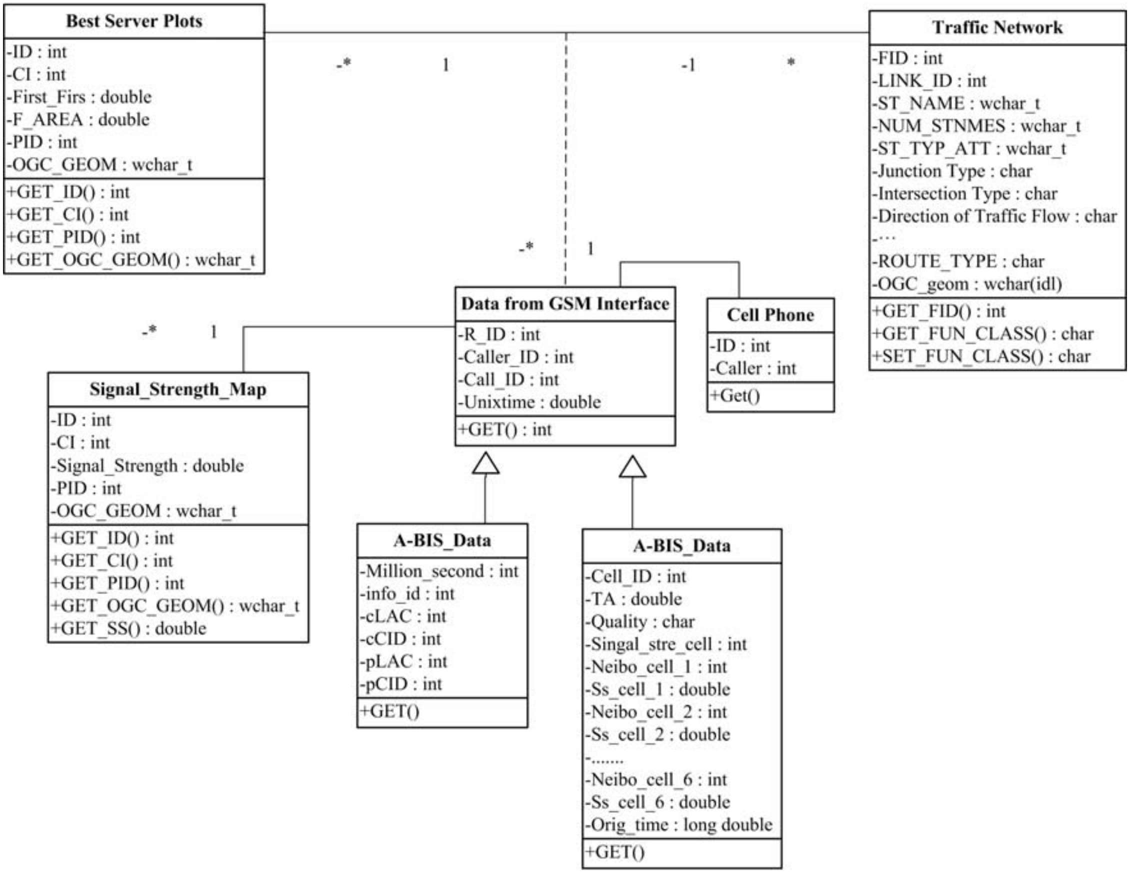

Fig. 3: Data structure in database for traffic information acquisition

Fig. 4 displays the result of generation of vehicle's trajectory by integrating digital road map and cellular phone network.

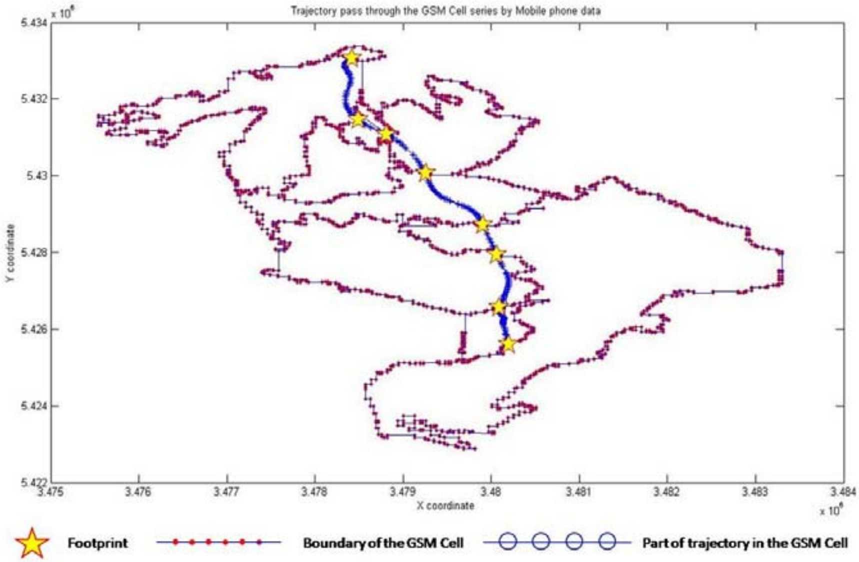

Fig. 4: Trajectory generated by integrating the mobile phone data and digital road map

Modular System for Construction Machine Guidance

The modular system for construction machine guidance (PoGuide), which was developed at the institute, is subject to continuous improvement. The core is a simulator for Hardware-in-the-Loop simulations. Meanwhile two new tachymeters were integrated into the system. Beside a remote-controlled model truck, a remote controlled-model caterpillar is also available. Furthermore, the simulator consists of a controller computer and a remote control (shown in Fig. 5).

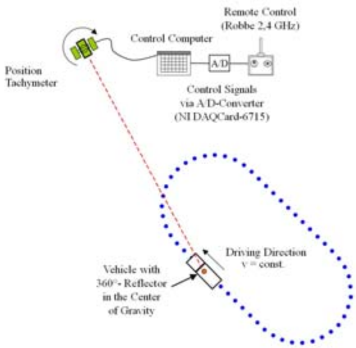

Fig. 5: Simulator - Configuration and model vehicles

Within the field of software modules the simulator was enhanced with several further modules. These include a trajectory generator, an automatic steering calibration, a software simulator and an enhanced control module (shown in Fig. 6). It is possible to store driven trajectories with the trajectory generator. Furthermore it is possible to drive these trajectories autonomously again with the enhanced control module (position control). The use of computed trajectories is also possible. The automatic steering calibration allows an automated determination of the steering parameters. With the using of a defined interface all three modules are able to use virtual or real sensors. The virtual sensors are working with recorded sensor data. With the software simulator it is possible to optimize different controllers and Kalman filters. For this propose the corresponding vehicle model will be used.

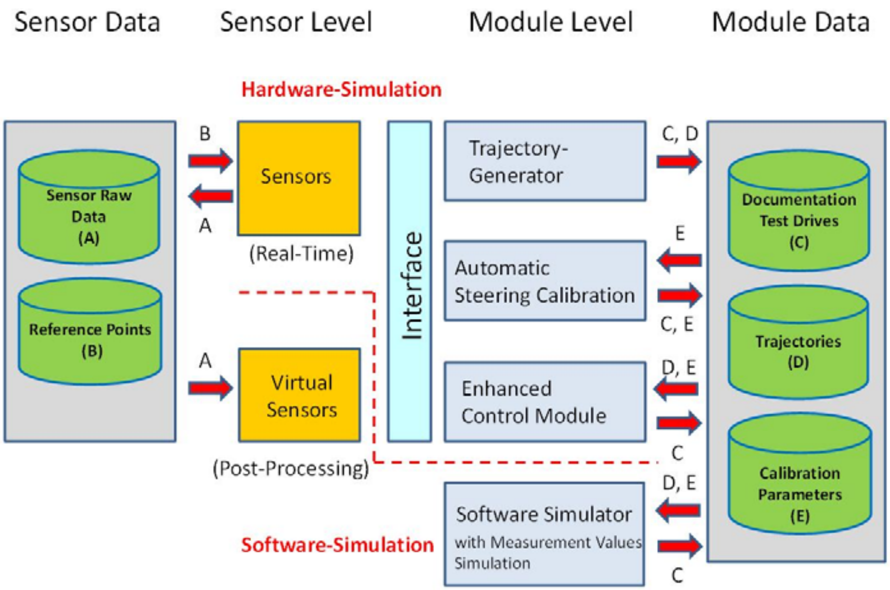

Fig. 6: Components of the simulator (A-E represents the data flow)

In Fig. 7 two test drives of a caterpillar are shown, for which a PID-controller and the enhanced control module has been used. In the upper figure a test drive is displayed without using a pre-control. In the lower figure a test drive is displayed where the pre-control with calibrated steering parameters has been used. The blue line represents the lateral deviation of the caterpillar during the test drive. The lower bar shows each element of the reference trajectory (red/grey=straight line; green/light grey=clothoide; blue/black=circle).

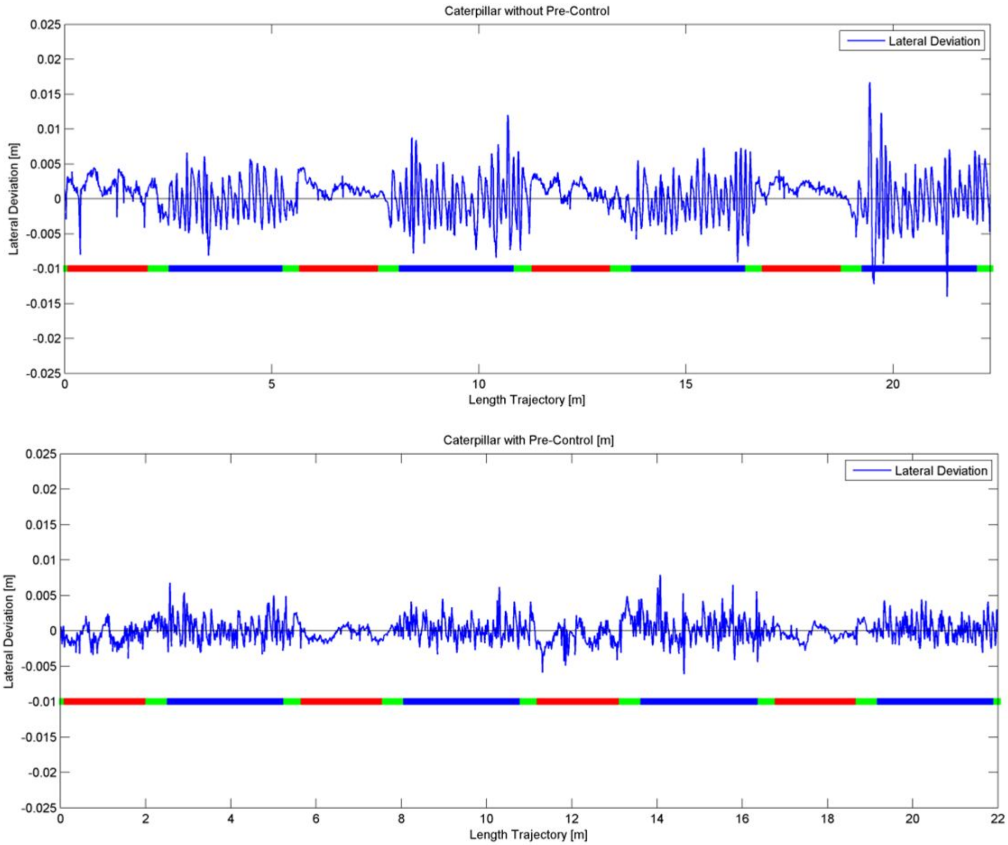

Fig. 7: Comparison of two test drives of a caterpillar without (above) and with (below) pre-control

An enhancement in curve areas is obvious. Altogether, the total RMS (Root Mean Square) can be improved from 3 mm without pre-control to 2 mm by using a pre-control.

In the future the system shall be used under outdoor conditions, too. For this an outdoor simulator is presently under construction. Thus it will be possible to also use GNSS-sensors as position sensors. Further sensors shall be integrated for measurements of inclination and acceleration. With the use of these sensors, dead reckoning will be possible.

Automatic Low-Cost GNSS Monitoring System

Monitoring is one of the main tasks in engineering geodesy. Beside the traditional tachymeter, only GNSS receivers can measure the 3-dimensional positions automatically and continuously. However, the geodetic dual frequency GNSS receivers are not suitable for monitoring a huge object, because they are quite expensive (some of them cost more than 20,000 Euro). In the recent years, low-cost single frequency (L1 only) receivers (one costs about 100 Euro) have been proved that they reach almost the same accuracy as geodetic ones.

Automatic Communication via Wireless Mesh Network (WMN)

An automatic low-cost GNSS monitoring system has been tested at IIGS. Fig. 8 shows the overview of this system. The test system consists of three stations: a central station (master) and two clients. The master collects continuously raw data from the two clients via WLAN in real-time. The data of all the stations are transferred to the computer at the central station. The data processing is executed there.

Each station has one CabLynx router which is the wireless router and has been configured for realizing the data transfer via wireless mesh network (WMN). In the classical network topology, the clients can just transfer the data to the master. But in the mesh network, the data transmission between the clients is also possible. After starting the system, IP addresses of the clients are given by the master automatically and dynamically. With WMN, data of the clients can automatically find their own path to reach the master. If there is no direct connection between one client and the master, the data of this client can be transferred via the other clients in the mesh net until it reaches the master. If one client could not operate, the remaining clients could still communicate with each other. That means the mesh network, which is self-organized and self-healed, provides a higher reliability and redundancy.

Since the network is self-organized and the data transmission direction is variant and previously unknown, an omni-directional antenna (from firma VIMCOM) is necessary here. Additionally, to make sure that this system can run continuously and autonomously, the power supply of each station is provided with one solar panel, one charge controller and one back up battery. The most important parts of the router are the u-blox GPS antenna ANN-MS and the latest-generation u-blox GPS receiver LEA-6T. By using the LEA-6T receiver is possible to output the GPS raw data in binary format (UBX-format).

Data Processing in Post-Processing

The clients transfer data to the master that is connected to a computer for data processing. Since all the stations transfer data to the computer through the same port, the belonging of the data should be identified previously. A program has been written for this purpose, the raw data are identified by the IP address from which they were sent and stored directly in different files in the computer.

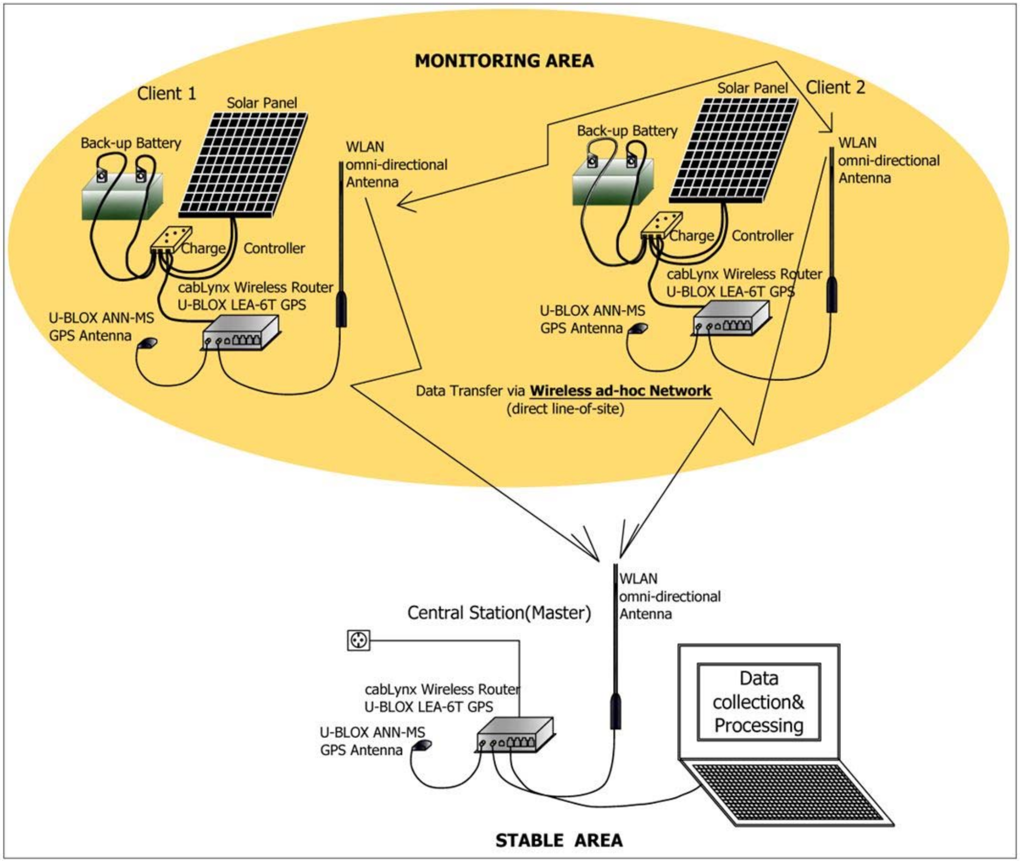

Fig. 8: System architecture

In order to analyze the results using raw data the flowing steps are realized:

- ▷ The binary format (UBX format) is transformed to standard exchange format (RINEX format) and edited using the powerful free software TEQC.
- ▷ The calculation of the baseline or coordinates of the rover stations related to the reference station. That can be solved by the GPS software Wa1 from Wasoft.

First Results

Several tests have taken place in April and November 2011 in two test areas in Stuttgart. It has to test the accuracy of this system depending on observation time and shadowing conditions. Here, the results of the test, which was carried out in November as an example, will be presented. Fig. 9 shows the test scenarios.

The coordinates of the client 1 and 2 as well as the master are known better than millimeter. The master and client 2 had a shadowing free environment, while client 1 was nearby the forest and trapped in shadowing environment (southwest). The session took about one hour.

In order to analyze the accuracy depending on the length of observation time, the observation time interval of one hour was analyzed and then was divided into several short time intervals: 5, 10, 15, 20, 25 and 30 minutes. For the accuracy analysis, the given and the measured values of baselines are compared and their difference are calculated. The mean value and the standard deviation of these differences from the different divided time intervals are then estimated. The mean value can be regarded as the reproducibility (absolute) accuracy compared with the true value. And the standard deviation can be regarded as the repeatability (relative) accuracy for the stability of the measurements.

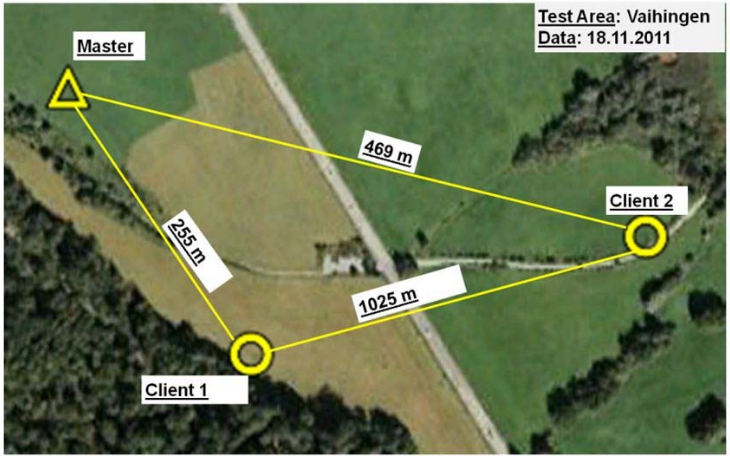

Fig. 9: Test scenarios in Stuttgart-Vaihingen (Session 1)

Besides, only the fixed solutions are taken for the data analysis. So the value „reliability“ can be determined, which is the percentage of the fixed solutions of the total results. The results of 5 minutes intervals are not accurate and unreliable. Only about 50% of the measurements have solutions with fixed ambiguities. For this reason, only the results of 10 to 30 minutes time intervals will be presented. The Table 2 shows the results of the baseline between master and client 1 as an example.

The mean values and the standard deviations do not become much better with longer observation time. So after the first results, it is not necessary to have a observation time of one hour, to reach a repeatability (relative) accuracy of 1 cm or even 5 mm. But in shadowing environment, the reliability will be better with longer observation time (starting from 20 minutes or 30 minutes). The mean values indicate that there may exist some systematic errors (some of them are more than 1 cm) in the coordinates. The reason of this fact is unclear here.

Time Interval		Mean of the Difference [mm]			Standard Deviation of the Difference [mm]			Reliability
		North	East	Height	North	East	Height	
10 min	Master& Client1	-11.4	-3.8	-5.9	4.8	2.6	6.9	-11.4
15 min		-11.2	-3.5	-5.2	4.7	0.9	6.2	-11.2
20 min		-10.5	-2.4	-2.7	2.5	0.4	1.3	-10.5
25 min		-11.0	-3.2	-5.2	4.8	1.0	5.0	-11.0
30 min		-10.9	-3.0	-4.0	4.3	0.3	3.5	-10.9

Table 2: Accuracy analysis depending on the time interval

In the future, more tests with expanded observation time and different net configurations should be carried out, to have more data to analyze the problems and improve the accuracy of the system. To apply the system on large monitored objects, such as landslides, bridges, the system should achieve mm-level precision, the accuracy should be improved. For instance, the individual calibration of each antenna with a ground plate may enhance the accuracy of the positioning. Besides, the development of an improved ground plate and a „low cost“ chock ring may reduce multipath effects. Other alternative low-cost antennas can be tested. Additionally, the data processing should be realized automatically in near real time.

Orientation Determination of the SOFIA Telescope

The Stratospheric Observatory for Infrared Astronomy (SOFIA) was developed as a joint project of the German Aerospace Center (DLR) and the National Aeronautics and Space Administration (NASA). For this purpose, a Boeing 747SP was modified so that a reflector telescope could be installed. This construction makes possible that astronomical observations can be carried out during a flight. The telescope is located behind a hatch inside the aircraft. It can be opened during the flight. The spatial orientation of the plane is determined by using gyroscopes.

In the course of this project, replacements on the telescope may be undertaken. To improve the first orientation after these activities, an independent geodetic procedure for the orientation determination should be developed in cooperation with the Deutsches SOFIA-Institut (DSI). The implementation was realized within a diploma thesis.

In a first step a basic network was realized by static GPS measurements on the surrounding area of the aircraft hangar in Palmdale, California. The coordinates of the network points could be calculated by using the measured GPS observations in a network adjustment. Afterwards, the network was densified by terrestrial measurements so as to have enough connecting points for the orientation determination inside the aircraft hangar (see Fig. 10). The used instruments are GNSS receivers (system 1200) and industrial theodolites (TM5100A) from Leica Geosystems. With this equipment, the UTM coordinates of the single network points has been determined with high accuracy. The standard deviation of Eastings is 1-3 mm, of Northings 1-2 mm and of the heights 1-3 mm.

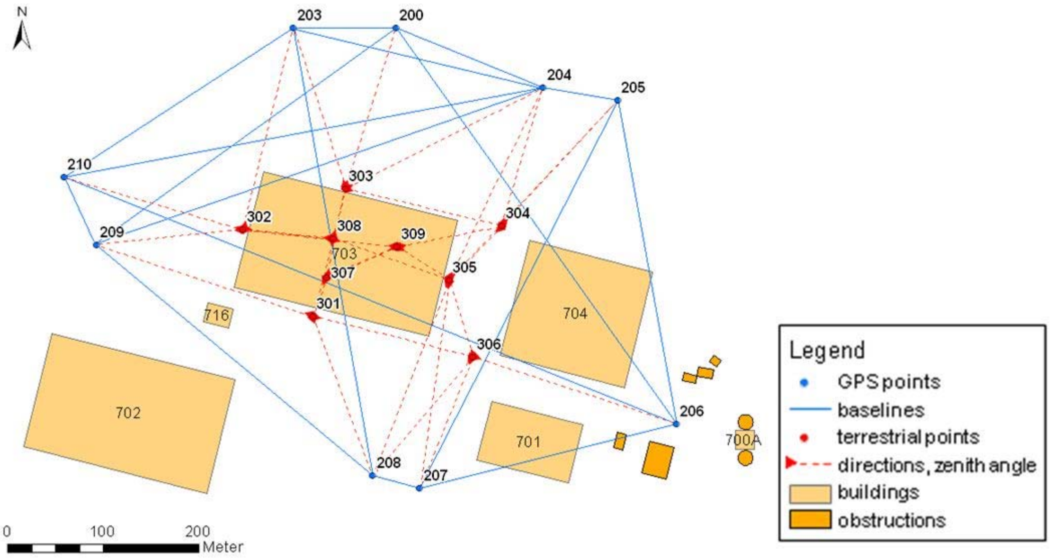

Fig. 10: Basic network on the surrounding area of the aircraft hangar in Palmdale, California

For the real orientation determination, the telescope hatch of the plane was opened on ground. Four visible points on the telescope framework were chosen. These points were measured with the available theodolites, the point coordinates were calculated by intersections. Since the point coordinates are also known in a local precise telescope coordinate system, parameters for co-ordinate transformation could be determined. So the central points of the primary mirror and the secondary mirror were converted to UTM coordinates. Those two points are shown as point 5 and 6 in Fig. 11.

With regard to the covariances, the orientation vector can be determined with accuracy better than 2 arc seconds.

Due to the location of the aircraft hangar near to the San Andreas Fault, annual network deforma-tions of several centimeters are suspected. Periodic control measurements of the network points must be accomplished to enable high-precision orientation determinations in future.

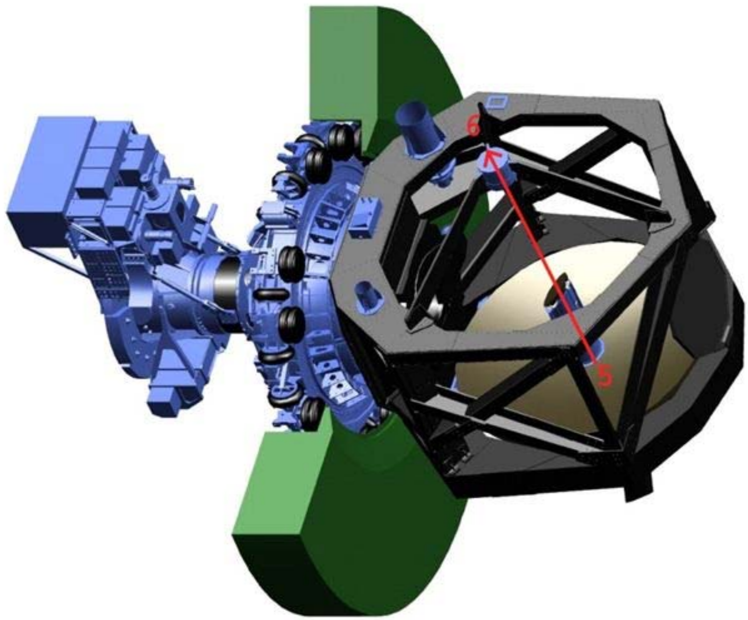

Fig. 11: SOFIA telescope with orientation vector (source: DLR)

Laserscanning Applications in the Field of Architecture

Architecture is one important field of application of laser scanners. In addition to the mapping of the current situation of a building, scans of different epochs can also be used to detect deformations. In cooperation with the Institute for Computational Design (ICD), several objects have been scanned with a FARO Focus3D laser scanner.

ICD/ITKE Research Pavilion 2011:

The structure of the ICD/ITKE Research Pavilion in the Stadtgarten was reproducing the biological structure of sea urchins. In the context of a study thesis, this pavilion was measured with the mentioned laser scanner to enable a comparison between a simulation of the pavilion and the real structure. There were several measurements from stations inside and outside of the pavilion. Checkerboard targets, as it can be seen in Fig. 12, are used as reference points for the registering process. To detect deformations which may occur, measurements were carried out in two measurement epochs. The measurement data are currently evaluated and analyzed in the course of the study thesis.

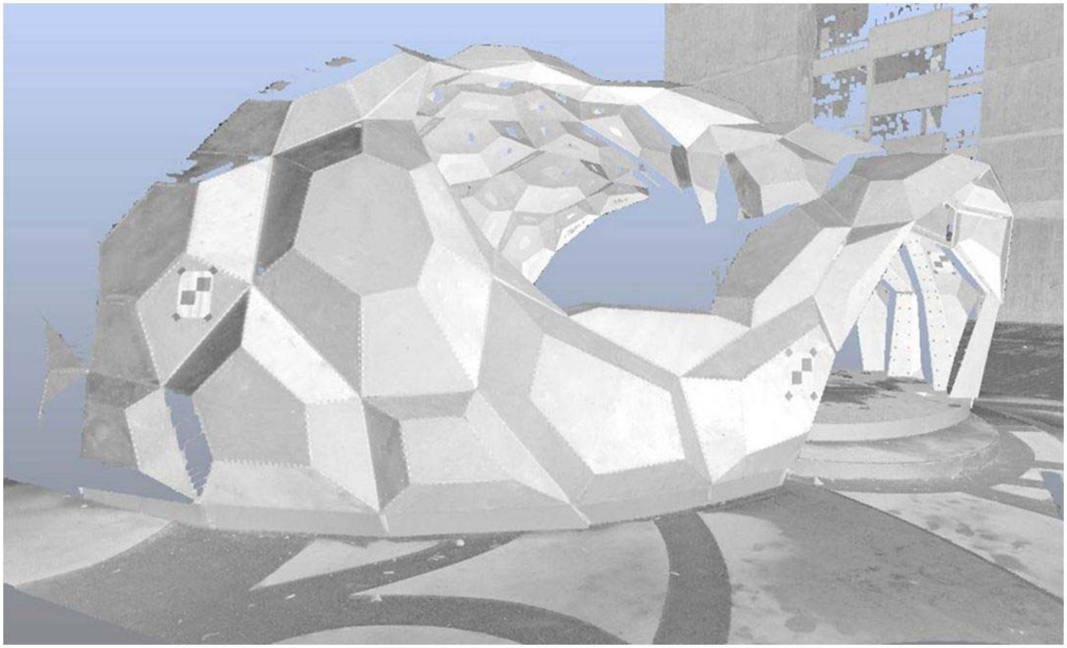

Fig. 12: Single Scan of measuring the Research Pavilion

Aggregate Architectures

Measurements of delicate aggregate structures are another field of application for the laser scanner. The term aggregate architectures specifies a system of loosely-coupled individual elements. At ICD, such (architectonical) systems are simulated and realized by dumping numerous elements (> 100) with a robotic arm concurrently.

The structure must be determined metrologically to compare the simulated and the real structure. Because of the large number of individual elements and the resulting size of the structure, a laminar measurement is performed by using the laser scanner. The spatial orientation of the individual elements shall be detected by analyzing the created point cloud. Currently, single elements (e.g. Fig. 13) or small groups have already been measured in first experiments. Because of the slight breadth of the structure heads (ca. 2 mm), the full resolution of the laser scanner is utilized. Especially at the edges, there is a problem with flawed measurements. As it is shown in Fig. 14, the measured point cloud can be used to calculate the coarse axis orientation with appropriate algorithms. Actually the algorithms are developed further to detect the single axis of more complex structures.

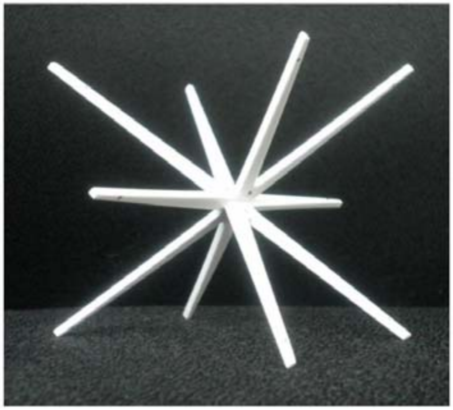

Fig. 13: Individual element of the aggregate structure

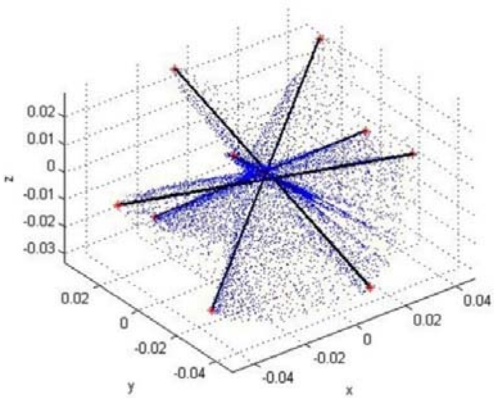

Fig. 14: Point cloud with determined axis orientation

Activities of Prof. Dr.-Ing.Dr.sc.techn.h.c.Dr.h.c. Klaus W. Linkwitz in 2011: Formfinding of Lightweight Surface Structures

During the winter semester 2010/2011 the compact course „Formfinding of Lightweight Tension Structures“ was incorporated into the 4-semester Master Course „Computational Mechanics of Materials and Structures (COMMAS)“ for foreign students and was given from 14th to 20th February 2011.The lecture, consisting of 32 weekly hours and the exercises comprising 16 weekly hours per semester were given from Mondays to Fridays all-day and on Saturdays and Sundays half-day.

The additional appertaining practical computer exercises were performed on Windows XP computers in the CIP pool of the course „Water Resource Engineering and Management (WAREM)“ of the department „Civil and Environmental Engineering“ in the University Campus Pfaffenwald in Vaihingen. The exercises were intensified, since a final graded project-work was demanded from the students.

Prof. Linkwitz visited the Technical University of Donetsk, Ukraine on the occasion of its 90th birthday. During his visit he spent several days in the institute of Prof. Mogilny to gain an insight into the entire scope of the scientific work.

Moreover, Prof. Linkwitz gave a lecture on the „Effective Education of Engineers and Geodesists“ at the University of Donetsk.

Publications

Beetz, A., Czommer, R., Schwieger, V.: Signalstärken-Matching und Map-Aiding-Methoden zur Positionsbestimmung von Mobilfunkteilnehmern in Echtzeit für Verkehrsprognosen. Zeitschrift für Vermessungswesen, Jahrgang 136, Heft 3/2011. S. 150-164, 2011.

Linkwitz, K.: Experiences and Results of Observing the Long-Time Shape Behaviour of a Thin Widespanning Grid-Shell-Membrane-like Interaction of Shape and Load-bearing Capacity. In: 5th International Conference on Textile Composites and Inflatable Structures STRUCTURAL MEMBRANES 2011 E. Oñate, B. Kröplin and K.-U.Bletzinger (Eds), Barcelona, 04.-08.10.2011

Schweitzer, J.; Schwieger, V.: Modeling of Quality for Engineering Geodesy Processes in Civil Engineering. In: Journal of Applied Geodesy, Vol. 5, Heft 1/2011, S. 13-22, 2011.

Schwieger, V., Heunecke, O.: DIN 18709, Teile 4 und 5, zur Ausgleichungsrechnung, Statistik und Auswertung kontinuierlicher Messreihen erschienen. Allgemeine Vermessungsnachrichten, Jahrgang 118, Heft 08-09/2011, S. 313-315, 2011.

Schwieger, V.: Positionsbestimmung von Fahrzeugen, Themenheft Forschung Nr. 7 „Intelligente Fahrzeuge“, Rektor der Universität Stuttgart, Stuttgart 2010/11.

Weston, N.D., Schwieger, V.: Cost effective GNSS positioning techniques. Coordinates, Vol. VII, Issue 6, pp 7-11, June 2011.

Zhang, L., Schwieger, V.: Ein Echtzeit-Qualitätskontrollsystem für Wohnhausbauprozesse. Allgemeine Vermessungsnachrichten, Jahrgang 118, Heft 11-12/2011, S. 368-380, 2011.

Zhang, L., Schwieger, V.: Real Time Quality Assurance Indexes for Residential House Construction Processes. FIG Working Week, Marrakesch, Marokko, 18.-22.05.2011.

Presentations

Linkwitz, K.: „Zur aktuellen Ausbildung des Ingenieurs und Geodäten“, 90 Jahre Technische Universität Donetsk, Technische Universität Donetsk Ukraine 27.05.-09.06.2011

Schwieger, V.: Interdisziplinäre Herausforderungen der Ingenieurgeodäsie. Antrittsvorlesung im Rahmen des Geodätischen Kolloquiums der Universität Stuttgart, 04.02.2011

Schwieger, V., Zhang, L., Schweitzer, J.: Quality Models and Quality Propagation in Construction Processes. Geo-Siberia, Nowosibirsk, Russland, 27.-29.04.2011.

Schwieger, V.: Construction Machine Guidance at University Stuttgart. Technical University of Construction Bucharest, Rumänien, 07.11.2011.

Schwieger, V.: Quality Evaluation and Geo-Referencing. Technical University of Construction Bucharest, Rumänien, 08.11.2011.

Schwieger, V.: Quality in Engineering Geodesy Processes. Technical University of Construction Bucharest, Rumänien, 08.11.2011.

Schwieger, V.: Map Matching Applications. Seminar SE 3.05 „GPS/INS-Integration und Multisensor-Navigation“, Carl-Cranz-Gesellschaft e.V., Oberpfaffenhofen, 16.11.2011.

Doctorates

Laufer, Ralf: Prozedurale Qualitätsmodellierung und -management für Daten - ingenieurgeodätische und verkehrstechnische Anwendungen (Hauptberichter: Prof. Dr.-Ing. habil. V. Schwieger, Mitberichter: Prof. Dr.-Ing. habil. D. Fritsch.) Published: Bayerische Akademie der Wissenschaften, Verlag C. H. Beck, DGK, Reihe C, Nr. 662

Diploma Thesis

Gao, Yang: Positionsbestimmung für verschiedene Bewegungsmodelle mittel Kalman Filter

Haußmann, Susanne: Orientierungsbestimmung für das SOFIA-Teleskop (in Kooperation mit DSI)

Rosca, Alexandra: Vergleich von drei GPS Auswertesysteme - Leica Geo Office, GIPSY OASIS (GOA II) und WA1

Scheiblauer, Brigitte: Erstellung eines Feldkalibrierverfahrens für das Messsystem „Tiger“ der Fa. Angermeier in Kooperation mit der Firma ANGERMEIER INGENIEURE GmbH.

Wu, Bohan: Evaluierung und Weiterentwicklung eines Verfahrens zur Klassifikation von Fahrbahnen nach Oberflächengüte mittels Seriensensorik

Master Thesis

Roman, Maria Alexandra: „Commissioning and Investigations regarding a Low-cost GPS Monitoring System“, in collaboration with Faculty of Geodesy (Technical University of Civil Engineering Bucharest)

Zhang, Yin: Sensor Integration and Enhancement of a KALMAN-Filter for a Construction Machine Simulator

Education

Basic Geodetic Field Work (Zhang, Stange)	5 days
Geodetic Measurement Techniques II (Zhang)	0/1/0/0
Geodetic Measurement Techniques I (Metzner, Zhang)	3/1/0/0
Integrated Field Work (in German) (Metzner, Zheng)	10 days
Statistics and Error Theory (Schwieger, Zhang)	2/2/0/0
Surveying Engineering in Construction Process (Schwieger, Zheng)	3/1/0/0
Surveying Engineering II (Schwieger, Zheng)	2/1/0/0
Surveying Engineering III (Schwieger, Beetz)	2/1/0/0
Surveying Engineering IV (Schwieger, Beetz)	2/1/0/0
Thematic Cartography (in German) (Beetz, Scheider)	1/1/0/0
Multisensor Systems for Terrestrial Data Acquisition (in German) (Schwieger, Schweitzer)	1/1/0/0
Transport Telematics (in German) (Metzner, Schützle, Scheider)	2/1/0/0
Reorganisation of Rural Regions (Meyer)	1/0/0/0
Integrated Field Work (Metzner, Zheng)	10 days
Terrestrial Multisensor Data Acquisition (Schwieger, Schützle)	2/1/0/0
Thematic Cartography (Schützle)	1/1/0/0
Transport Telematics (Metzner, Schützle, Schweitzer)	2/1/0/0
Kinematic Measurements and Positioning (Schwieger, Beetz)	2/1/0/0
Acquisition and Management of Planning Data (Metzner, Stange)	2/1/1/0
GIS-based Data Acquisition (Schwieger, Schweitzer)	1/1/0/0
Data Management and Analysis (Metzner, Beetz)	1/1/0/0
Geodesy in Civil Engineering (Metzner, Scheider)	2/2/0/0
Geoinformationsystems (Metzner, Beetz)	(2/1/0/0)

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HÖCK MARGARETE, Phys. T.A.
SCHLESINGER RON, Dipl.-Ing. (FH)
VOLLMER ANITA, Secretary

Guests

ABDEL-MONEM M, Dr., Cairo/Egypt (16.8.-14.11.)
BOLTE B, Kiel (5.10.)
BORKOWSKI A, Prof., Wroclaw/Poland (27.4.-7.5.)
EINSPIGEL D, Prague/Czech Republic (17.9.-30.10.)
HAGEDOORN J, Dr., Potsdam (1.-4.11.)
KLEMANN V, Dr., Potsdam (17.-21.10.)
MARTINEC Z, Prof. Dr., Dublin/Ireland (1.9.-25.11.)
RAJAPPAN R, Chennai/India (3.5.-24.6.)
SHARIFI MA, Prof. Dr., Tehran/Iran (4.7.-25.8.)
VARGA P, Prof. Dr., Budapest/Hungary (6.6.-1.7., 3.11.-3.12.)
VISHWAKARMA BD, Roorkee, Uttarakhand/India (since 17.10.)
YOU RJ, Prof. Dr., Tainan/Taiwan (16.3.-13.5.)
ZHANG S, Dr., Wuhan/China (since 2.3.)

Additional Lecturers

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

Research

Sensitivity analysis of future satellite formations and configurations of them

By means of „Quick-Look-Tools“ (QLT) error propagation of future satellite missions is studied. With such Quick-Look-Tools the influence of a variety of important parameters as orbit height, inclination, satellite distance, instrumental noise, measurement and formation type can be studied. For this reason the QLT are an important tool for designing future missions, although temporal aliasing - one of the main problems for time variable gravity field detection - cannot be investigated with them. A sensitivity analysis of the basic formations (inline, pendulum, cartwheel, LISA) is shown in Figure 1 and Figure 2. As shown by the triangle plots and the degree-RMS curves, the advanced formations are able to improve the sensitivity by approximately one order of magnitude compared to the inline-formation. Additionally, these formations lead to a higher isotropy as shown by the covariance functions in Figure 2. The North-South structures caused by the inline-formation are eliminated and isotropic circular covariance patterns appear. The higher isotropy is also visible in the triangle plots of formal errors, where the accuracy of spherical harmonic coefficients of higher order is improved.

One of the ideas for a future mission design is to combine formations in different inclinations (and repeat patterns), the so-called Bender-design. It was already shown by several studies that such a design has capabilities for temporal de-aliasing and advantages concerning sensitivity, especially for short estimation periods, e.g. 4 or 7 days. By means of Quick-look-tools, the sensitivity of Bender-designs can be studied. Figure 3 and Figure 4 show the results of a sensitivity analysis of Bender-designs using a polar inline formation and inclined inline/pendulum/cartwheel formations. The inclinations used are I = 97° (sun-synchronous, SSO) and I = 63° (low inclination). As visible from Figure 3 and Figure 4, the sensitivity and isotropy can be increased by means of a Bender-formation compared to the single polar inline formation. Adding an inclined inline-formation already leads here to a very promising result concerning the formal errors, although still North-South patterns are visible in the covariance-functions. In case of an inclined pendulum, it has to be taken care which satellite is the leader. Very promising results are obtained for the Bender configurations with an SSO-pendulum with the left satellite as leader or with the (I=63°)-pendulum with the right satellite as leader, where also a high level of isotropy is reached. The Bender-configurations applying the inclined cartwheel also perform quite well. In total, the most promising results are obtained by the Bender-configuration with the SSO-pendulum with the left satellite as the leader.

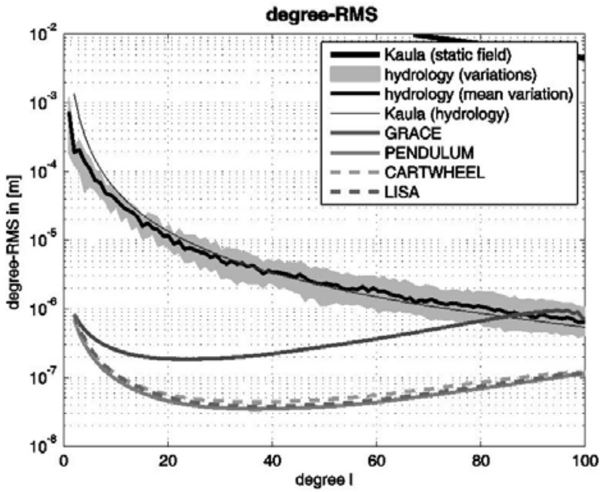

Figure 1: Degree-RMS of the four natural formations

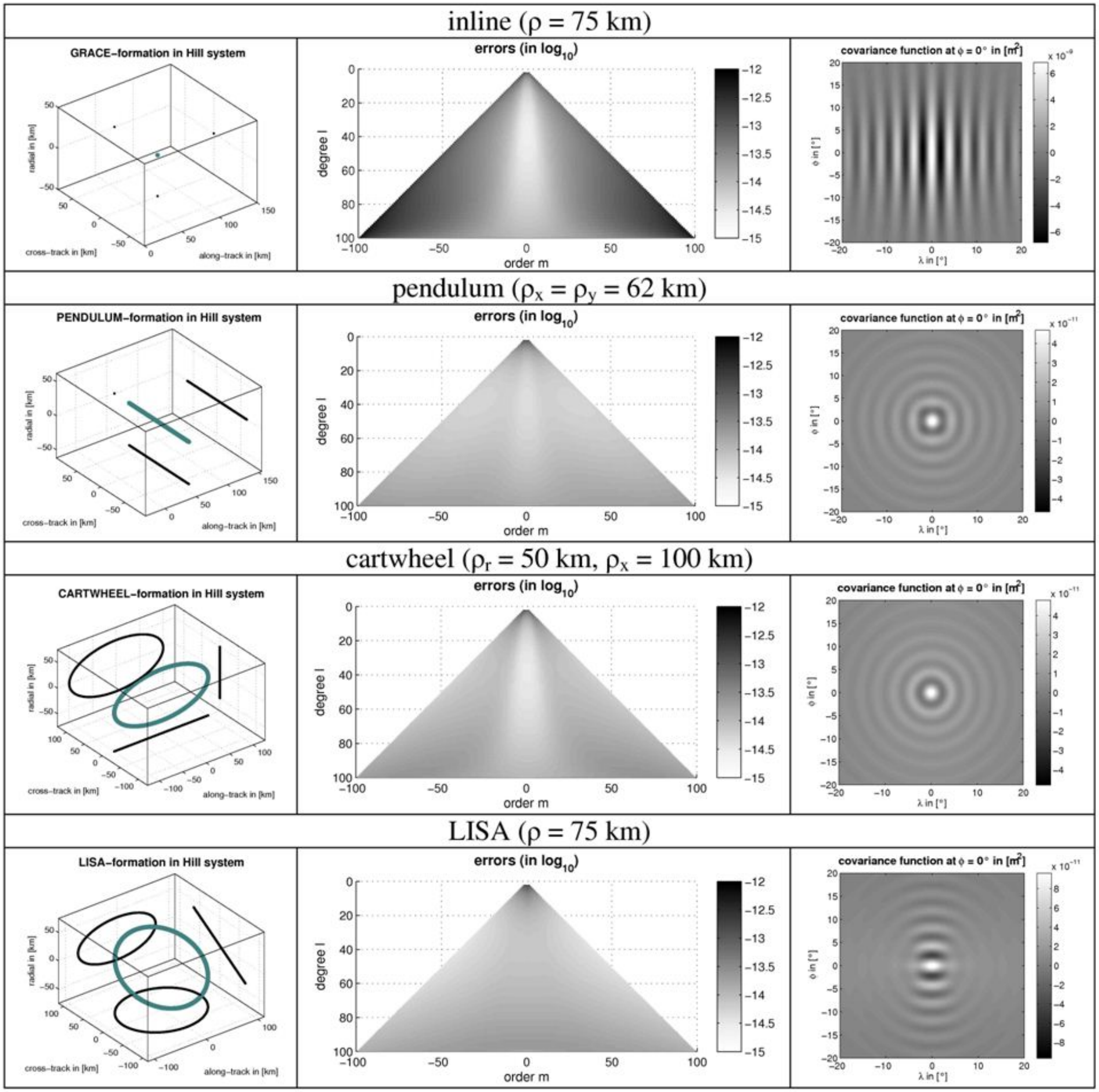

Figure 2: Formal errors, covariance functions and relative motion in the Hill-system of the four natural formations

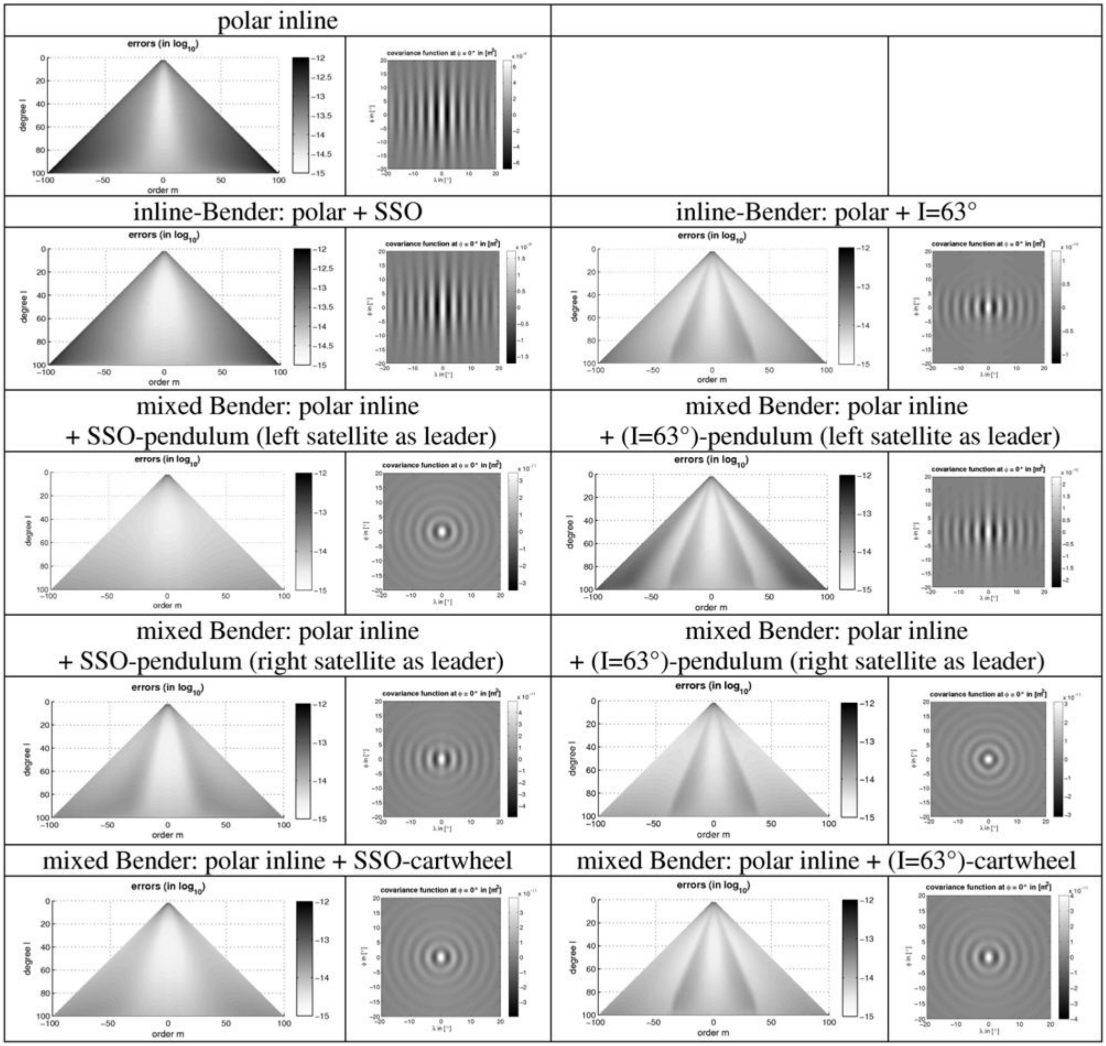

Figure 3: Formal errors and covariance-functions of mixed-Bender configurations (polar inline + SSO/(I=63°) inline/pendulum/cartwheel)

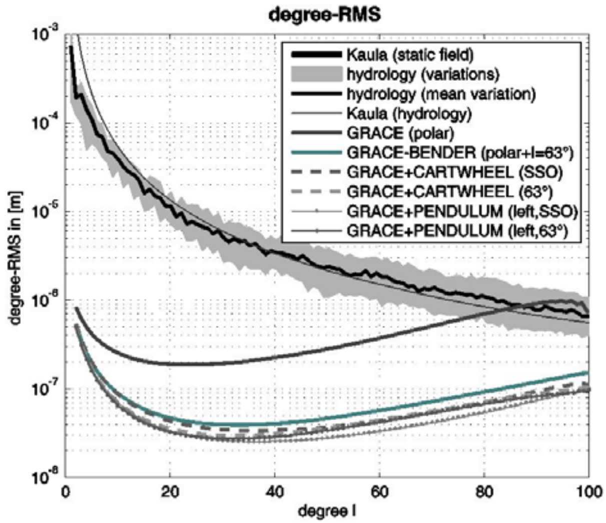

Figure 4: Degree-RMS of mixed Bender-configurations

Future time-variable gravity field mission design using genetic algorithms

Designing a future satellite mission for optimal time-variable gravity field determination is a highly complex and difficult task. Besides the development of very sensitive measurement instruments, e.g. a laser-link for ll-SST and advanced accelerometers, spatio-temporal aliasing of high-frequent time-variable gravity signals from e.g. atmosphere, tides, oceans and hydrology is a severe problem. By means of a dedicated configuration- and orbit-design, the problem of undersampling is tried to be mitigated. Design-parameters which seem to be of great importance for sampling issues are the orbit parameters itself, namely inclination I and repeat mode (β/α). As studies show, adding a second pair with different inclination (and possibly different repeat mode) will help further in reducing sampling problems. Establishing two or more pairs, also their difference of the ascending node Ω might be of interest. Finally the formation type itself has a great impact for reducing the striping problem well known from GRACE. The reason for this lies to a lesser extent in an improved sampling but rather in an improved sensitivity and isotropy. However, finding out a suitable set of design parameters is a huge and non-linear problem, which calls for the application of genetic algorithms.

First of all, an efficient simulation algorithm for the estimation of the time-variable gravity field (e.g. monthly solutions) was established. This algorithm accepts all of the mentioned input parameters, time variable gravity fields of atmosphere, ocean, hydrology, ice, solid earth and ocean tides and makes use of nominal orbits and the homogeneous Hill-solution for the simulation of the formations.

Afterwards, this algorithm was integrated into an open source genetic algorithm within the python programming environment using the $(\mu + \lambda)$-evolution strategy. Figure 5 shows the flowchart of such a genetic algorithm. The first step is usually the random creation of a population of individuals. All members of this population are evaluated using the fitness function. A new generation of individuals is then created by applying two main strategies:

- ▷ mutation: one of the individuals is selected and one or more of its attributes are modified slightly.
- ▷ crossover: two or more of the selected individuals are recombined, with each of their children possessing traits of all its parents.

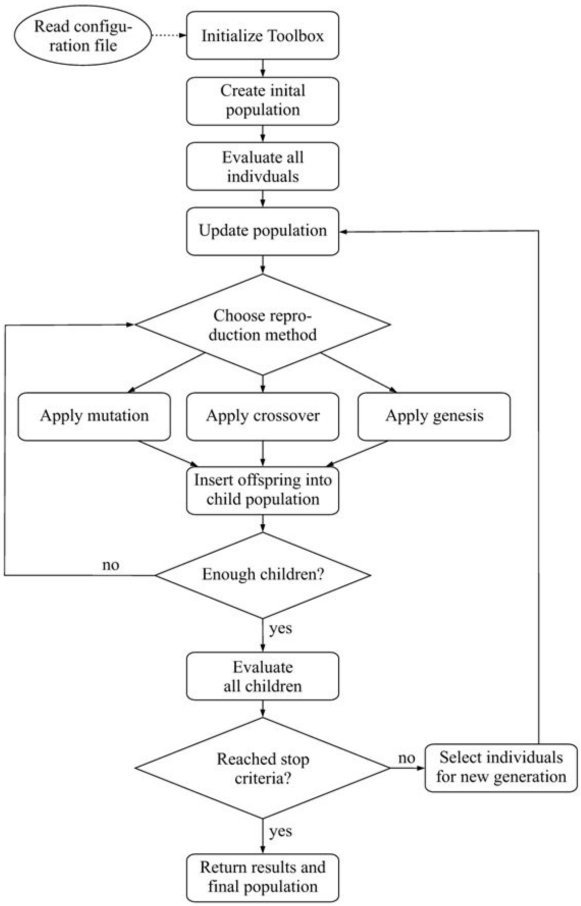

Figure 5: Flowchart of the implemented genetic algorithm

The selection of the individuals that are used to form this new generation usually favors those with high fitness values, although it is desirable to keep some diversity in the population. This reduces the risk of the population getting stuck in a local minimum of the solution space during evolution, and thus increases the chance of finding a globally optimal solution to the examined problem.

The algorithm was used for the following task: find a second pair in the orbit height h = 300 - 500 km with the searched-for parameter-set $(\alpha, \beta, I, \Omega, \rho_x, \rho_y)$ completing a Bender-type mission of a fixed first pair of $(\alpha, \beta, I, \Omega, \rho_x, \rho_y)$ = (32,503,90°,0°,225 km,0 km), (ρ_x/ρ_y are along-track/cross-track separation). The convergence for 50 generations of the genetic algorithm for this scenario is displayed in Figure 6. A convergence towards a higher fitness-level is visible, with a stronger rise within the first 15 generations.

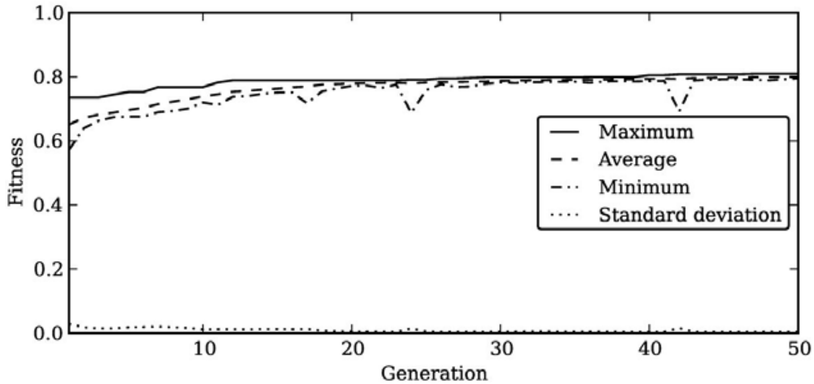

Figure 6: Evolution of the population statistics measured at the end of each generation

However, there are some generations at an advanced stage, which contain low minimum fitness values. These are mainly due to mutation and normally refused in the next step. Testing close-by input values of the final result reveals that neighboring input pairs with slightly better fitness values can be found. Nevertheless, genetic algorithms prove to be a powerful tool for orbit and satellite constellation design.

Long-wavelength gravity field analysis of GOCE-SST data using the acceleration approach

The GOCE mission, which was launched in March 2009, was designed to recover the Earth s static gravity field up to degree/order 250/250. Therefore it carries a highly sensitive gradiometer instrument on board. However, due to the restricted sensitivity of this instrument for the long wavelength features the data analysis has to be supplemented by orbit analysis from the hl-SST measurements. Within the official state-of-the-art GOCE-only gravity field solutions of the ESA

(European Space Agency) the orbit analysis is conducted by means of the energy balance approach. As previous studies have shown, this approach is inferior by approximately a factor of $\sqrt{3}$ by using only a 1D-observable compared to other hl-SST or orbit analysis methods. Therefore, within a joint activity of the Institute of Geodesy and the Space Research Institute (Austrian Academy of Sciences, Graz) it is proposed to apply instead the acceleration approach, which proved to be an efficient tool in CHAMP and GRACE data analysis. This approach evaluates the equation of motion directly. Therefore the kinematic orbits (official GOCE product, delivered by the Astronomical Institute of the University of Bern, AIUB) have to be differentiated twice and corrected for disturbing accelerations. Due to the drag-free system of GOCE the accelerometer measurements are neglected.

In contrast to the CHAMP and GRACE analysis, where the orbits were sampled with dt = 30 s, the 1s-sampling of the GOCE orbits lead to severe problems due to strong amplification of high-frequency noise. Different filter and weighting techniques have been tested in order to mitigate this problem. Finally the best solution was a) downsampling the orbits to dt = 30 s for numerical differentiation and b) applying empirical covariance functions, which have been obtained from residual analysis. Note that downsampling here means that the sampling points for numerical differentiation are chosen 30 s apart whereas the differentiation filter moves along the original 1 s-sampled orbit track, i.e. the whole data-set is exploited. The results are displayed in Figure 7. It shows, that our model GIWF is of comparable accuracy as an alternative solution obtained by AIUB with the variational equations. Furthermore, it outperforms the official TIM solution, whose long-wavelength part was estimated by the energy balance approach, up to degree 25-30.

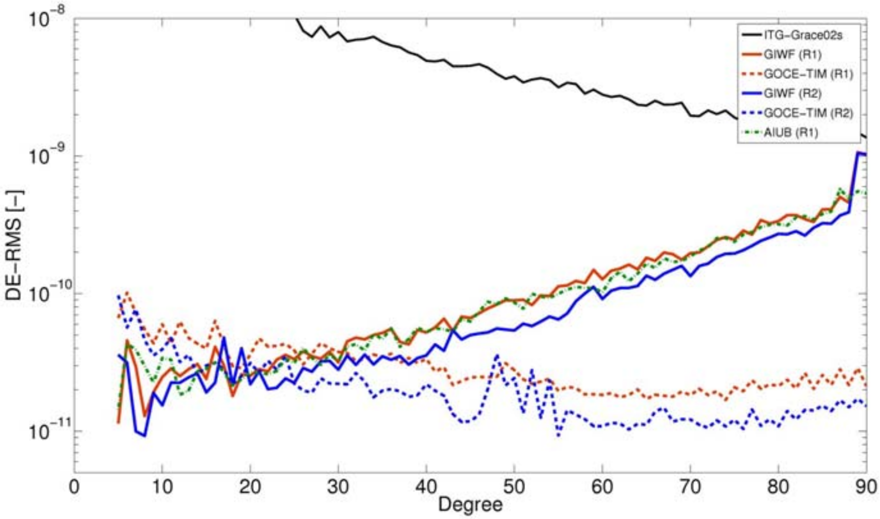

Figure 7: GOCE real data results in terms of degree-RMS over the periods November 1, 2009 to January 11, 2010 (R1) and November 1, 2009 to July 5, 2010 (R2). Orders m $<$ 5 omitted

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

The aim of Gravity field and steady-state Ocean Circulation Explorer (GOCE) Mission is to provide global and regional models of the Earth's gravity field and of the geoid with high spatial resolution and accuracy. Opposed to commonly applied analysis methods, the approach based on the rotational invariants of the gravitational tensor constitutes an independent alternative for gradiometer data exploitation. In the framework of the REAL-GOCE project we have investigated the complete analysis procedures in deriving the GOCE gravity field with rotational invariants (WP 120). The main achievements are:

- ▷ after spectral analysis of GOCE invariant I_2, see Figure 8, two key components of GOCE invariant analysis, a moving-average (MA) filter with order 50 has been successfully estimated and the filter cascade (high-pass and MA filters) has been implemented in GOCE invariant analysis, see Figure 9;
- ▷ the polar gap problem is solved through the order-dependent Kaula regularization with a proper regularization parameter;
- ▷ based on two months of GOCE rotational invariants of gravitational tensor a high-resolution global gravity field model until degree/order 224 has been derived by rotational invariants, where the GOCE SST solution until degree/order 110 (GIS) is used as reference model in the linearization of invariants. The RMS degree variances and degree median errors with respect to the EGM08 model (see Figure 10) show that the invariant solution is consistent with the three official GOCE solutions published in July 2010, especial for the middle and higher degrees, which complementarily supports the published GOCE combination solutions.

Comparison of full-repeat and sub-cycle solutions in gravity recovery simulations of future satellite missions

When using high quality sensors in future gravity missions, aliasing of the high frequency (short period) geophysical signals to the lower frequency (longer period) signals is one of the most challenging obstacles. Two sampling theorems mainly govern the space-time sampling of a satellite-mission: (i) Heisenberg uncertainty theorem which states that the product of spatial resolution and time resolution is constant, and (ii) the Nyquist theorem, requires the number of satellite revolution in a time interval equals or be larger than two times of the maximum spherical harmonic degree which is aimed to be detected and which, therefore, limits the spatial resolution of the solution.

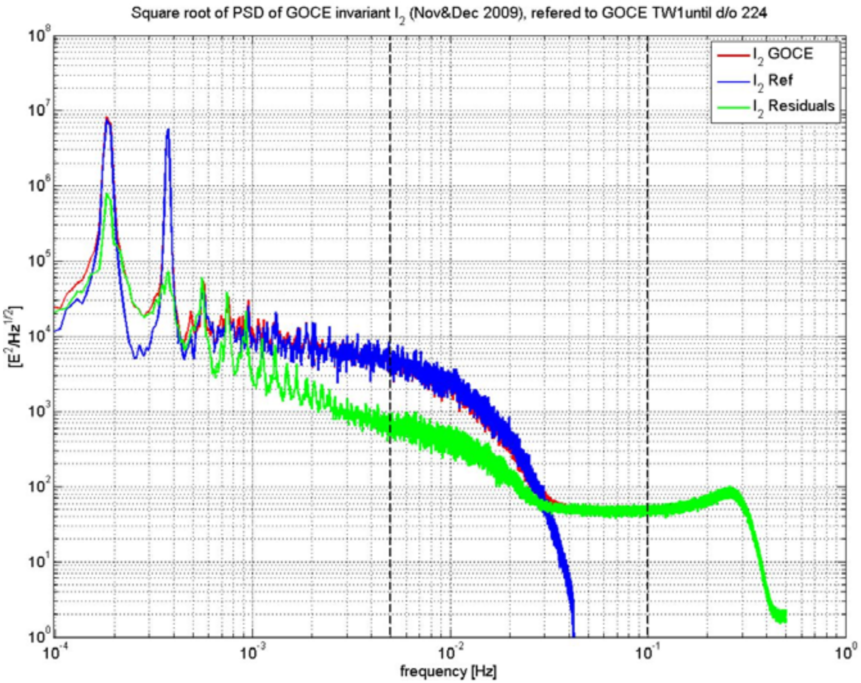

Figure 8: Spectral characteristics of GOCE invariant I_2 for November and December 2009

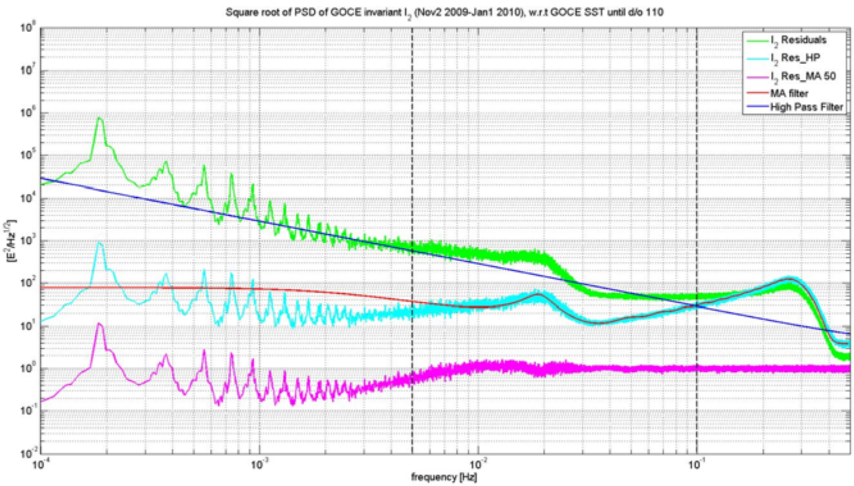

Figure 9: PSD of GOCE Invariant I_2 residuals, High pass filtered and ARMA filtered residuals for November and December 2009

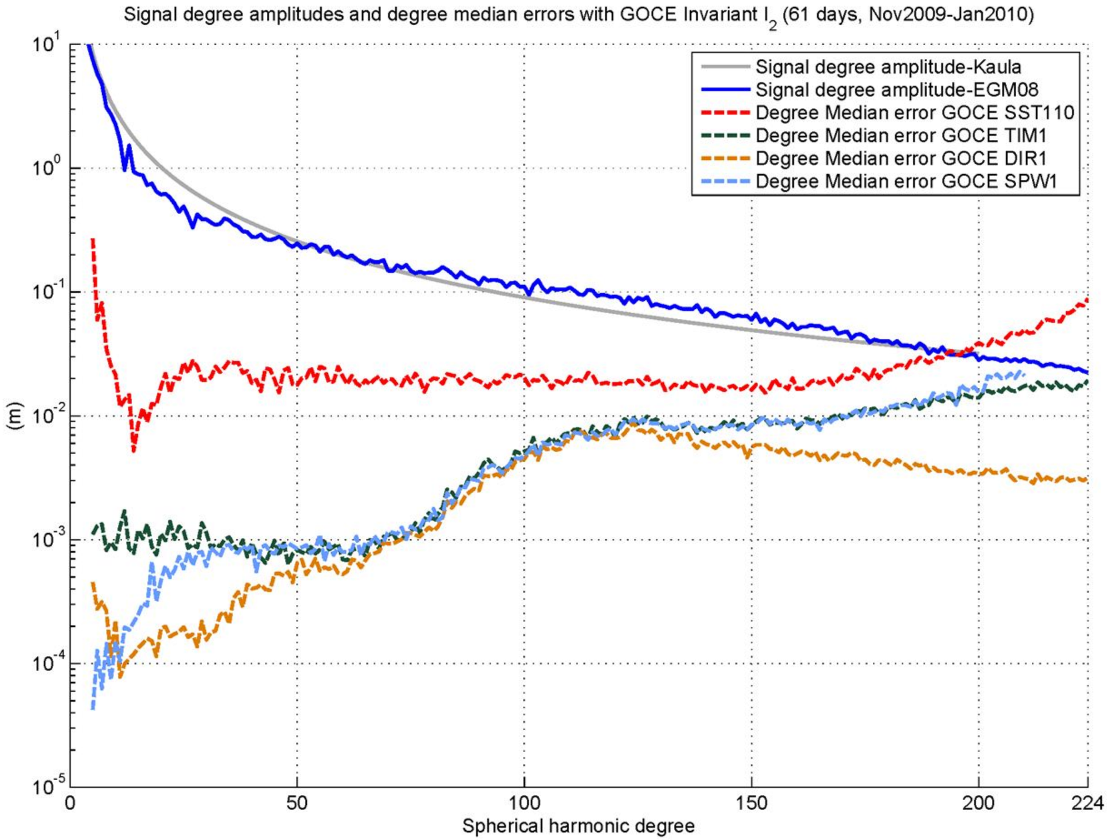

Figure 10: Signal degree amplitudes and degree median errors of GOCE Invariant I_2 solution with respect to the EGM08 model

It is obvious that short-time solutions of the configurations are less affected by the temporal aliasing, while they are suffering more from spatial aliasing. Here, we investigate the quality of sub-cycle solutions of different formation flights, where the sub-cycle (SC) is the smallest number of days after which an „Ascending Node Crossing" (ANX) falls at $1 \times S_i$ or $(\alpha - 1) \times S_i$ from the first ANX (α is the repeat period in nodal days when the satellites has β number of revolutions).

The input models for time-variable gravity fields atmosphere, ocean, hydrology, ice and solid Earth (AOHIS), as well as the difference between two ocean tidal models (tidal error) are used for simulation of the gravity recovery solutions via a „Quick-look Simulation" tool. The recovery solutions are simulated for different time intervals (in nodal days), including the full repeat period and sub-cycle. Moreover, the quality of the solutions are investigated by employing different repeat orbits of GRACE-like (inline) configurations, alternative formation flights like Pendulum and Cartwheel and two pairs of satellite missions of different inclinations.

The correlation between sub-cycle solutions (related to homogeneity of the satellite groundtracks on the Earth) of different repeat orbits and the quality of the recovery solutions are studied (Figure 11). For most of the repeat orbits, a significant drop for six days solution is seen. That is almost independent of the configuration (except for the drifting orbits with one day sub-cycles). The drop is approximately around the time interval when the number of revolutions is equal to maximum spherical harmonic coefficients which is aimed to be detected ($\beta \geq L_{max}$). This is called „Modified Colombo-Nyquist Law".

The optimal repeat orbits of one pair satellite mission have been searched for short time recovery solutions. By employing of two pairs satellite missions, the quality improvement, in both time and space domains, is achieved. That means we can then have short time recovery solutions with higher spatial resolution compared to the solution by just one pair satellite mission. Also, by employing some post-processing analysis such as regularization and „EOF+KS-Test" white noise filtering, we can achieve some more improvements, although some signals might be lost, as well (Figure 12).

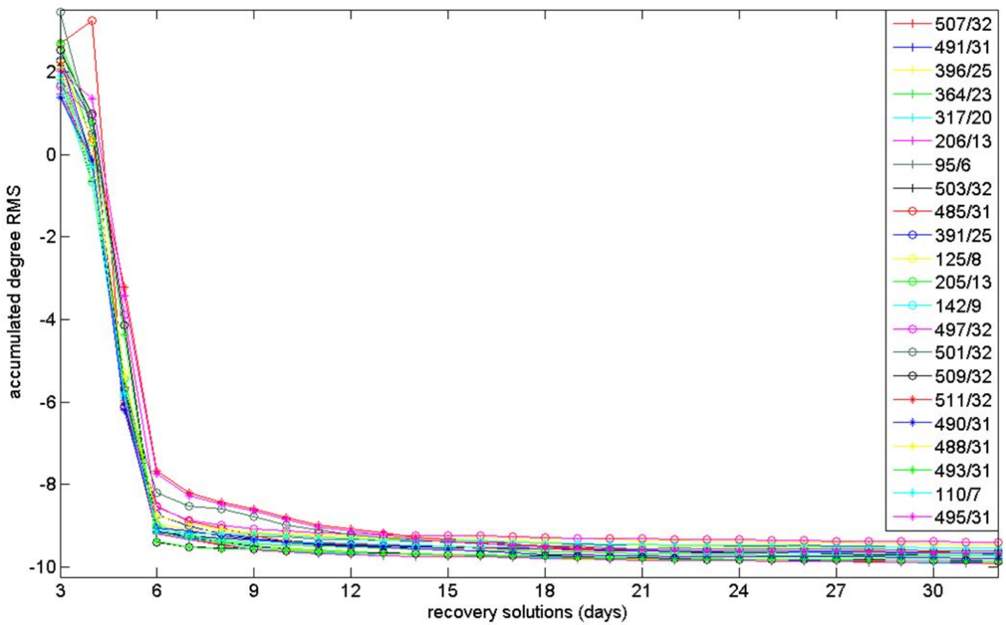

Figure 11: „Accumulated Degree RMS" of the errors of inline (GRACE-like) configurations for different repeat orbits (solutions to maximum degree and order 90). The Y-axis is in logarithmic scale.

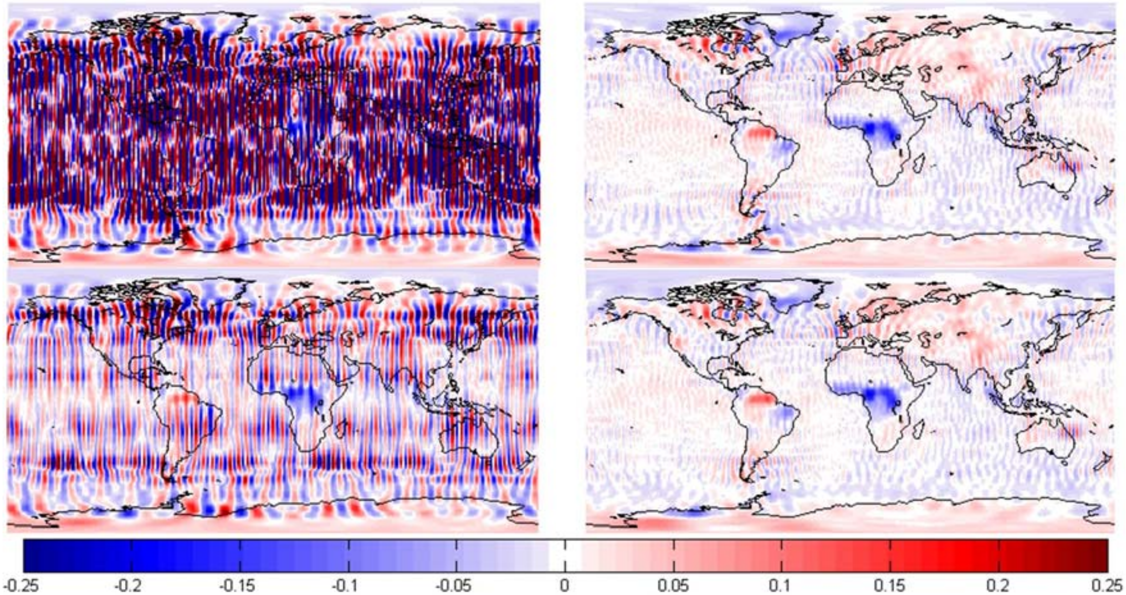

Figure 12: „Equivalent Water Height“ (EWH) maps of recovery solutions by one pair satellite mission (left) and two pairs configuration (right), before (above) and after (below) white noise filtering by „EOF+KS-Test“ tool for 7 days recovery solutions as sub-cycle solutions.

Application of the differential gravimetry approach to the next generation of intersatellite observations

The GRACE-mission proved to be one of the most important satellite missions in recent times as it enabled the recovery of the static gravity field with unprecedented accuracy and, for the first time, the determination of temporal variations on a monthly (and shorter) basis. The key instrument is the K-band ranging system which continuously measures the changes of the distance between the two GRACE satellites with an accuracy of a few micrometer. Thanks to the success of this mission, proposals have been made for the development of a GRACE-follow-on mission and a next-generation GRACE satellite system, respectively. Apart from options for a multi-satellite mission, the major improvement will be the replacement of the microwave based K-band ranging system by laser interferometry. The expected improvement in the accuracy is in the range of a factor 10 to 1000. Two types of solution strategies exist for the determination of gravity field quantities from kinematic observations (range, range-rate and range-acceleration). The first type is based on numerical integration. The most common ones are based on the classical integration of the variational equations, a variant of it called the Celestial Mechanics Approach or the so-called short-arc method. The second type of solution strategies tries to make use of in-situ (pseudo)-observations.

The most typical ones are the energy balance approach, the relative acceleration approach or the line-of-sight gradiometry approach. From a theoretical point of view all approaches are in one way or the other based on Newton's equation of motion and thus all of them should be applicable to the next generation of satellite missions as well. Practically, problems arise due to the necessity of approximations and linearizations, the accumulation of errors, the combination of highly-precise with less precise quantities, e.g. K-band with GPS, and the incorporation of auxiliary measurements, e.g. accelerometer data. These problems are often circumvented by introducing reference orbits, reducing the solution strategies to residual quantities, and by frequently solving for initial conditions and/or additional empirical or stochastic parameter. In the context of the next generation of low-low satellite-to-satellite tracking systems, the question is whether these methods are still sufficient to fully exploit the potential of the improved range observations.

Initial tests indicate that the solutions strategies needs refinement. Figure 13 shows the difference degree RMS between input and solved-for spherical harmonic coefficients. The light blue color shows the current limitation due to the microwave intersatellite link. The blue line indicates the improvement of a laser system with respect to the microwave system. In the conservative assumption here, the improvement is approximately one order of magnitude. In the application of the relative acceleration approach, which has been used here, different types of observations need to be combined, i.e. the less accurate GPS-observations contaminated the solution and limited the accuracy of the solution. The limitation can be seen as the red line in Figure 13. About one order of accuracy is lost. This limitation can be circumvented by introducing a reference orbit and reducing the observations to residual quantities. Subject of the adjustment process are then corrections to the initial gravity field which has been used to generate the reference orbit. With this method solutions on the accuracy level of a microwave system limited solution can be achieved. However, for the next generation of intersatellite observations, this approximation is not sufficient. Instead higher order terms need to be considered which demand an integration of the variational equations. Figure 13 also shows such an attempt where a minor improvement is visible for degrees higher than approximately 15. In this test, only changes to the spherical harmonic coefficients are estimated but no corrections for errors in the initial conditions of the orbit of the two satellites have been applied. It is currently under investigation if these corrections can be estimated with sufficient accuracy as they are also based on GPS observations.

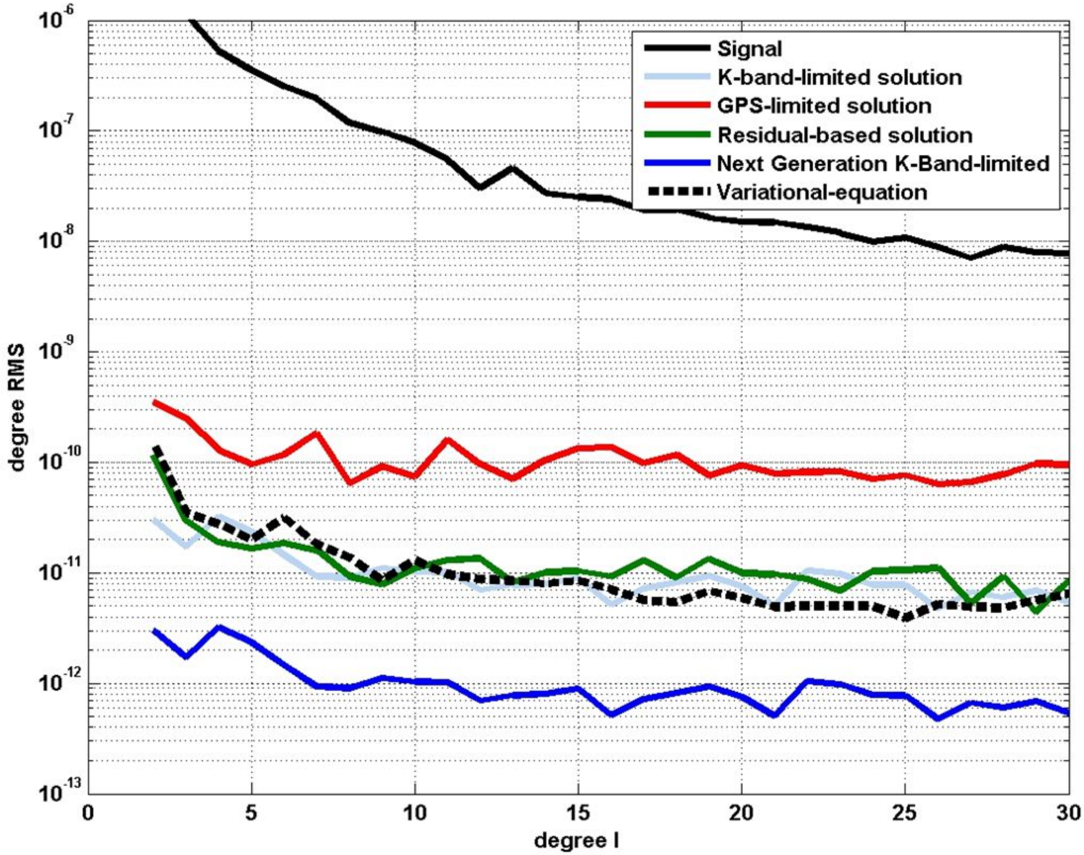

Figure 13: Difference degree RMS for different solutions of a simulation study

Theses

Doctoral Theses

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

ANTONI M: Nichtlineare Optimierung regionaler Gravitationsfeldmodelle aus SST-Daten (Nonlinear optimization of regional gravity field models from SST data)

Diploma/Master Theses

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

ELLMER M: Optimization of the orbit parameters of future gravity missions using genetic algorithms (Optimierung der Orbitparameter zukünftiger Schweremissionen mithilfe genetischer Algorithmen)

LAGU AM: Evaluation of EGM2008 in the State of Baden-Württemberg using GPS and Leveling (Vergleich des EGM2008 in Baden-Württemberg durch Kombination von GPS und Nivellement)

LEINSS B: Orbitverdichtung mittels Kalman-Filterung am Beispiel der Satellitenmission GRACE (Orbit densification by means of a Kalman-Filter applied to the satellite mission GRACE)

LI Y: Satellite Altimetry for hydrological purpose (Satellitenaltimetrie für hydrologische Anwendungen)

NWOKE C: Monitoring the Uplift of the Land Surface using Gravimetry. A Case Study of the Geothermal Drill Site in the Town of Staufen, Breisgau (Überwachung von Landhebungen mittels Gravimetrie. Eine Fallstudie anlässlich der Geothermiebohrungen in Staufen/Breisgau)

SCHENK M: Development and Rating of Monitoring and Mitigation Methods for Ionospheric Threats to Differential GNSS Applications for Precision Approach Guidance in Aviation (Entwicklung und Beurteilung von Methoden zur Überwachung und Abschwächung ionosphärischer Bedrohungen für präzise Landeanflüge in der Luftfahrt)

WANG L: GOCE gravity models and gravity gradient assessment (GOCE-Schwerefeldmodelle und Beurteilung der Gravitationsgradienten)

Publications

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

Refereed Journal Publications

BAUR O AND N SNEEUW: Assessing Greenland ice mass loss by means of point-mass modeling: a viable methodology. Journal of Geodesy 85 (2011) 607-615, DOI 10.1007/s00190-011-0463-1

GRAFAREND E: The transition from three-dimensional embedding to two-dimensional Euler-Lagrange deformation tensor of the second kind: variation of curvature measures. Pure and Applied Geophysics (2011), DOI 10.1007/s00024-011-0419-7

GRAFAREND E: Space gradiometry: tensor-valued ellipsoidal harmonics, the datum problem and application of the Lusternik-Schnirelmann category to construct a minimum atlas. International Journal on Geomathematics 1 (2011) 145-166, DOI 10.1007/s13137-011-0013-2

GRAFAREND E AND W KÜHNEL: A minimal atlas for the rotation group SO(3). International Journal on Geomathematics 2 (2011) 113-122, DOI 10.1007/s13137-011-0018-x

KELLER W AND J HAJKOVA: Representation of planar integral-transformations by 4-D wavelet decomposition. Journal of Geodesy 85 (2011) 341-356

LIN Y, S ZHANG, J CAI AND N SNEEUW: Application of wavelet support vector regression on SAR data de-noising. Journal of Systems Engineering and Electronics 22 (2011) 579-586

TOURIAN M, J RIEGGER, N SNEEUW AND B DEVARAJU: Outlier identification and correction for GRACE aggregated data. Studia Geophysica et Geodaetica 55 (2011) 627-640, DOI 10.1007/s11200-009-9007-z

ZOU X, J CAI, N SNEEUW AND J Li: Numerical study on the mixed model in the GOCE polar gap problem. Geo-spatial Information Science 14 (2011) 216-222, DOI 10.1007/s11806-011-0532-x

Other Refereed Contributions

GRAFAREND E: Spacetime gradiometry: tensor-valued ellipsoidal harmonics, the datum problem and an application of the Lusternik-Schnirelmann Category to construct a minimum atlas. In: Contadakis ME et al (Eds., 2010): The apple of knowledge. In honor of Prof. em. D.N. Arabelos, pp. 121-145, ZHTH, Thessaloniki 2010

KELLER W, M KUHN AND WE FEATHERSTONE: A set of analytical formulae to model deglaciation. - Induced polar wander. In: Kenyon S, MC Pacino and U Marti (Eds.): Geodesy for the Planet Earth. Proceedings of the 2009 IAG Symposium, Buenos Aires, pp 527-537, Springer Berlin Heidelberg, 2011

ROTH M, O BAUR AND W KELLER: Tailored usage of the NEC SX-8 and SX-9 systems in satellite geodesy. In: Nagel WE, DB Kröner, MM Resch (Eds.): High Performance Computing in Science and Engineering ’10, Springer Berlin Heidelberg, pp. 561-572

Non-refereed Contributions

ANSELMI A, S CESARE, P VISSER, T VAN DAM, N SNEEUW, T GRUBER, B ALTÉS, B CHRISTOPHE, F COSSU, PG DITMAR, M MURBÖCK, M PARISCH, M RENARD, T REUBELT, G SECHI AND JG TEXIEIRA DA ENCARNACAO: Assessment of a next generation gravity mission to monitor the variations of Earth's gravity field. ESA Contract No. 22643/09/NL/AF, Executive Summary, Thales Alenia Space report SD-RP-AI-0721, March 2011

REUBELT T, N SNEEUW AND S IRAN POUR: Quick-look gravity field analysis of formation scenarios selection. In: Geotechnologien, Science Report No. 17, pp 126-133. Statusseminar „Observation of the System Earth from Space", Bonn (4.10.)

VAN DER WAL W, L WANG, P VISSER, N SNEEUW AND B VERMEERSEN: Evaluating GOCE data near a mid-ocean ridge and possible application to crustal structure in Scandinavia. In: Proceedings 4th GOCE User Workshop ESA SP-696, July 2011, ESA, Munich (31.3.-1.4.)

WEIGELT M, O BAUR, T REUBELT, N SNEEUW AND M ROTH: Long wavelength gravity field determination from GOCE using the acceleration approach. In: Proceedings 4th GOCE User Workshop ESA SP-696, July 2011, ESA, Munich (31.3.-1.4.)

Poster Presentations

ANTONI M, W KELLER AND M WEIGELT: Comparison of genetic algorithm and descend direction algorithm for SST data. EGU General Assembly, Vienna, Austria (3.-8.4.)

BAUR O, M WEIGELT, T REUBELT AND N SNEEUW: Towards an optimal GOCE-only gravity field solution: recovery of long-wavelength features via the acceleration approach. EGU General Assembly, Vienna, Austria (3.-8.4.)

CAI J, N SNEEUW AND O BAUR: GOCE gravity field model derived from the rotational invariants of the gravitational tensor. BMBF Geotechnologien Statusseminar „Erfassung des Systems Erde aus dem Weltraum IV", Stuttgart (11.10.)

CAI J, N SNEEUW, Q YANG AND O BAUR: Stochastic modeling of GOCE invariants in real data analysis. IUGG, Melbourne, Australia (28.6.-7.7.)

CAI J, N SNEEUW, Q YANG AND O BAUR: Implementing a stochastic model for GOCE invariants. 4th GOCE User Workshop, ESA, Munich (31.3.-1.4.)

HIRTH M, W FICHTER, T REUBELT, N SNEEUW AND S IRAN POUR: Performance aspects of future gravity mission constellations. EGU General Assembly, Vienna, Austria (3.-8.4.)

IRAN POUR S, N SNEEUW AND T REUBELT: Quality assessment of sub-cycle vs. full repeat period solutions of future gravity field missions, BMBF Geotechnologien Statusseminar „Erfassung des Systems Erde aus dem Weltraum IV", Stuttgart (11.10.)

KELLER W: Representation of planar integral-transformations by 4D wavelet decomposition. EGU General Assembly, Vienna, Austria (3.-8.4.)

REUBELT T, N SNEEUW AND S IRAN POUR: Are subcycle solutions meaningful for time variable gravity field analysis from future satellite missions? AGU Fall Meeting 2011, San Francisco, California, USA (5.-9.12.)

REUBELT T, N SNEEUW, S IRAN POUR, W FICHTER AND M HIRTH: Sensitivity analysis of future satellite formations and configurations of them. EGU General Assembly, Vienna, Austria (3.-8.4.)

SCHLESINGER R, M ROTH, N SNEEUW AND C NWOKE: Schweresignal im Geothermiefall Staufen - Jahresanalyse. Geodätische Woche Nürnberg (27.-29.9.)

VISSER P, M MURBÖCK, T VAN DAM, T REUBELT, A ANSELMI, L MASSOTTI, P DITMAR, JT DE ENCARNACAO, T GRUBER, N SNEEUW, S CESARE, F COSSU, M PARISCH, G SECHI AND M AGUIRRE: Scientific assessment of a next generation gravity mission. EGU General Assembly, Vienna, Austria (3.-8.4.)

WANG L, W VAN DER WAL AND N SNEEUW: GOCE gravity models compared to EGM2008, GRACE and ship gravity measurements. EGU General Assembly, Vienna, Austria (3.-8.4.)

WEIGELT M, O BAUR, T REUBELT, N SNEEUW AND M ROTH: Long wavelength gravity field determination from GOCE using the acceleration approach. 4th GOCE User Workshop, ESA, Munich (31.3.-1.4.)

ZHANG S, N SNEEUW, J CAI AND J LI: Zero-difference ambiguity fixing for PPP and precise orbit determination. Geodätische Woche Nürnberg (27.-29.9.)

ZHAO W AND N SNEEUW: Local gravity field modeling by gradiometry. Geodätische Woche Nürnberg (27.-29.9.)

Conference Presentations

BAUR O AND N SNEEUW: Assessing Greenland ice mass loss by means of point-mass modeling: a viable methodology. EGU General Assembly, Vienna, Austria (3.-8.4.)

BAUR O AND N SNEEUW: Are genetic algorithms a universal parameter estimation tool in geodesy? QuGOMS - The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems, Munich (13.-15.4.)

CAI J: Biased and unbiased estimations in geodetic data analyses. QuGOMS - The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems, Munich (13.-15.4.)

CAI J: Revisiting the search criteria for solving the mixed integer-real valued adjustment problem with GNSS carrier phase observations. The 2nd China Satellite Navigation Conference (CSNC 2011), Shanghai, China (18.-20.5.)

CAI J, N SNEEUW, Q YANG AND O BAUR: GOCE gravity field model derived from rotational invariants. Geodätische Woche Nürnberg (27.-29.9.)

ELSAKA B, JC RAIMONDO, T REUBELT, S IRAN POUR, J KUSCHE, F FLECHTNER AND N SNEEUW: Full-Scale mission simulations. BMBF Geotechnologien Statusseminar „Erfassung des Systems Erde aus dem Weltraum IV“, Stuttgart (11.10.)

HIRTH M, W FICHTER, B SHEARD, G HEINZEL, T REUBELT AND N SNEEUW: Control system design issues of future gravity missions. GNC 2011 - 8th International ESA Conference on Guidance and Navigation Control Systems. Karlovy Vary, Czech Republic (5.-10.6.)

IRAN POUR S, N SNEEUW, M WEIGELT AND T REUBELT: Assessment of the aliasing effect of white noise on different solutions in gravity recovery simulations of a GRACE-like mission. IUGG General Assembly - Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia (28.6.-7.7.)

IRAN POUR S, N SNEEUW, T REUBELT AND M WEIGELT: Comparison of full-repeat and sub-cycle solutions in gravity recovery simulations of a GRACE-like mission. EGU General Assembly, Vienna, Austria (3.-8.4.)

IRAN POUR S, N SNEEUW, T REUBELT AND M WEIGELT: Quality assessment of simulations of future gravity field missions for hydrological purposes. Geodätische Woche Nürnberg (27.-29.9.)

KELLER W: Umordnung großer, schwach besetzter Normalgleichungsmatrizen mithilfe graphentheoretischer und genetischer Algorithmen. Geodätische Woche Nürnberg (27.-29.9.)

KELLER W AND J HAJKOVA: Representation of planar integral-transformations by 4-D wavelet decomposition. EGU General Assembly, Vienna, Austria (3.-8.4.)

MOGHTASED-AZAR K, E GRAFAREND, F TAVAKOLI AND HZ NANKALI: Estimated Principal Components of Deformation Tensors Derived from GPS Measurements under Assumption of Both Independent and Correlated Tensor Observations (Case Study: Zagros Mountains, Iran). Joint International Symposium on Deformation Monitoring 2011, Hong Kong, China (2.-4.11.)

MURBÖCK M, R PAIL, T GRUBER, T REUBELT, N SNEEUW, W FICHTER AND J MÜLLER: Concepts for future gravity satellite missions. Fragile Earth, Geological Processes from Global to Local Scales, Associated Hazards and Resources. International Conference, Munich (4.-7.9.)

ROESE-KOERNER L, B DEVARAJU, WD SCHUH AND N SNEEUW: Describing the quality of inequality constrained estimates. QuGOMS - The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems, Munich (13.-15.4.)

SCHALL J, O BAUR, JM BROCKMANN, J CAI, A EICKER, B KARGOLL, I KRASBUTTER, J KUSCHE, T MAYER-GÜRR, W-D SCHUH, A SHABANLOUI AND N SNEEUW: REal data

AnaLysis GOCE - Gravity field determination from GOCE. BMBF Geotechnologien Statusseminar „Erfassung des Systems Erde aus dem Weltraum IV", Stuttgart (11.10.)

SNEEUW N: Spaceborne gravimetry: a novel tool for continental-scale storage change monitoring. EGU General Assembly, Vienna, Austria (3.-8.4.)

SNEEUW N, M WEIGELT AND X XU: Sampling the Earth with Satellites in Near-polar Orbit. IUGG General Assembly - Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia (28.6.-7.7.)

TOURIAN M, J RIEGGER AND N SNEEUW: Long-range spatial correlations in GRACE products: a matter of S2-tidal aliasing? EGU General Assembly, Vienna, Austria (3.-8.4.)

TOURIAN M, J RIEGGER, N SNEEUW AND B DEVARAJU: Analysis of GRACE uncertainties by hydrological and hydrometeorological observations. QuGOMS - The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems, Munich (13.-15.4.)

VISSER P, P DITMAR, J ENCARNACAO, M MURBÖCK, T GRUBER, T VAN DAM, N SNEEUW, T. REUBELT, A ANSELMI, S CESARE, F COSSU, M PARISCH, G SECHI, L MASSOTTI AND M AGUIRRE: Scientific assessment of a next generation gravity mission. AGU Fall Meeting 2011, San Francisco, California, USA (5.-9.12.)

WEIGELT M AND W KELLER: GRACE Gravity Field Solutions Using the Differential Gravimetry Approach. IUGG General Assembly - Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia (28.6.-7.7.)

WEIGELT M, A JÄGGI, L PRANGE, W KELLER AND N SNEEUW: Towards the time-variable gravity field from CHAMP. IUGG General Assembly - Earth on the Edge: Science for a Sustainable Planet, Melbourne, Australia (28.6.-7.7.)

Books

GRAFAREND E AND J AWANGE: Linear and Nonlinear Models: Fixed Effects, Random Effects and Total Least Squares. 600 pages, Springer, Berlin, Heidelberg, New York 2011

Guest Lectures and Lectures on special occasions

MARTI, U (Bundesamt für Landestopografie, swisstopo, Wabern, Switzerland): Geodetic Works for the Gotthard Base Tunnel (8.6.)

ROESE-KOERNER, L (Institut für Geodäsie und Geoinformation, Theoretische Geodäsie, Universität Bonn): Inequalities in Geodesy-toys or useful tools? (24.2.)

VÖLTER, U (intermetric Gesellschaft für Ingenieurmessung und raumbezogene Informationssysteme mbH, Stuttgart): Anmerkungen zu den aktuellen Vermessungsarbeiten für den Einbau der festen Fahrbahn im Gotthard Basis Tunnel (13.1.)

Lectures at other universities

CAI J

Biased and unbiased estimations in geodetic data analyses. Wuhan University, Wuhan, China (6.1.)
Advanced Satellite Positioning Data Proceeding. Central South University, Changsha, China (24.5.)
Modern Geodetic Deformation Analysis. Central South University, Changsha, China (24.5.)
GOCE data analysis based on rotational invariant . Wuhan University, Wuhan, China (5.9.)
GOCE-only high-resolution gravity field model based on rotational invariant methodology. Wuhan University, Wuhan, China (28.12.)

GRAFAREND E

The Perspective 4 Point (P4P) Problem as well as the Twin Perspective 4 Point (TP4P) Problem - 3d resection and 3d intersection - by Moebius barycentric coordinates: application to Geodetic Positioning, Photogrammetry, Machine Vision, Robotics and Computer Vision, Remote Sensing. Geodetic Institute, Masala/Helsinki, Finland (19.8.)
Von A. Einstein über H. Weyl und E. Cartan zur Quantengravitation, Leibniz Sozietät der Wissenschaften, Berlin (13.10.)

SNEEUW N

Geodätische Raumverfahren für die Hydrologie, Geodetic Colloquium, Universität Bonn (20.10.)
Hydrogeodesy, ITC, WRS Colloquium, University of Twente, Enschede, The Netherlands (30.11.)

Research Stays

CAI J: School of Geodesy and Geomatics, Wuhan University, China (1.-16.1.)

KELLER W: Landwirtschaftliche Universität Wroclaw, Poland (26.8.-10.9.)

Lecture Notes

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

GRAFAREND E AND F KRUMM

Kartenprojektionen (Map Projections), 238 pages

HAUG G

Grundstücksbewertung I (Real Estate/Property Valuation I), 32 pages
Grundstücksbewertung II (Real Estate/Property Valuation II), 11 pages

KELLER W

Dynamic Satellite Geodesy, 90 pages
Foundations of Satellite Geodesy, 51 pages
Observation Techniques in Satellite Geodesy, 50 pages

KRUMM F AND SNEEUW N

Adjustment Theory, 141 pages

KRUMM F

Adjustment Theory, 128 pages
Map Projections and Geodetic Coordinate Systems, 165 pages
Mathematical Geodesy, 153 pages
Reference Systems, 157 pages

SCHÖNHERR H

Amtliches Vermessungswesen und Liegenschaftskataster (Official Surveying and Real Estate Regulation), 52 pages

SNEEUW N

Analytic Orbit Computation of Artificial Satellites / Dynamic Satellite Geodesy, 90 pages
History of Geodesy, 38 pages
Geodesy and Geodynamics, 68 pages
Geodesy and Geoinformatics, 31 pages
Physical Geodesy (Measurement Techniques of Physical Geodesy, Modeling and Data Analysis in the Field of Physical Geodesy), 137 pages

WOLF D

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

Participation in Conferences, Meetings and Workshops

CAI J

BMBF Geotechnologien Statusseminar 2011, „Erfassung des Systems Erde aus dem Weltraum III“, Stuttgart, Germany (11.10.)
DFG SPP1257 Summer School, Mayschoss (12.-16.9.)
Geodetic Week, Nürnberg, Germany (26.-29.9.)
GOCE User Workshop, München, Germany (31.3.-1.4.)
REAL GOCE Project Meeting, Stuttgart (10.10.)
REAL GOCE Project Meeting, München (30.3.)
The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Syst - QuGOMS, München, Germany (13.-15.4.)

DEVARAJU B

IUGG General Assembly, Melbourne, Australia (28.6.-7.7.)

IRAN POUR S

BMBF Geotechnologien Statusseminar 2011, „Erfassung des Systems Erde aus dem Weltraum III“, Stuttgart, Germany (11.10.)

Project meeting 4 of „Zukunftskonzepte für Schwerefeld-Satellitenmissionen“ (Geotechnologies - Observation of the System Earth from Space III), Menlo Systems GmbH, Martinsried, München (17.-18.1.)

Project meeting 5 of „Zukunftskonzepte für Schwerefeld-Satellitenmissionen“ (Geotechnologies - Observation of the System Earth from Space III), IBZ, Stuttgart University, Stuttgart (12.10.)

REUBELT T

„Full-Scale-Meeting“ of „Zukunftskonzepte für Schwerefeld-Satellitenmissionen“ (Geotechnologies - Observation of the System Earth from Space III), IAPG, München, Germany (12.5.)

AGU Fall Meeting 2011, San Francisco, California, USA (5.-9.12.)

BMBF Geotechnologien Statusseminar 2011, „Erfassung des Systems Erde aus dem Weltraum III“, Stuttgart, Germany (11.10.)

EGU General Assembly, Vienna, Austria (3.-8.4.)

Project meeting 4 of „Zukunftskonzepte für Schwerefeld-Satellitenmissionen“ (Geotechnologies - Observation of the System Earth from Space III), Menlo Systems GmbH, Martinsried, München (17.-18.1.)

Project meeting 5 of „Zukunftskonzepte für Schwerefeld-Satellitenmissionen“ (Geotechnologies - Observation of the System Earth from Space III), IBZ, Stuttgart University, Stuttgart (12.10.)

ROTH M

Geodetic Week, Nürnberg, Germany (26.-29.9.)

The 14th Results and Review Workshop, HLRS Stuttgart (4.-5.10.)

CRAY XE6 Optimization Workshop, HLRS Stuttgart (2.-4.11.)

SCHLESINGER R:

Geodetic Week, Nürnberg, Germany (26.-29.9.)

SNEEUW N

BMBF Geotechnologien Statusseminar 2011, „Erfassung des Systems Erde aus dem Weltraum III“, Stuttgart, Germany (11.10.)

European Geosciences Union (EGU), General Assembly 2010, Vienna, Austria (3.-8.4.)

Geodetic Week, Nürnberg, Germany (26.-29.9.)

GOCE User Workshop, München, Germany (31.3.-1.4.)

IUGG General Assembly, Melbourne, Australia (28.6.-7.7.)

The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Syst - QuGOMS, München, Germany (13.-15.4.)

TOURIAN M

DFG-SPP1257 Symposium, Review Meeting, Potsdam (12.-14.10.)
DFG-SPP1257 Workshop „Mass transport and mass distribution in system Earth", Dipperz/Fulda (22.-24.2.)

WEIGELT M

GOCE User Workshop, München, Germany (31.3.-1.4.)
IUGG General Assembly, Melbourne, Australia (28.6.-7.7.)

University Service

GRAFAREND E

Member Faculty of Aerospace Engineering and Geodesy
Member Faculty of Civil- and Environmental Engineering
Member Faculty of Mathematics and Physics

ROTH M

Chairman of the PR-Commission of the study course Geodesy & Geoinformatics

SNEEUW N

Associate Dean (Academic) Geodäsie & Geoinformatik and GEOENGINE, Stuttgart
Member China Commission, International Affairs (IA)
Stand-by Member Senate Committee for Structural Development, Stuttgart
Vice-Chair Examining Board of the Faculty of Aerospace Engineering and Geodesy, Stuttgart
Member Search Committee Differentialgeometrie

Professional Service (National)

GRAFAREND E

Emeritus Member German Geodetic Commission (DGK)

SNEEUW N

Full Member German Geodetic Commission (DGK)
Chair DGK section „Erdmessung"
Member Scientific Board of DGK
Member Scientific Advisory Committee of DGFI
Chair AK7 (Working Group 7), „Experimentelle, Angewandte und Theoretische Geodäsie", within DVW (Gesellschaft für Geodäsie, GeoInformation und LandManagement)

Professional Service (International)

CAI J

Luojia Professor at School of Geodesy and Geomatics, Wuhan University, China Member of the Institute of Navigation (ION, USA)
Member of European Geosciences Union (EGU)

GRAFAREND E

Elected Member of the Finnish Academy of Sciences and Letters, Finland
Elected Member of the Hungarian Academy of Sciences, Hungary
Member Royal Astronomical Society, Great Britain
Corresponding Member Österreichische Geodätische Kommission (ÖGK)
Member Flat Earth Society
Elected Member Leibniz-Sozietät, Berlin
Fellow International Association of Geodesy (IAG)

SNEEUW N

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

WEIGELT M

Chair of the study group JSG0.6: Applicability of current GRACE solution strategies to the next generation of inter-satellite range observations, (Intercommission Committee on Theory, IAG)
Member of study group JSG0.3: Methodology of Regional Gravity Field Modeling (Intercommission Committee on Theory, IAG)
Member Inter-Commission Working Group (IC-WG2): „Evaluation of Global Earth Gravity Models“ (IAG)

Courses - Lecture/Lab/Seminar

Adjustment I, II (Krumm, Roth)	4/2/0
Advanced Mathematics (Keller, Weigelt)	3/2/0
Analytic Orbit Computation of Artificial Satellites (Sneeuw, Reubelt)	2/1/0
Dynamic Satellite Geodesy (Keller)	1/1/0
Foundations of Satellite Geodesy (Keller)	1/1/0
Geodesy and Geoinformatics (Sneeuw)	1/1/0
Geodetic Reference Systems (ICRS-ITRS) for Satellite Geodesy and Aerospace (Weigelt)	2/1/0
Geodetic Seminar II (Krumm, Sneeuw)	0/0/2
Gravity Field Modeling (Keller)	2/1/0

Integrated Field Work Geodesy and Geoinformatics (Keller, Sneeuw)	10 days
Map Projections and Geodetic Coordinate Systems (Krumm, Roth)	2/1/0
Mathematical Geodesy (Krumm)	2/1/0
Mathematical Geodesy (Krumm, Roth)	2/2/0
Measurement Techniques of Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Modeling and Data Analysis in the Field of Physical Geodesy (Engels, Reubelt)	2/1/0
Observation Techniques and Evaluation Procedures of Satellite Geodesy (Keller, Weigelt)	1/1/0
Official Surveying and Real Estate Regulation (Schönherr)	2/0/0
Orbit Determination and Analysis of Artificial Satellites (Keller, Reubelt)	2/1/0
Physical Geodesy (Sneeuw, Reubelt)	2/1/0
Real-Estate/Property Valuation I, II (Haug)	2/1/0
Reference Systems (Krumm, Roth)	2/2/0
Satellite Geodesy Observation Techniques (Weigelt)	1/1/0
Satellite Geodesy (Keller)	2/1/0
Statistical Inference (Krumm, Roth)	2/1/0

Institute of Navigation

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Dipl.-Ing. Bernhardt S c h ä f e r	Navigation Systems
Dipl.-Ing. Wolfgang S c h ö l l e r	Education/Navigation Systems
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Dipl.-Ing. Xue W e i	Inertial Navigation
Dr. Ing. Franziska W i l d - P f e i f f e r	Navigation Systems

EDP and Networking

Regine S c h l o t h a n

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Technician Peter S e l i g - E d e r
Electrician Sebastian S c h n e i d e r
Mechanician Master Michael P f e i f f e r

External teaching staff

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

Research Projects

Development of a Low-Cost Integrated Navigation System for Aircraft Applications

In the context of the „3D Pilot“ project the position, the velocity and the orientation of an aircraft in real-time are determined. The development of the integrated navigation system is a part of his project. It is based on low-cost hardware, and the focus of research is an Extended Kalman Filter (EKF) with an optimal setting of parameters.

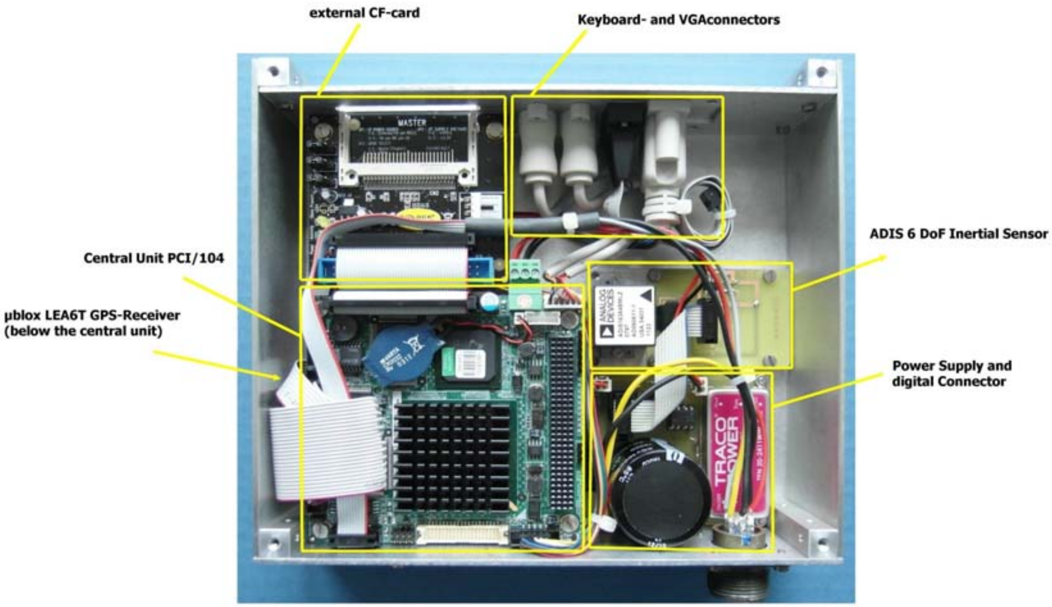

Figure 1: Low-cost integrated navigation system

The integrated navigation system contains a μ-Blox LEA 6T GNSS receiver, an ADIS 3D accelerometer and an ADIS 3D gyroscope (see Figure 1). The GNSS receiver uses GPS with SBAS of 1 Hz data rate and it delivers improved positions and velocities with accuracy of 3 m and of 5 cm/s respectively. The ADIS sensors measure the acceleration and the rotation rate of 50 Hz data rate. A processor combines these data on-line by using 15 states EKF (see Figure 2).

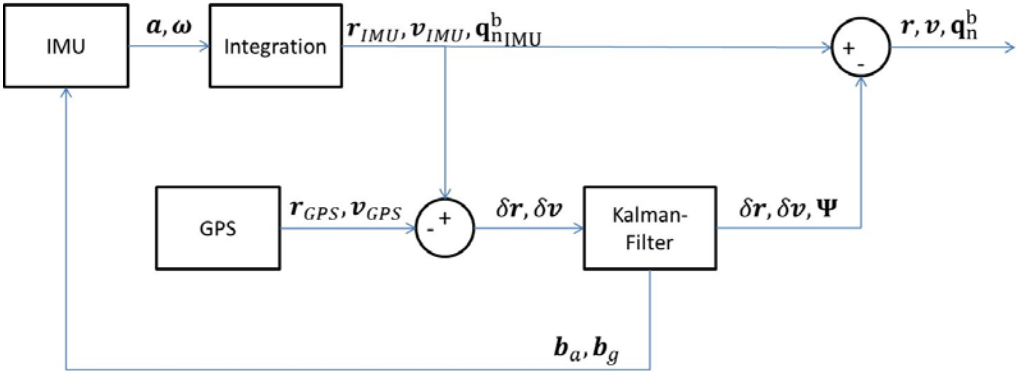

Figure 2: Flow-chart of the EKF

Evaluating the system performance is tested in real situations. Therefore, a high quality commercial INS from Applanix was used. The reference data results are based on the double-difference GPS-phase measurements, which are tightly coupled with smoothed MEMS measurements in post processing.

The standard deviations of the low-cost navigation system with regard to the commercial system are below of 0.5 m in position, of 0.2 m/s in velocity and of 0.3° in orientation (see Table 1).

	Average	Standard deviation
North	-0.034 m	0.244 m
East	0.552 m	0.274 m
Altitude	-0.728 m	0.406 m
v_n	-0.014 m/s	0.108 m/s
v_e	0.008 m/s	0.094 m/s
v_d	0.015 m/s	0.070 m/s
Roll	-0.006°	0.102 °
Pitch	-0.336°	0.105 °
Yaw	-0.033°	0.242 °

Table 1: Statistic of the low-cost INS-system compared with the commercial Applanix system

Development of GNSS Software

In the framework of the „3D Pilot“ project real-time software for the calculation of positions and velocities with appropriate accuracies was implemented in C/C++. The algorithm used is based on GPS observations with SBAS correction data and follows the documents „IS-GPS 200E“ and „RTCA 229D“. All parts of the software are running in real-time with position and velocity outputs of 1 Hz. The results show that the accuracy of position and velocity is below of 3 m and below of 0.05 m/s respectively.

Development of a GNSS software receiver has started and was implemented in C/C++. The software receiver works with sampled data from a front end for the L1-frequency. The front end converts down the frequency of the received signal to an intermediate frequency of 4.092 MHz with a sampling frequency of 16.368 MHz. The real power spectrum of a received and frequency down converted signal with the front end is shown in figure 1.

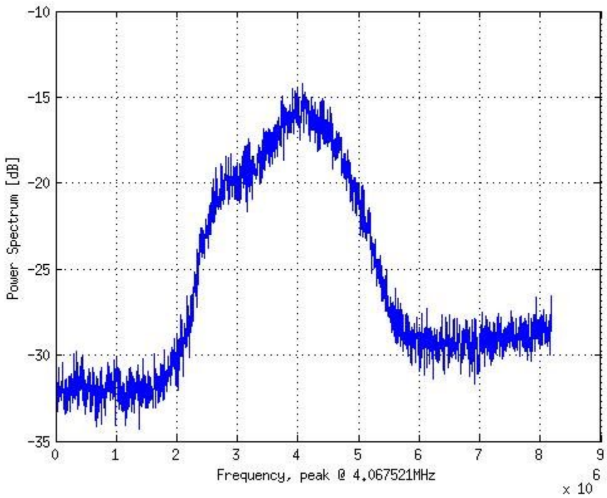

Figure 1: Power spectrum of a frequency down converted signal

Currently only the civil GPS C/A-Code on L1 - frequency is tracked. For real time applications we are working on an optimized algorithm performing the correlations within less computation time.

Body-mounted MEMS inertial sensors for activity monitoring and positioning

Conventional inertial sensors used today are so-called Micro Electro Mechanical Systems (MEMS). Due to their small dimensions and low costs, they can be found in a wide field of applications. MEMS inertial sensors offer new possibilities for highly portable applications of the inertial navigation technology e.g. in the field of indoor tracking and personal navigation. The detection of human body posture, postural transition and gait classification can be carried out by a combination of various sensors, usually accelerometers and gyroscopes. The performance of body posture and transition detection and gait classification with MEMS sensors attached to the body is evaluated at the Institute of Navigation and new algorithms were developed and tested.

Hybrid MEMS sensors (Accelerometer and Gyroscope), attached to the shoes, were used to create a two-dimensional positions for a pedestrian navigation solution. The step lengths, derived by a modified strapdown algorithm at both feet, were used to calculate the heading information. As a reference the GAITRite of the Robert-Bosch-Hospital of Stuttgart was used.

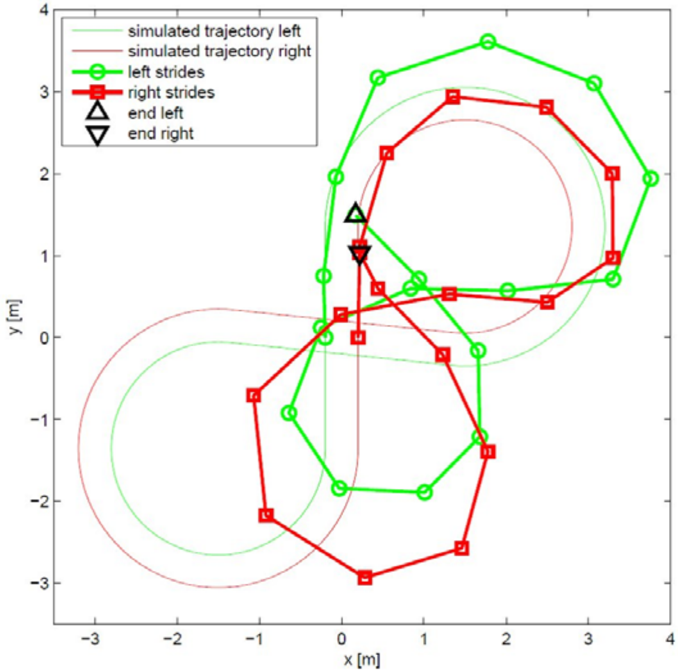

Figure 1: Simulated Trajectories and result of the dead reckoning with measured stride lengths and derived heading for both feet.

Phenological Impact on a transferable classification concept for multitemporal TerraSAR-X-data (PI-X)

During 2010 only some images could be received for the test sides due to conflicts with other users. N 2011 the situation was better and a full set of 8 images for the vegetation period (April - October) could be acquired for one test side. For the second one 6 images were available. The goal of the analysis is to figure out typical reflectance curves for several crop types for the vegetation period. At a later stage, these curves are meant to be used as reference curves for a classification. In parallel with the imaging of the test sides by TerraSAR-X the situation of several fields in the test sides were noticed during fieldwork. In total 1013 parcels for test side 1 to the east of Heilbronn and for test side 2 1810 parcels on and at the foot of the Swabien Alb were visited. The main crop types are sugar beet, maize and different cereals. As an example figure 1 shows reflectance curves for barley, maize, rape, sugar beet and wheat for test side 1. The curves end when a field was harvested. That these curves can be used as reference curves are confirmed by a comparison between summer and winter barley (figure 2).

Barley_1 are fields seeded in autumn 2010 („winter barley“) whereas Barley_2 are fields seeded in Spring 2011 („summer barley“). Both the Barley_1 and the Barley_2 fields were harvested early August 2011. The Barley_1 as well as the Barley_2 line are identical, but shifted. This can be explained by different development stages. Whereas for Barley_ 1 the ear is fully developed and visible in May it is inside of the corn stalk for Barley_2. The existence of the ear caused a strong attenuation for Barley_1 in May and delayed for Barley_2 in June, when Barlay_2 was at the same development stage.

In the end of 2012 a new full dataset for the test sides will be available, hopefully. A validation of the reflectance curves will be possible then.

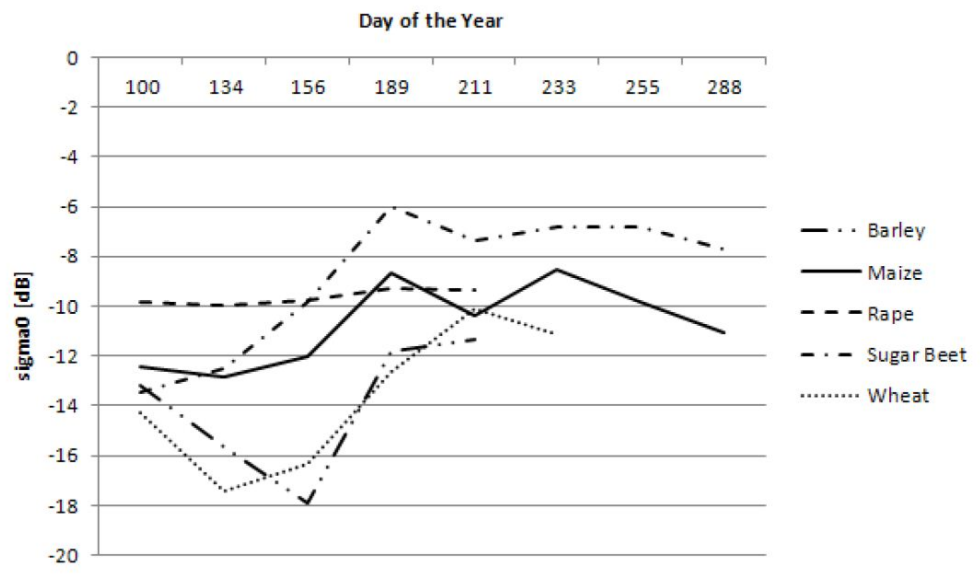

Fig. 1: Backscatter values of different crop types

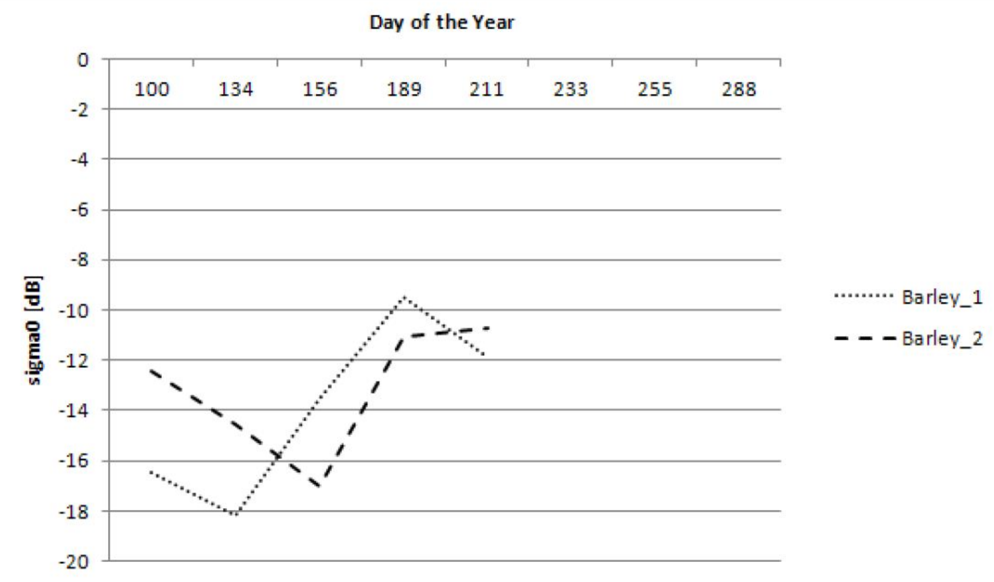

Fig. 2: Backscatter values for winter barley (Barley_1) and summer barley (Barley_2)

Publications and Presentations:

Schäfer, B.; Wild-Pfeiffer, F.; Xue, W.; Becker, C.; Lindemann, U.: Applications of bodymounted MEMS inertial sensors. IUGG 2011, 28 June - 7 July 2011, Melbourne, Australia

Schäfer, B.: Determination of heading information from gait cycle pattern using stride length estimation with reduced IMUs on right and left foot, in: „Proceedings of the 2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN'2011) - short papers, posters and demos“, Moreira, Adriano J. C.; Meneses, Filipe M. L. (eds.). Guimarães, Portugal; ISBN 978-972-8692-63-6

Schäfer, B.; Ellmer, M.; Zechmann, H.: Kinematische Positionierung eines Rennwagens mit Low-Cost GPS - Aufbau des Systems und Validierung erster Ergebnisse. Geodätische Woche 2011, 27-29 September 2011, Nürnberg

Reinhold, A., Xue, W., Wild-Pfeiffer, F., Pfeiffer, R.: „Untersuchung der Lage- und Orientierungsgenauigkeit von MEMS-Inertialsensoren hinsichtlich der Integration in einen handgeführten 3D-Scanner“, Geodätische Woche 2011, 27.- 29.09.2011, Nürnberg.

Wild-Pfeiffer, F., Schäfer, B.: „MEMS-Sensoren, auch für die Geodäsie“, ZfV, 136 (1/2011), S.30-39.

Wild-Pfeiffer, F.: „Grundlagen zur Erfassung körperlicher Aktivität mittels MEMS-Sensoren", Colloquium des Masterstudiengangs Sportwissenschaft: Gesundheitsförderung, 10.03.2011, Stuttgart.

Wild-Pfeiffer, F.: „Effects of topographic and isostatic masses in satellite gravity gradiometry", Vortrag im Rahmen des Forschungsaufenthaltes am Institut für Theoretische Geodäsie, Slovak University of Technology, 31.08.2011, Bratislava.

Diploma Thesis

Friederichs, T.: Entwicklung eines Algorithmus zur Bestimmung der Objektlage und Position im dreidimensionalen Raum (Wild-Pfeiffer)

Master Thesis

Bartholomew Thiong´o Kuria: Differentiation of some important cultures in Baden-Wuerttemberg, Germany using TerraSAR-X data

Study Thesis

Enderle, Florian: „Orientierung eines dreiachsigen MEMS Magnetfeld- und Beschleunigungssensors"; Studienarbeit, Institut für Navigation; Universität Stuttgart; Juli 2011; (Schäfer).

Reinhold, A.: Erstellung eines Konzepts zur Untersuchung der Lage- und Orientierungsgenauigkeit von MEMS-Sensoren hinsichtlich der Integration in einen 3DInnenschuhscanner (Xue, Wild-Pfeiffer)

Dohrer, M.: Entwicklung von Ilias-Lernmaterialien im Bereich „Fernerkundung" zur Förderung von eigenmotiviertem Lernen (Wild-Pfeiffer)

Participation in Conferences, Meetings and Workshops:

Wild-Pfeiffer, F.

Research Stay at the Department of Theoretical Geodesy, Slovak University of Technology, Bratislava (29.08. - 02.09.2011)
Gyro Symposium, Karlsruhe, 20.-21.09.2011
Geodetic Week, Nürnberg, 28.-29.09.2011

Schäfer B.

International Union of Geodesy and Geophysics (IUGG) General Assembly 2011, 28 June - 7 July 2011, Melbourne, Australia
International Conference on Indoor Positioning and Indoor Navigation (IPIN) 2011, 21-23 September 2011, Guimarães, Portugal
Geodätische Woche 2011, 27-29 September 2011, Nürnberg

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

Wild-Pfeiffer, F.
Workshop der „Frauen im DVW", Kassel, 26.-27.02.2011
Meeting „Frauen im DVW", Intergeo Nürnberg, 28.09.2011

Guest Lectures

Weidner, U. (Institute of Photogrammetry and Remote Sensing, Karlsruhe Institute of Remote Sensing): „Hyperspectral Remote Sensing", 08.06.2011.

Freiberger Jr., J. (Setor de Geodésia e Topografia, Departamento de Engenharia Rural, Universidade Federal de Santa Maria, RS, Brasil): „The Brazilian GNSS reference network: stand and perspectives", 20.07.2011.

Saatkamp, E. D. (Setor de Geodésia e Topografia, Departamento de Engenharia Rural, Universidade Federal de Santa Maria, RS, Brasil): „The RTCM SC-104 standard: decoding, data transmission by RDS, and coding", 20.07.2011.

Education (Lecture / Practice / Training / Seminar)

Navigation and Remote Sensing (Kleusberg, Schäfer)	2/1/0/0
Introduction of Geodesy and Geoinformatic (BSc) (Kleusberg, Schäfer)	2/2/0/0
Electronics and Electrical Engineering (Wehr, Fang)	2/1/0/0
Satellite Measurement Engineering (Wehr, Fang)	2/1/0/0
Aircraft Navigation (Schöller, Wehr)	2/0/0/0
Parameter Estimation in Dynamic Systems (Kleusberg)	2/1/0/0
Navigation I (Kleusberg, Xue)	2/2/0/0
Inertial Navigation (Kleusberg, Xue)	2/2/0/0
Remote Sensing I (Wild-Pfeiffer, Pasternak)	2/2/0/0
Remote Sensing I (BSc) (Wild-Pfeiffer, Pasternak)	2/1/0/0
Remote Sensing II (Wild-Pfeiffer, Pasternak)	1/1/0/0
Satellite Programs in Remote Sensing, Communication and Navigation I (Liebig)	2/0/0/0
Satellite Programs in Remote Sensing, Communication and Navigation II (Liebig)	2/0/0/0
Radar Measurement Methods I (Braun)	2/0/0/0
Radar Measurement Methods II (Braun)	2/1/0/0
Navigation II (Becker)	2/2/0/0

Integrated Positioning and Navigation (Kleusberg)	2/1/0/0
Interplanetary Trajectories (Becker)	1/1/0/0
Practical Course in Navigation (Schöller)	0/0/2/0
Geodetic Seminar I, II (Fritsch, Sneeuw, Keller, Kleusberg, Möhlenbrink)	0/0/0/4
Integrated Fieldwork (Schäfer, Fang)	(SS 2011)

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Geoinformatics

Chair: Prof. Dr.-Ing. Dieter Fritsch	
Deputy: Dr.-Ing. Volker Walter	GIS and Remote Sensing
Dr.-Ing. Susanne Becker	Point Cloud Interpretation
Dipl.-Ing. Yevgeniya Filippovska	Data Quality

Photogrammetry and Computer Vision

Chair: Prof. Dr.-Ing. Dieter Fritsch	
Deputy: Dr.-Ing. Michael Cramer	Digital Airborne Sensors
M.Sc. Eng. Angela Budroni	Indoor Model Reconstruction
Dipl.-Ing. Alessandro Cefalu	Photogrammetric Calibration and Object Recognition
Dipl.-Ing.(FH) Markus Englich	Sensor Laboratory
Dipl.-Ing. Alexander Fietz	Indoor Mapping
M.Sc. Eng. Ali Mohammed Khosravani	Indoor Modeling and Positioning
M.Sc. Eng. Wassim Moussa	Sensor Fusion
M.Sc. Eng. Mohammed Othman	Image Orientation
Dipl.-Ing. Michael Peter	Indoor Positioning
Dipl.-Ing. Carina Raizner	Objective Stray Light Measurement
Dipl.-Ing.(FH) Werner Schneider	Digital Photogrammetry Laboratory
M.Sc. Eng. Rongfu Tang	Bundle Block Adjustment Extension
Dipl.-Ing. Konrad Wenzel	Dense Image Matching in Close Range Applications

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Chair: apl. Prof. Dr. Norbert Haala
Dipl.-Ing. Mathias Rothermel Semi-Global Matching

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Research Projects

Geoinformatics

Data Model for Hybrid 3D Geoinformation Systems

In the last years, substantial technological progress in managing 3D geospatial data could be observed. New technologies for the collection of 3D data (in particular airborne and terrestrial laser scanner) as well as an increasing performance of CPUs and GPUs have made it possible that today 3D data can be collected for large areas and handled on standards PCs. However, there is still a lack of appropriate tools for integrated data management and analysis solutions that can cope with the great diversity of 3D geodata. Thus, we deal with the development of a hybrid 3D geoinformation system which is able to combine and analyse heterogeneous 3D geodata in an efficient and consistent way.

The huge diversity of geodata becomes obvious when considering existing data models. While the 2D world mainly distinguishes between raster and vector representations, much more modelling concepts are in use for data of higher dimensions. Typical data models for 2.5D surfaces are grids or TINs; 3D solids can be described by voxel and boundary representations (BRep) as well as by mathematical definitions like parametric instancing or half-space modelling. Constructive solid geometry (CSG) and cell decomposition specify different modelling strategies for generating complex 3D objects through the combination of several basic 3D primitives, which can be represented in any of the aforementioned data models for solids. Beyond that, geodata can also be heterogeneous with respect to its quality properties (e.g. accuracy, density, completeness). Considering all these aspects, a meaningful and effective usage of geodata necessarily requires geoinformation systems which are hybrid in the sense of data model, dimension and quality.

We developed a data model which is meant to provide an application-independent conceptual basis for smart geoinformation systems. The data model is hybrid with respect to structural and geometric aspects. Through targeted extensions of the widely accepted standard ISO 19107, our concept is able to bridge the gap between 2D, 2.5D and 3D data, and break down barriers between various modelling strategies. Ignoring performance issues, our data model is based on a working hypothesis which states that all modelling types considered so far can be transferred to BRep. By internally creating boundary representations for all data sets, even inhomogeneous geodata can be reduced to a common hybrid core comprising nodes, edges, faces and solids. For a start, we assume an ideal world (Figure 1, left) in which coordinates of corresponding object representations coincide exactly. In this case, consistency for multi-representations is ensured, and geometric correspondences between different object representations (so-called *hybrid identities*) are given implicitly through incident geometries.

In practice, we usually face geodata which is geometrically and topologically heterogeneous due to inaccuracies, generalization processes or incomplete data acquisition. As a consequence, multiple object representations derived thereof show significant discrepancies between corresponding geometries (Figure 1, right). Thus, knowledge about hybrid identities is not given implicitly any more, but has to be added explicitly instead. The concept we developed for the explicit modelling of hybrid identities allows not only for the connection of objects or object parts given in different types, geometric data models, dimensions and quality levels; it also supports consistency analyses and updating measures which is an important aspect considering the frequently occurring changes in geodata. The system supports multi-representations which can be based on either the same or differing data models. Additionally, it is also possible to model parts of a single object using different modelling concepts. While, for example, the main body of a building can efficiently be represented by cell decomposition, decorative elements such as 2.5D reliefs could be added as fine surface meshes.

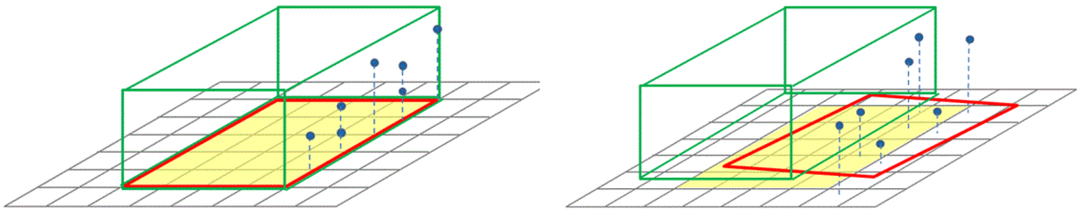


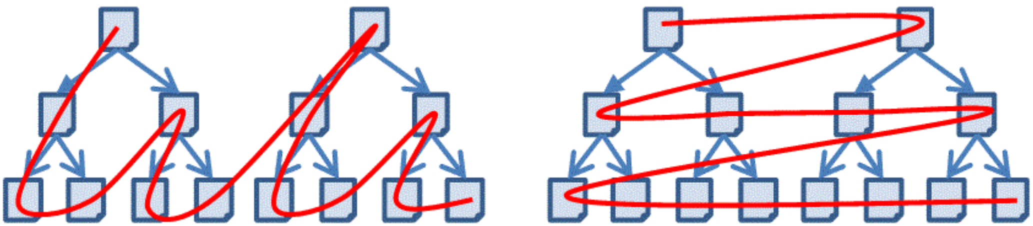
Figure 1: Multiple representations of a building in an ideal consistent and error-free world (left), and in the real world (right).

Automatic Map Retrieval in the Internet

The internet contains huge amounts of maps representing almost every part of the Earth in many different scales and map types. However, this enormous quantity of information is completely unstructured and it is very difficult to find a map of a specific area and with certain content, because the map content is not accessible by search engines in the same way as web pages. However, searching with search engines is at the moment the most effective way to retrieve information in the internet and without search engines most information would not be findable. In order to overcome this problem, methods are needed to search automatically for maps in the internet and to make the implicit information of maps explicit so that it can be processed by machines.

The search for specific file types which contain spatial data is only restricted possible with existing search engines. Many search engines do not support the search for specific file types at all, such as Microsoft Bing or Lycos. Other search machines support the search for specific file types, but only for a limited set of file types. For example, Google support the search for the file types: pdf, ps, dwf, kml, kmz, xls, ppt, rtf and swf. Although the file types kml and kmz represent geographical features, in most of all cases they contain only the coordinates of points of interest and not comprehensive map data. In contrast, Esri Shapefile (shp) is a very popular geospatial vector data format for geographic information and a huge amount of maps in shape format are available in the internet. Since commercial search engines do not support the search for Shapefiles, we developed a web crawler for this task. A web crawler is a computer program that browses the World Wide Web in a systematical way. A web crawler starts at a predefined web page and extracts all links of this page. Then, the web crawler follows the links and again extracts the links of the linked web pages. This is repeated until a break criterion is reached or the whole World Wide Web is retrieved. The visited pages are stored in a database to avoid that a link that has already been followed is used again.

Different strategies can be used to optimize the search result of a web crawler: depth-first search, breadth-first search and best-first search (see Figure 2). In depth-first search, the web crawler starts at a predefined page, extracts the links of this page and follows the first link. Again the links are extracted and the first link is followed. This is repeated until no new link can be found. The next link, which is used, is the second link of the first page. In breath-first search, the web crawler also starts at a predefined page and extracts the links of this page. Each link is followed and all links of the next level are extracted. These links are again followed and all links of the next level are extracted, etc. In best-first search, the links are ranked according to a measure which quantifies the relevance of the links. With this strategy it is possible to find relevant pages faster, but the definition of an appropriate measure is often very difficult.



a) b)

Figure 2: Depth-first search (a) and breadth-first search (b).

Since the World Wide Web contains an enormous amount of pages, it is not possible to retrieve the whole Web with one single web crawler. For this reason we have developed an alternative strategy to decrease the search space. First, we search for a specific textual search term (for example: „Shapefile download“) with Google. Then, the web crawler retrieves only the web pages of the corresponding result list. The web pages are retrieved with a breadth-first search which evaluates only the first three link levels, since we assume that the web page contains a direct link to a Shapefile or an indirect link which can be accessed by following maximum two links. Additionally we evaluate maximum 30,000 links at one server. This avoids that web servers with a huge amount of web pages are completely evaluated, such as Wikipedia. Since Wikipedia is a very popular web site, web pages of Wikipedia are very often at the top in the result list of a Google search.

Shapefiles in the internet can be found normally only in zip-archieves, since the information of an ArcGIS geodatabase is normally stored in different files which must be used together (e.g. shp-file contains the geometrical data, dbf-file contains the thematic data, shx-file contains a positional index and prj-file contains coordinate system and projection information). Therefore the web crawler searches for zip-files, extracts the content of the zip-file and then searches for Shapefiles.

We tested our approach with different configurations: (1) a normal breath-search without any limitations and without using a Google result list (the entry point of the web crawler was the homepage of the Institute for Photogrammetry: www.ifp.uni-stuttgart.de) and (2)-(4) with the described strategy and using a Google result list with the search terms (2) „Shapefile download“, (3) „Shapefile free“ and (4) „Shapefile“. The web crawler retrieved exactly 300.000 web pages for all strategies. Table 1 shows the results of the different searches.

Strategy	Number of visited servers	zip files	shp files	hit rate
breadth-search	9	23	0	0.00%
„Shapefile download“	33	25,188	4,594	1.53%
„Shapefile free“	18	12.264	629	0,20%
„Shapefile“	14	2,992	528	0,18%

Table 1: Results of different search strategies.

Quality Evaluation of Generalized Building Footprints

Generalization operators are difficult to formalize: each different generalization approach represents its own and unique implementation. Therefore, different generalizations of the same object are possible which can change the geometry of the object in different ways. The objective of this research consists in proposing a generic quality evaluation framework for generalization operators. It aims to assess the quality of generalized building footprints both on level of single objects and data sets and enables the comparison of generalization alternatives.

The developed quality characteristics are based on measures which describe the similarity of the original footprint and its generalization. In order to avoid the identification of correspondences of objects parts of the original and generalized footprint (which often cannot be determined uniquely), the footprints are considered as sets of points.

Generally, the quality of generalized building footprints is considered from two different aspects, which are *contour trueness* and *area trueness*. Contour trueness can be estimated by the (1) maximum deviation of two contours and the (2) percentage of contour overlapping. The computation of the first characteristic is based on the Hausdorff distance, which was adapted to our problem: the maximum deviation is measured only within the difference areas instead of considering the two contours as a whole (see Figure 3a). The second characteristic (percentage of contour overlapping) is computed with buffers (see Figure 3b).

The area trueness represents two aspects of object change: spatial and quantitative. The symmetric difference of the intrusions and extrusions characterizes the total change of the spatial extension of a footprint, while the numeric difference enables the quantitative comparison of a footprint before and after generalization (see Figure 3c). Figure 4 shows a visual representation of the quality information.

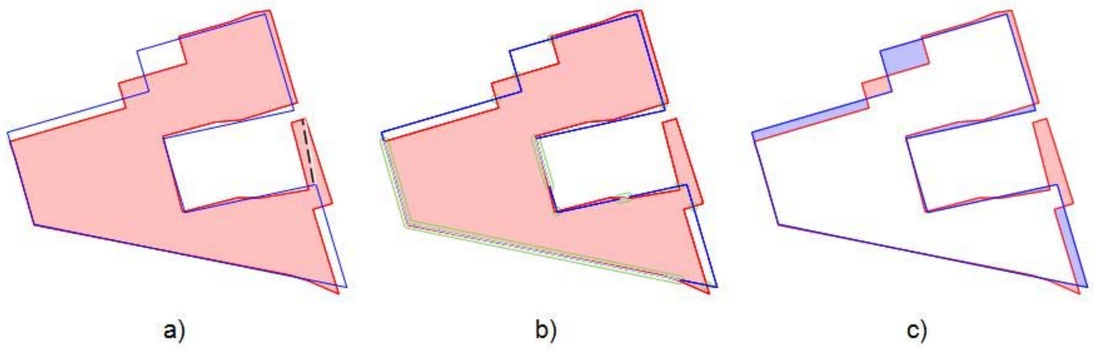


Figure 3: Quality characteristics of a generalized footprint a) maximum contour deviation, b) percentage of contour overlapping, c) areal changes.

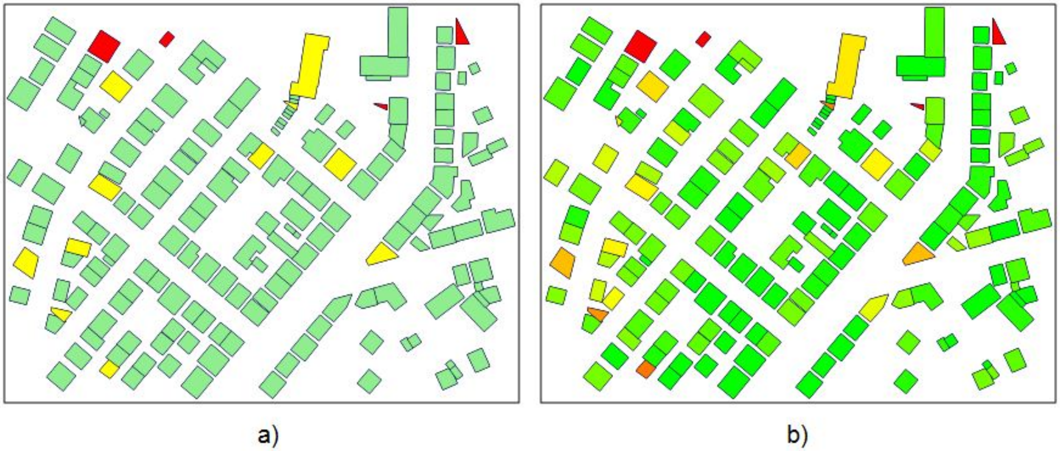


Figure 4: Quality evaluation of generalized building footprints a) traffic light model, b) palette.

Photogrammetry and Computer Vision

Modeling of Building Interiors from Photographed Evacuation Plans

At the Institute for Photogrammetry we developed an automatic approach for the reconstruction of building interiors by analysing photographed evacuation plans. The image analysis steps that are used to reconstruct a CAD-like floor model are as follows: Firstly, the layout of the image taken by the user is analyzed in order to detect the various elements of the evacuation plan. These elements can be the caption, other text, an overview plan, the plan's legend and the detailed floor plan itself. This information then is used to cut the detailed plan from the full image and to analyze the legend in order to find the symbols used in the plan. Secondly, the foreground (i.e. the walls) is separated from the background, a step which is facilitated by the fact that the background of evacuation plans is normally in a single color which is in most of the cases white.

The resulting binary image can contain emergency and evacuation symbols as well as evacuation routes and text. The detection of these elements is necessary because a) areas occluded by them have to be identified and corrected in later steps, b) the information they carry should also be included in the reconstructed model and c) they may reveal further information like the direction of staircases. Using the binary image without symbols and other elements, a 2D model can be derived. However, the 2D model still is stored in image coordinates. The necessary transformation to world coordinates can be derived by matching the indoor model to a building footprint (identified in a geographic information system with the help of the address contained in the plan or by user interaction). In the scaled model, stairs and staircases can be distinguished from rooms by their size and aspect ratio. Combining the number of detected stairs and a standard stair height will then deliver an approximate room height usable to extrude the 2D model to a 3D model.

In addition to the possibility to reconstruct a coarse model, the position of the user can be extracted from the photographed plan. The analysis of the legend of the plan delivers the „you are here“ symbol depicting the user’s position in the image, which can be found by using template matching. Using the transformation parameters known from the model reconstruction step, this position can be transformed to world coordinates. The orientation of the user taking the photo with respect to the plan may be derived from a perspective transformation which is computed using the plan’s corners visible in the image.

Figure 5: Evacuation plan of our institute; automatically derived 2D model in Google Maps; automatically derived 3D model with identified doors.

New Self-calibration Models for Airborne Camera Calibration

Camera calibration is an essential subject in photogrammetry. Self-calibration by using additional parameters (APs) has been widely accepted and substantially utilized for camera calibration in the photogrammetric community. Although the traditional self-calibration APs were widely used for many years even in digital era, they might be inadequate to fit the distinctive features of digital airborne cameras, such as push-broom, multi-head, virtual images composition, multiple image formats, etc. The incorporation of navigation sensors into airborne camera systems also demands for calibrating the whole system rather than camera lens distortion only.

We developed a novel family of APs for airborne camera calibration. We point out that photogrammetric self-calibration can, to a very large extent, be considered as a function approximation or, more precisely, a curve fitting problem in mathematics. Based on the rigorous approximation theory, the whole family of Legendre APs, which is derived from well-defined orthogonal Legendre Polynomials, is developed.

As an example, the Legendre APs with $M_x = M_y = 5$ and $N_x = N_y = 5$ are:

$$
\begin{aligned}
\Delta x \quad = \quad & a_1 p_{1,0} + a_2 p_{0,1} + a_3 p_{2,0} + a_4 p_{1,1} + a_5 p_{0,2} + a_6 p_{3,0} + a_7 p_{2,1} + a_8 p_{1,2} + a_9 p_{0,3} \\
& + a_{10} p_{4,0} + a_{11} p_{3,1} + a_{12} p_{2,2} + a_{13} p_{1,3} + a_{14} p_{0,4} + a_{15} p_{5,0} + a_{16} p_{4,1} + a_{17} p_{3,2} + a_{18} p_{2,3} \\
& + a_{19} p_{1,4} + a_{20} p_{0,5} + a_{21} p_{5,1} + a_{22} p_{4,2} + a_{23} p_{3,3} + a_{24} p_{2,4} + a_{25} p_{1,5} + a_{26} p_{5,2} + a_{27} p_{5,3} \\
& + a_{28} p_{3,4} + a_{29} p_{2,5} + a_{30} p_{5,3} + a_{31} p_{4,4} + a_{32} p_{3,5} + a_{33} p_{5,4} + a_{34} p_{4,5} + a_{35} p_{5,5} \\
\Delta y \quad = \quad & a_2 p_{1,0} - a_1 p_{0,1} + a_{36} p_{2,0} - a_3 p_{1,1} - a_4 p_{0,2} + a_{37} p_{3,0} + a_{38} p_{2,1} + a_{39} p_{1,2} + a_{40} p_{0,3} \\
& + a_{41} p_{4,0} + a_{42} p_{3,1} + a_{43} p_{2,2} + a_{44} p_{1,3} + a_{45} p_{0,4} + a_{46} p_{5,0} + a_{47} p_{4,1} + a_{48} p_{3,2} + a_{49} p_{2,3} \\
& + a_{50} p_{1,4} + a_{51} p_{0,5} + a_{52} p_{5,1} + a_{53} p_{4,2} + a_{54} p_{3,3} + a_{55} p_{2,4} + a_{56} p_{1,5} + a_{57} p_{5,2} + a_{58} p_{5,3} \\
& + a_{59} p_{3,4} + a_{60} p_{2,5} + a_{61} p_{5,3} + a_{62} p_{4,4} + a_{63} p_{3,5} + a_{64} p_{5,4} + a_{65} p_{4,5} + a_{66} p_{5,5}
\end{aligned}
$$

The Legendre APs are empirically tested by using data from the recent DGPF project (German Society for Photogrammetry, Remote Sensing and Geoinformation), which was carried out in the test field Vaihingen/Enz nearby Stuttgart, Germany. Some results are shown in Figure 6 and Figure 7. In Figure 6, the „self calibrating“ accuracy by using Legendre APs reaches very close to the theoretical one and it means that the optimal accuracy has been achieved. In Figure 7, the comparisons are shown on the external accuracy of a DMC (GSD 20cm) calibration block (47GCPs/138ChPs, p60%-q60%) by using different APs. Legendre APs achieve similarly best accuracy with Brown models. However, Legendre APs perform much better in low correlations.

As conclusion, Legendre APs are orthogonal, rigorous, generic and effective for calibrating all digital frame airborne camera architectures, no matter which system design have been chosen by the camera manufacturer. In principle, they can be used for calibrating frame cameras of large, medium and small format CCDs, mounted in single- and multi-head systems. Moreover, the very low correlation between Legendre APs and other parameters, such as those for exterior orientation (EO) and GPS/IMU offsets or misalignments, guarantees reliable calibration results. Further, Legendre APs can also be considered as the superior generalization of the conventional polynomials APs proposed by Ebner and Grün.

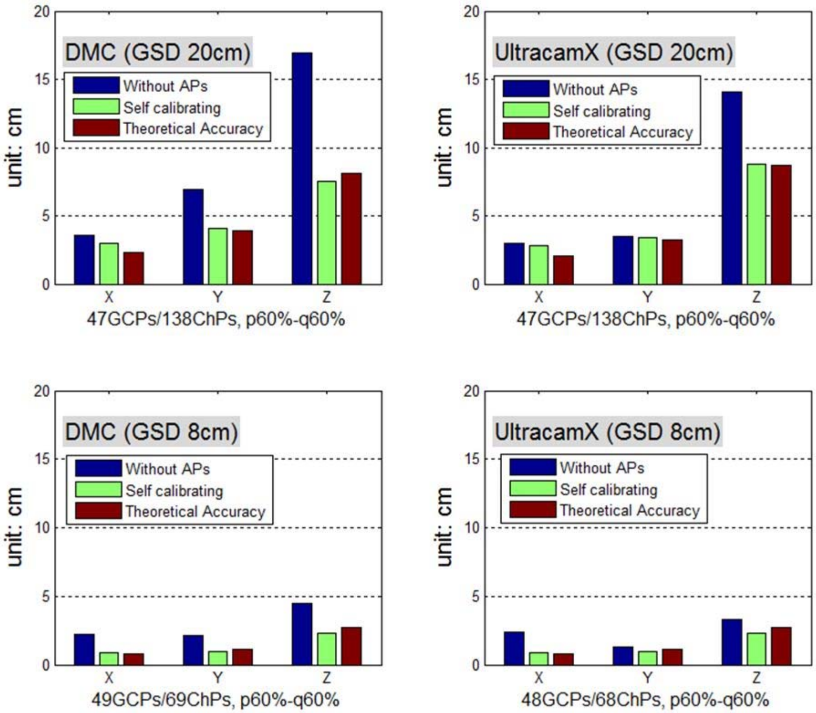


Figure 6: External accuracy in four in-situ calibration blocks, dense GCPs and p60%-q60%.

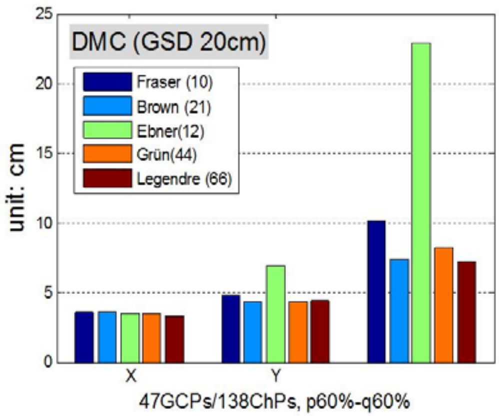


Figure 7: Comparison of the external accuracy of a DMC (GSD 20cm) calibration block.

High-end large format airborne imaging

The major focus in airborne data acquisition is still on the improvement of large format cameras and other sensors. The new Vexcel UltracamEagle sensor is a flagship now providing 260 MPix, but still following the syntopic imaging concept. Additionally for the first time a mapping camera is equipped with an exchangeable lens system. Different to this, Intergraph/ZI's system DMC II 250 now provides up to 250 MPix pan images from one single monolithic CCD, which is different to the concept of merging of smaller format CCD frames in order to derive a large format but virtual image. Figure 23 shows the four about 40 MPix multi-spectral channel CCDs (one of each used for red, green, blue and near infrared) and the monolithic large format panchromatic CCD. This large format panchromatic sensor has 16768 x 14016 pixel, arranged on a 93.900 x 78.489 mm^2 sized CCD. This is the world-wide largest CCD frame sensor from serial production. The current state and the main technical parameters of the „big three" large format sensors are compared in Table 2.

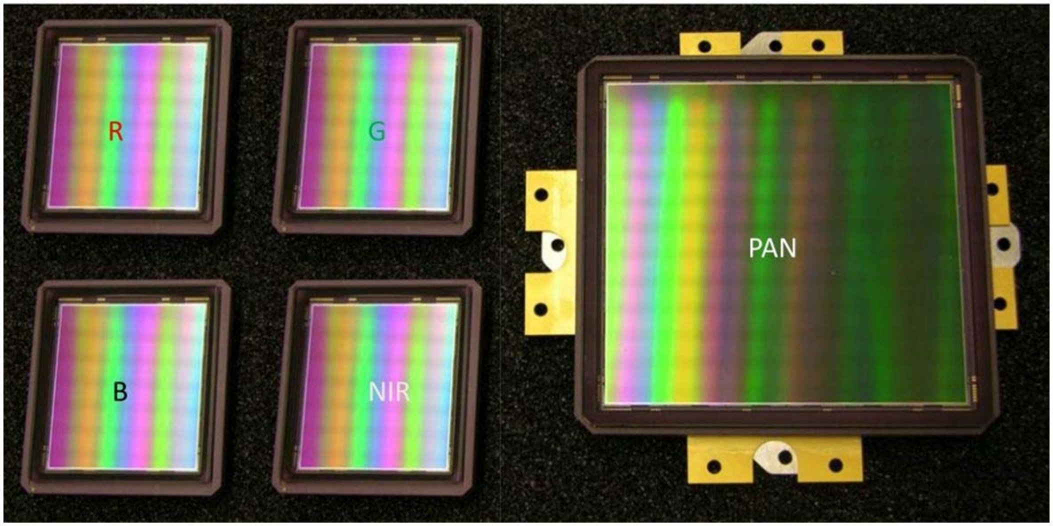


Figure 23: CCD frame sensors from DALSA used in the DMC II camera set-up. The large format monolithic 250 MPix pan-chromatic chip (right) and the smaller format 40 MPix CCD frames (left), where one is used for each of the four MS bands. (© Neumann, 2011).

Sensor	Concept	Image size / extension		# camera heads
		PAN	MS (original resolution) / Pan-sharpening ratio	
UltraCam-Eagle Vexcel Imaging	frame pan multi-head virtual images	20010 x 13080 pix at 5.2 μm, 104.052 x 68.016 mm²	6670 x 4360 pix at 5.2 μm, 34.684 x 22.672 mm² PAN:MS 1:3	4 (pan) 4 (MS)
DMC II 250 Z/I Imaging	Frame Pan single head No virtual images	16768 x 14016 pix at 5.6 μm, 93.900 x 78.489 mm²	6800 x 6096 pix at 7.2 μm pixel size, 48.960 x 43.891 mm² PAN:MS 1:2.4	1 (pan) 4 (MS)
ADS80 Leica Geosystems	Line Single head Line images	12000 pix at 5.6 μm, 78.000 mm (no staggering applied here)	12000 pix at 5.6 μm, 78.000 mm PAN:MS 1:1	1

Table 2: Main parameters of current large format digital airborne mapping systems.

In addition to those developments in large format imaging, there also is quite some progress in the so-called „medium-format sector". Most recent systems now are reaching up to 80 MPix (per camera head) and offer improved image quality due to forward motion compensation and in case of the Leica Geosystems RCD30 parallel RGB and NIR image acquisition.

This also shows the increased role of multi-spectral data acquisition which now merges the former clearly separated worlds of geometrically focused photogrammetry and remote sensing relying on multi-spectral data classification. Radiometry in general is increasing in importance. With the new digital airborne cameras the clear separation between geometry and radiometry, which to a certain extend was due to the available sensor technologies, now is close to vanish. It is the move from analog to digital airborne imaging forcing this change. The much better radiometric quality of digitally recorded image data in comparison to scanned analog imagery is commonly accepted.

But this only is one part of the advantages of digital image recording. The other aspect is that photo sensitive electronic devices have a linear characteristic curve describing the relation between exposure and density. This is different to film, where the light is recorded in an s-shaped logarithmic curve, dependent on the settings of the exposures and the later film development. In digital imaging this curve is linear per se, i.e. the relation between exposure and density does not change. If this function is known from radiometric calibration, the light rays, which are measured by individual pixels directly relate to a physical property of the imaged object. In addition, the multi-spectral capabilities should be mentioned. In the digital world, filters could be defined exactly to the user's need, which is much more complicated with color sensitive emulsions of a color film. This advantage of electro-optical sensors offers new fields of application in remote sensing, which already is established in satellite imaging for decades but new for the airborne imaging sensors. But all this also requests for extended radiometric calibrations of digital cameras in additional to the former geometric calibration only. This is why manufacturers as well as (first) users put increasing effort in the radiometric calibration of those sensors. This can be done from laboratory or via vicarious calibration from test sites, as it was analyzed in a recently finished project on the „Radiometric aspects of digital photogrammetric images" organized by the European Spatial Data Research organization (EuroSDR).

Multi-camera System for close range point cloud acquisition

In March 2011 the ifp has got an industrial contract to collect photos for a dense 3D point cloud generation of the two Tympana of the Royal Palace in Amsterdam. The work took place as part of the restoration work which was carried out at the whole building. For this purpose we planned to use a multi-camera system incorporating a structure-and-motion and a dense matching implementation. Regarding the hardware, one goal for the Amsterdam project was to combine low to medium cost hardware components to set-up a more sophisticated multi-sensor system.

The multi-camera configuration enables us to obtain a high resolution point cloud from one single shot. The sensor design was customized to meet certain requirements and restrictions. First of all our assignment was to scan the object with a point sampling distance of 1mm or less and with an accuracy of 1mm or better within twelve days. Furthermore the sensor needed to be small sized and light weighted to be applicable in the given surroundings. Also considerations made in the process of project planning and software implementation directly influenced some aspects of the sensor design and vice versa.

We chose to use industrial cameras as they are very small and light weighted and known to be robust. We defined the overlap of the images to be roughly 90% in both image directions at a working distance of 70cm in order to maintain a sufficient overlap at shorter distances. Based on this constraint we computed a base length of $\approx$ 7,5cm. Assuming an image measurement accuracy of 0.3 pixels this configuration easily holds the requirements. Having set up the configuration for single shot data acquisition, the next crucial issue was the registration of the single point clouds. We decided to use photogrammetric bundle adjustment to solve the registration task. Again a high overlap between the images of the different stations is benefitting to the stability of the results. For this purpose we incorporated a fifth camera with even shorter focal length to the system.

All five cameras have been mounted to two custom aluminum adapter plates, which again have been mounted on an aluminum profile. This construction is very compact and provides high stability. For protection of the cameras it was extended by further aluminum profiles surrounding the cameras as a rigid frame (Figure 8). The whole construction has a size of $\approx$ 25x25x15cm and a weight of roughly 2kg (not taking into account the cables).

Enhancement of the object's surface texture was another important issue to be solved in order to generate high quality matching results. Although the freestone surface provided a good texture at large areas there also were areas with homogenous characteristics and also a lot of areas which have been darkened by environmental influences. In such cases, correspondences in the images can either not be found or are ambiguous. In any case, such areas cannot be reconstructed accurately. Thus we decided to use active texture projection in our task. We added a MS Kinect device to our system, using only its' IR laser projector. Equipping the four matching cameras with 670nm blocking filters made the pattern visible to them while keeping it invisible to the bundle camera. Thus the bundle adjustment process, which incorporates automatic feature point extraction, is not influenced by the pattern moving with the sensor.

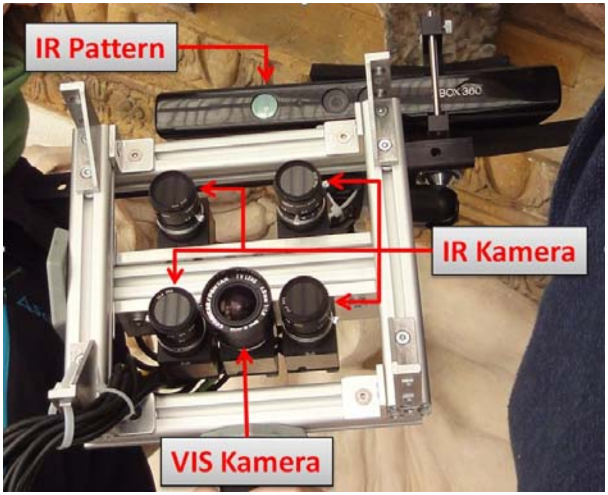


Figure 8: The Amsterdam sensor. Five cameras rigidly mounted and protected by an aluminum frame. A MS Kinect device provides additional texture projection.

Figure 9: Image taken by one of the matching cameras. The white speckles covering the lion head's surface are produced by the Kinect's IR laser projector and are not visible to the bundle camera. The image has been slightly enhanced to make the pattern easier to see for the reader.

Efficient Reconstruction of Large Unordered Image Datasets

The reconstruction of camera orientations and structure from unordered image datasets, also known as *Structure and Motion* reconstruction, has become an important task in photogrammetry. Current solutions require high computational efforts for image networks with high complexity and diversity. Unlike the methods suitable for landmark reconstruction from large-scale internet image collections, we focus on datasets where one cannot reduce the number of images without losing geometric information of the dataset. The exterior orientations can be derived precisely and automatically using feature extraction and matching with only few and rough initial information about the lens and the camera. Accurate intrinsic orientations are estimated as well using self-calibration methods.

Structure and Motion (SaM) methods enable the reconstruction of orientations and geometry from imagery with little prior information about the camera. The derived orientations are commonly used within dense surface reconstruction methods, which provide point clouds or meshes with high resolution. This modular pipeline is employed for different applications as affordable and efficient approach to solve typical surveying tasks.

Therefore, a pipeline was developed focusing on efficiency and accuracy. As shown in Figure 10, it is divided into four processing steps. It employs an initial image network analysis in order to avoid the costly matching of all possible image pairs and to guide the reconstruction process. The following tie point generation is designed to derive points with maximum accuracy and reliability. By building and optimizing a graph based on the image network, the dataset can be split into reliable patches of neighboring images which can be processed independently and in parallel within the reconstruction step. Finally, all patches are merged and optimized by a global bundle adjustment. Ground control points can be integrated within this step as well.

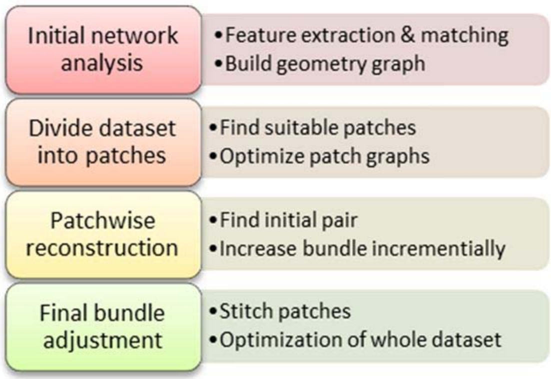


Figure 10: Flowchart of the pipeline.

The potential of this pipeline was demonstrated in two completely different scenarios: The cultural heritage project in Amsterdam and an unmanned aerial vehicles (UAV) flight mission nearby Vaihingen/Enz. Within the cultural heritage project 10,000 images were captured using a multi camera rig (as described before) at short acquisition distance. The exterior orientations of the images were derived without initial values using the presented pipeline with high accuracy requirements. By performing a dense image matching, two billion points could be derived with sub-mm resolution (as shown in Figure 11).

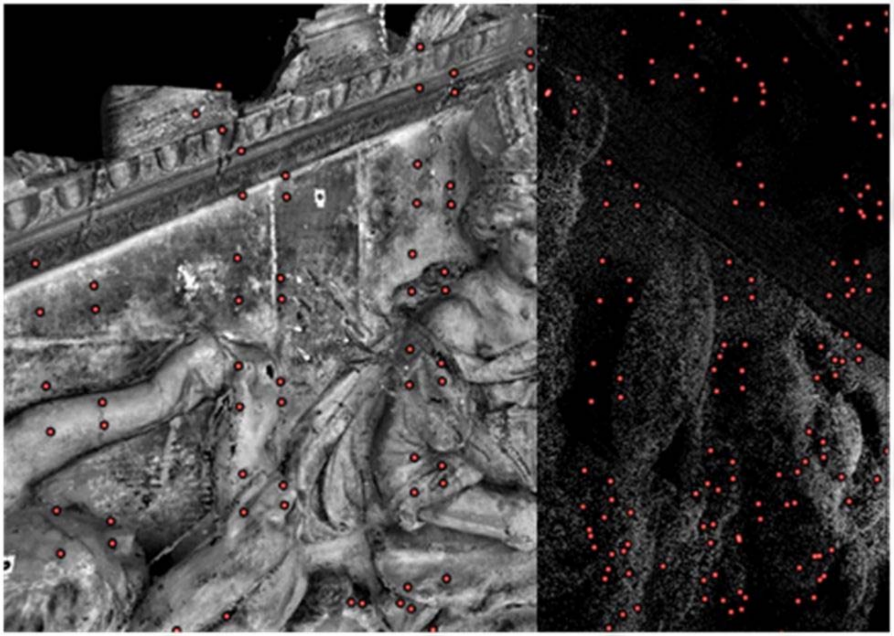


Figure 11: Camera stations (red), sparse point cloud from Structure from Motion (right) and point cloud derived by dense image matching (left) for a cultural heritage dataset.

The increasing use of UAVs for surveying tasks such as construction site progress documentation or surface model generation of small areas requires a method to derive spatial data at low costs. Typically, UAVs are equipped with consumer cameras providing only a small footprint. The imagery is challenging since the signal to noise ratio is high due to the small pixel size. Furthermore, the movements of the small aircraft lead to significant image blurring. As in Figure 12, the presented pipeline was applied to derive orientations and tie points. The small footprint of the consumer camera led to a dataset of 1204 images, where about 230 images were eliminated before the processing because of image blur or low connection quality. From the remaining 975 images 959 could be oriented successfully. Even though an image blur of up to several pixels was present for most images, the bundle adjustment succeeded with a mean reprojection error of 1.1 pixels.

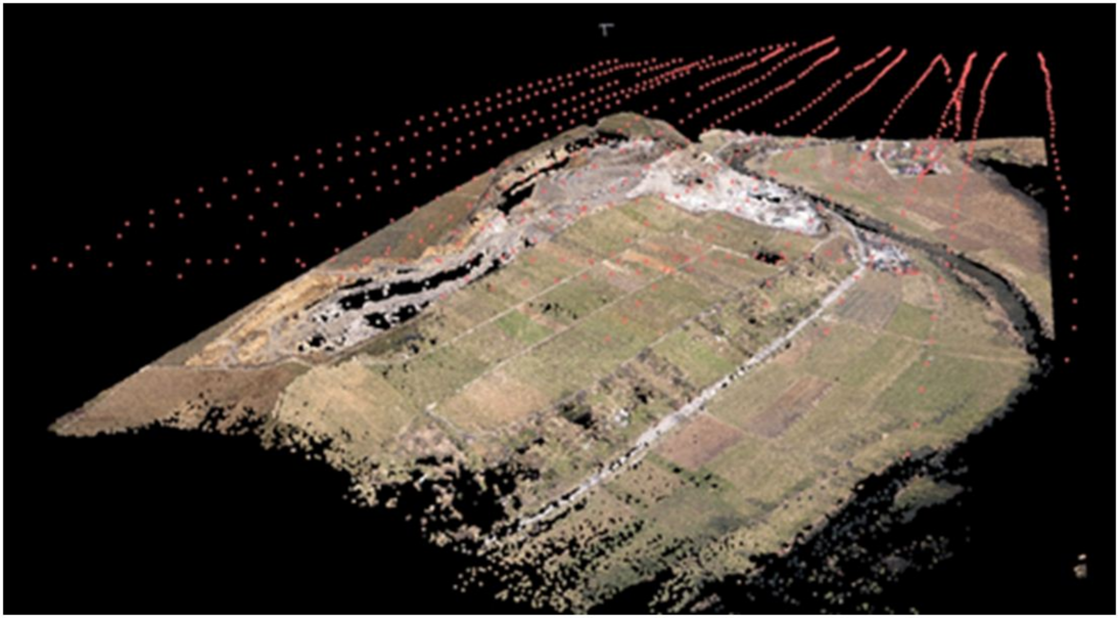


Figure 12: Sparse point cloud and camera stations (red) for an UAV image dataset.

Dense Image Matching in Close Range Applications

Image matching methods can be used to reconstruct 3D surfaces from images. By finding corresponding pixels between images collected from different angles, the depth can be estimated using a viewing ray intersection in space. Recently, methods for the reconstruction of 3D data without initial information have been developed which are using *Feature Points* to find and describe pixels and their correspondences reliable. *Structure and Motion* reconstruction methods employ these feature points to determine a sparse 3D point cloud and the camera position and rotation in space for each image.

This orientation information can be used to perform a *dense image matching* step, which determines a correspondence for almost each pixel in the image. This leads to a very dense point cloud. The key challenge of this dense image matching step is the resolution of ambiguities. Since grey values are usually not unique in an image, a method has to be found for the reliable determination of correspondences. One solution is represented by the *Semi Global Matching* algorithm, proposed by Heiko Hirschmüller in 2005. It uses an approximation of a global smoothness constraint of the observed surface over the image. By enforcing smoothness along paths through the image in different directions, not only ambiguities are resolved but also small untextured gaps can be filled. Also, the noise in the point cloud is reduced.

However, the Semi Global Matching algorithm was initially developed for the processing of aerial imagery, where the depth in relation to the acquisition distance is small. This is not the case for close range applications, where large depth variations can occur. In order to be able to process high resolution imagery from close range scenes, the Semi Global Matching algorithm was modified. Usually, all possible correspondences are evaluated for each pixel and for each possible depth within a certain range. Since this range is very large for close range imagery, the requirements regarding computation time and physical memory are very high. Thus, we implemented a hierarchical approach, where the depth search range is reduced for each pixel individually using an image pyramid. On low resolutions the possible depths are also significantly smaller, which enables very fast computations. By using this information as initial information in the next higher level of resolution the depth range can be narrowed down subsequently. By matching not only on one stereo pair, but many images instead, redundant observations are available for each point on the object surface. These multiple observations in image space to the object point enable a triangulation with noise reduction and outlier rejection. Consequently, a reliable low noise point cloud can be derived with quality information for each point.

Within a cultural heritage data recording project this modified dense image method was used in combination with an extended Structure and Motion technique to acquire point clouds with a resolution and accuracy below 1mm. The objects were the two Tympanums at the Royal Palace of Amsterdam with a complex relief surface covering an area of about 125m^2. Within 10 days 10,000 images were acquired using a multi-camera rig decribed above, which we specifically designed for acquiring such complex geometries at short distance. Finally, about 2 billion 3D points were computed.

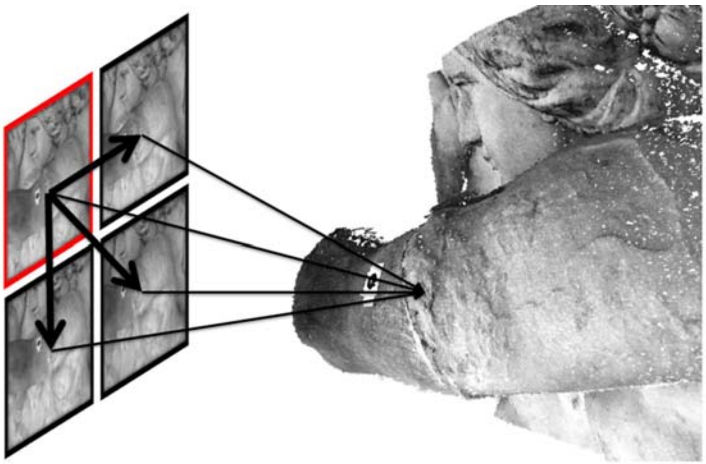


Figure 13: Dense image matching: finding corresponding pixels and intersecting their viewing rays in space.

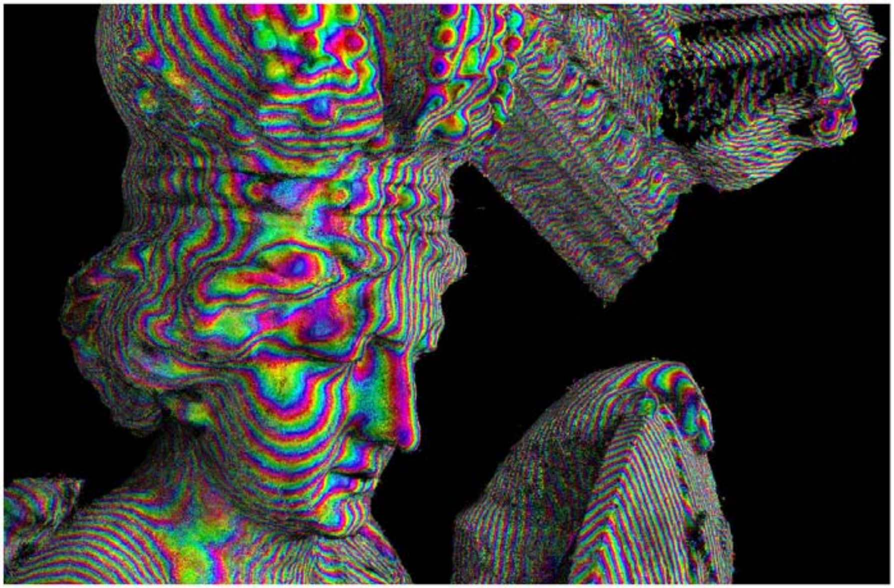


Figure 14: Point cloud extract from the Amsterdam project. 2 Billion 3D points were derived from about 10,000 images with sub-mm resolution and accuracy.

A Low-Cost Close-Range System for Indoor Modeling and Navigation

In recent years, active sensing is widely needed in many indoor applications like indoor 3D modeling, indoor navigation, mobile mapping, etc. This can be maintained using laser scanners (expensive and relatively large), or time of flight cameras (less expensive but low accurate). A low-cost alternative can be the Microsoft Kinect system which was originally designed as a user interface for the Xbox 360 game console. This system delivers dense point clouds of the environment (based on matching IR projected patterns) together with color images, both at a rate of 30Hz. One can expect a noise of about 3cm at 3m distance for the generated point clouds. Geometrical and optical calibration of the system allows for the generation of textured point clouds.

The point clouds collected from different viewpoints can be aligned using geometrical and visual information derived from the range sensor and RGB camera respectively. Figure 15 shows an example of automatic alignment of multiple point clouds, using visual information extracted from color images. In this example, SIFT features are extracted and matched in consecutive color images. Such features can then be transformed to a relative 3D coordinate system, having the stereo system calibrated. The matched 3D points can be directly used to approximately align the consecutive point clouds, which can be further improved using an ICP (iterative closest point) algorithm.

Figure 15: Alignment of multiple point clouds with color information from images.

One of the applications of active sensing in the indoor environments is update and refinement of available coarse 3D models. Figure 16 shows an example of the integration of Kinect point clouds and a coarse 3D model derived from a 2D evacuation plan. This data can be used for the detection of details like missing walls and cupboards in the coarse 3D model. This is especially useful for indoor navigation applications.

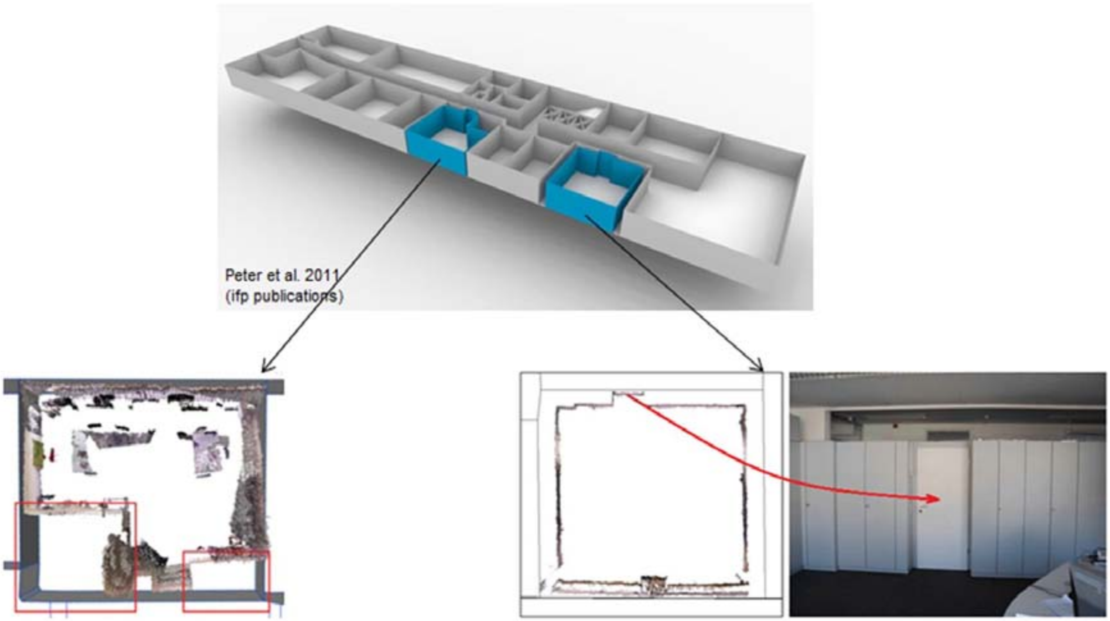


Figure 16: Update and refinement of a coarse 3D model.

Fast and Automatic Combination of Digital Images and Laser Scanner Data

Integration of close-range photogrammetry and terrestrial laser scanning techniques has to be performed in order to improve the geometry and the visual quality of collected 3D models. Moreover, this combination is needed to fill gaps in laser point clouds to avoid modeling errors, reconstruct more details in higher resolution and to recover simple structures with less geometric details. Therefore, we present a fast and flexible procedure for the automatic combination of digital images and laser scanner data (Figure 17).

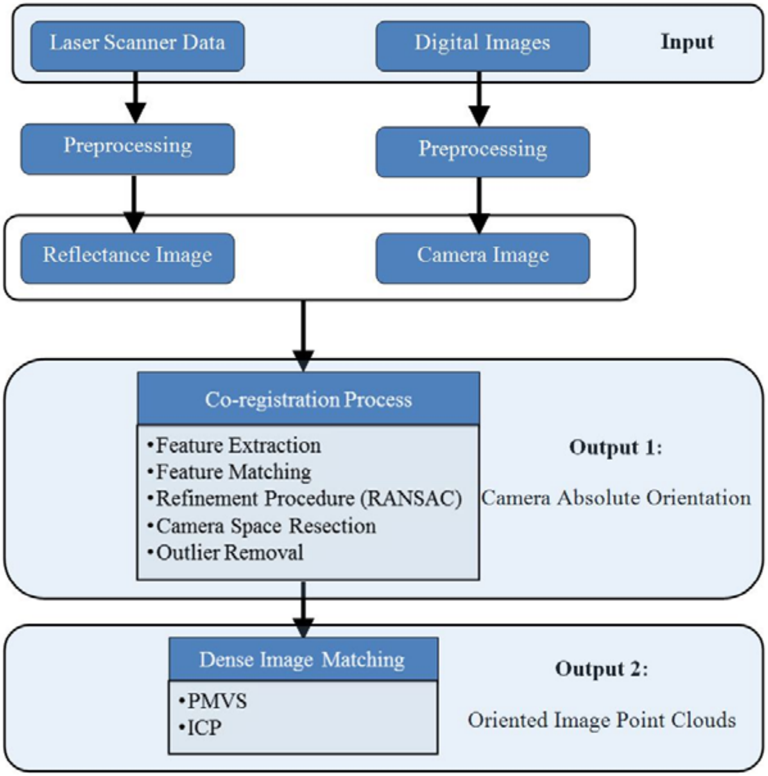


Figure 17: Processing chain for combining digital images and laser scanner data.

After the collection of laser scanner point clouds and photogrammetric images, a preprocessing of the data is performed. Then, a co-registration step is carried out in order to get the camera absolute orientation starting by extracting Affine-SIFT (ASIFT) features with their descriptors from the reflectance and digital images. As the features in both images are detected, a feature matching process based on the detected feature descriptors is followed in order to compute the 3D-to-2D correspondences. This step requires a refinement process by means of a RANSAC algorithm based on a closed-form space resection for the purpose of removing mismatches. Furthermore, accurate space resection methods such as Efficient Perspective-n-Point (EPnP) and orthogonal iteration (OI) algorithm have been used to get the camera's absolute orientation. An outlier removal operation is followed to improve the orientation. At last, with the resulting absolute orientation of the camera, we use a robust multi-view stereo (MVS) reconstruction algorithm like patch-based multi-view stereo (PMVS) to create oriented dense image point clouds, which are automatically combined with the laser scanner data to form a complete detailed representation of a scene. This combination can be improved by using ICP as a fine registration step (Figure 18).

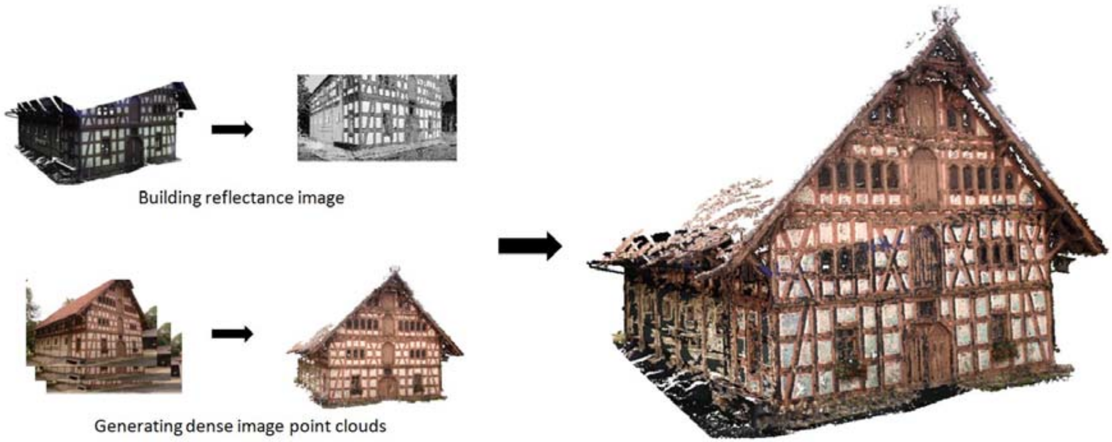


Figure 18: Combined laser scanner and image point clouds.

Photogrammetric Image Processing

Dense Matching of Aerial Imagery

For a considerable period, the acquisition of high quality Digital Elevation Models (DEM) was dominated by the use of airborne LiDAR. Meanwhile, automatic image based collection revived as a suitable alternative. This development was triggered by the increasing quality of digital airborne cameras as well as recent innovations in matching algorithms. Airborne imagery of good dynamic and signal-to-noise-ratio as available from digital aerial cameras is highly beneficial for automatic image matching. This is especially true for surfaces with relatively little surface texture. Consequently, the quality and accuracy of image based point transfer as basic observation for 3D surface reconstruction ameliorated considerably. Recent tests have already demonstrated the feasibility of image matching as a valid alternative to airborne LiDAR. One example for dense image alignment is the Semi-Global Matching (SGM) stereo method, which provides depth estimations for each image pixel. By these means a computation of dense 3D point clouds and DEM at surface resolution similar to the ground sampling distance of the available imagery is feasible.

Due to rather similar image content this method was shown to work reliably on standard nadir image configurations. Thereby accuracies and completeness of generated DEMs can be further enhanced exploiting redundancy given by highly overlapping imagery. However, also for more advanced geometries, as for oblique configurations good results can be obtained. Despite larger variations of viewing angles and image scale which cause the matching to be more challenging, rather dense surface point clouds can be generated. In this way results from nadir imagery can be further enhanced by complete house facades and 3D structures as balconies and treetops.

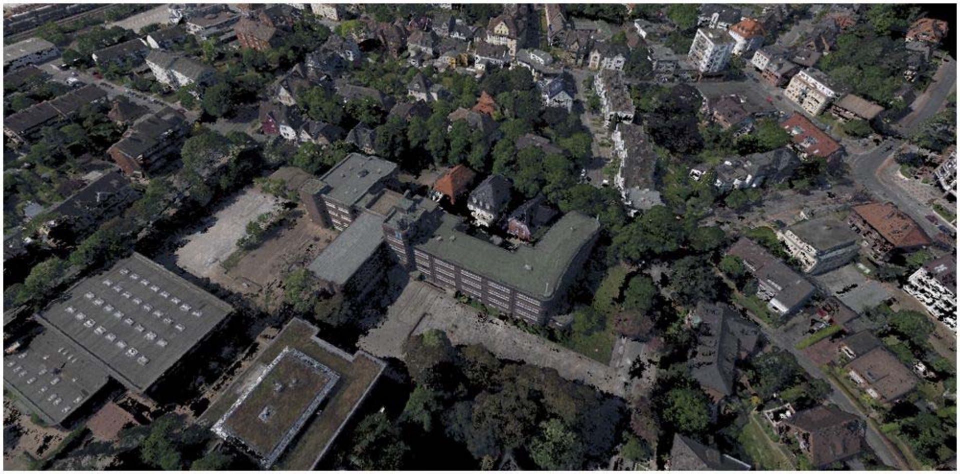


Figure 19: DEM derived with Semi-Global Matching.

Unmanned Airborne Systems / Vehicles (UAS / UAV) - An Interdisciplinary Research Topic

The today’s way of photogrammetric airborne imaging is covering a very large variety of systems and technologies, non-comparable to the situation only some few years ago: In case of airborne imaging the well-known, large format, sophisticated, high-end digital imaging systems are only one part of the spectrum. Now smaller format, lightweight, not only sensors but fully equipped, completely autonomous or remotely controlled unmanned platforms (UAV) are completing the spectrum. They may be used for more flexible or unconventional projects for smaller area application and thus may supplement the other sensors. Furthermore, these UAV should have their strong advantages in **d**ull, **d**irty and **d**angerous (3**d**) environments.

One of the most recognizable activities in the UAV research in 2011 was the UAV-g (Unmanned Aerial Vehicles in Geomatics) meeting organized at ETH Zurich. At this conference the current research on UAVs with the emphasis on applications in Geomatics was presented and discussed under the consideration of user requirements. The focus of the conference was on the exchange of UAV-g research activities between the different disciplines (artificial intelligence, robotics, photogrammetry, geodesy, computer vision, and aerospace engineering) and furthermore, the needs for future developments were formulated. The role of UAV in practice was additionally highlighted at the last Intergeo Nuremberg, Germany, October 2011. UAV was **the** issue on this year's Intergeo and with that the new „eye catcher". UAV clearly took the role of mobile mapping which was the main focus in the previous years at Intergeo.

Currently available UAV platforms can already be used as measuring systems for various mapping and monitoring applications. However, the operation of UAVs is limited by legal regulations - but there is quite some momentum to change the regulations to integrate these UAV systems into the civil managed airspace.

However, there is not only discussion on flight regulations, all this UAV-technology is also increasing acceptance from user's and also from authorities perspective. It should be noted that first national mapping agencies already showed interests in this technology. This is for sure not to get rid of the standard large format sensors but to support their work especially when there are special applications with limited region size or strong time or other limitations.

One potential application could be the fully automatic survey and documentation of digging in open pit mines or stone quarries. This is a quite dangerous scenario since terrestrial survey in these areas always is dangerous and time intensive due to the large working engines. The figures below illustrate one of our most recent projects, where one quarry close to Vaihingen/Enz was flown to derive most recent orthophotos and 3D surface models. Figure 20 shows the drapped orthophoto from a UAV flight, flown in March 2011. The fixed-wing micro UAV system was kindly provided as part of cooperation with the Institute of Flight Control and Mechanics (IFR) at the University of Stuttgart.

Using such UAV technologies repetitive flights can be done almost automatically at almost any time and low-cost. Figure 21 compares the UAV derived orthophoto from the 2011 campaign to another orthophoto derived from a standard large format digital airborne camera, the Z/I Imaging DMC namely. The DMC flight was part of the well-known Digital Camera Evaluation Project run under the umbrella of the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF). The figure shows, that the orthophotos are quite similar, even though the UAV images were taken with a very low cost, digital compact camera. Notice that the UAV flight was done in early March 2011, whereas the DMC imageries were taken in August 2008. Nevertheless, comparing the two images the changes in the quarry boundary become obvious. The changes are circled. The Digital Surface Model (DSM) allows for the estimation of volume changes, i.e. the documentation of the digging and re-filling progress within the quarry. Thus the DSM derived from UAV imagery is compared to an older DSM - in this case obtained from airborne laserscanning. The DSM differences are plotted in Figure 22. The dark (black) regions show digging area, the light (white) regions show refill zones. This also is clearly shown in the profile line.

This project was able to verify the high potential of UAVs. Future tests will be done, using a more accurate GPS/inertial integrated system for direct sensor orientation and also a geometrical more stable camera. With the most recent developments in digital compact imaging, small and light cameras may now be combined with standard fixed lens optics, thus these new sensors still fulfill the rigid weight limitations on such micro or mini UAVs. With such modified cameras, the radiometric performance should also increase.

Figure 20: Quarry nearby Vaihingen/Enz: Orthophoto from UAV flight 2011, drapped on the 3D surface model dense matching of UAV imagery.

Figure 21: Orthophoto from UAV imagery (March 2011) compared to orthophoto from large format high end digital airborne mapping camera DMC (Z/I-Imaging).

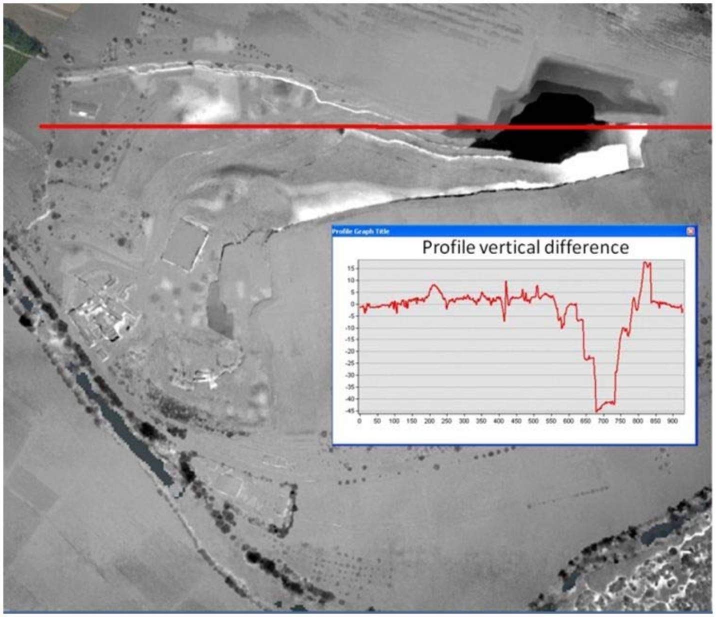


Figure 22: DSM height differences and difference profil: DSM from UAV images compared to a laserscanner reference DSM.

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Diploma Theses / Master Theses

Shakir, A.R.: Toponym recognition in scanned color topographic maps. Supervisor: Walter, V.

Daniel, K.: Volumetric Range Image Integration. Supervisors: Haala, N., Wenzel, K.

Sebastian, G.: Entwicklung einer Auskunfts- und Qualifizierungskomponente für ALKIS. Supervisor: Walter, V.

Mulkal: Determination of the Best Image Segmentation Algorithm for an Image. Supervisor: Walter, V.

Omidalizarandi, M.: Segmentation and classification of point clouds from dense aerial image matching. Supervisor: Haala, N.

Hu, X.: Methods for quality control of large Cartosat-1 stereo blocks. Supervisors: d’Angelo, P. (DLR), Cramer, M.

Zhou, D.: An Investigation of Semi-Global Matching using Mutual Information. Supervisor: Haala, N.

Li, C.: Detection and Classification of General Text Elements in Video. Supervisor: Fritsch, D.

Study Theses / Bachelor Theses

Schwarz, C.: Untersuchung von CBIR Verfahren zur Zuordnung von Ländern, Supervisor: Walter, V.

Activities in National and International Organizations

Cramer, M.:
- President EuroSDR Technical Commission I - Sensors, primary data acquisition and geo-referencing
- Co-Chair ISPRS Working Group I/5 - Integrated Systems for Sensor Georeferencing and Navigation

Englich, M.:
- Webmaster ISPRS

Fritsch, D.:
- Chairman Board of Trustees ‘The ISPRS Foundation’
- Member CyberOne Award Commitee
- Member Galileo/GMES Award Committee Baden-Württemberg
- Member Scientific Advisory Committee DFG Project ArcheInv, Univ. Bochum
- Member Jury Artur Fischer Invention Award
- Member D21 Advisory Board
- Member Board of Trustees German University in Cairo (GUC)
- Member GUC Academic Advisory Committee
- Member Apple’s University Education Forum (UEF)
- Member Advisory Board ISPRS
- Vice-President Research EuroSDR

Haala, N.:
- Co-Chair ISPRS WG III/4 - Automatic Image Interpretation for City-Modelling
- Vorsitz DGPF Arbeitskreis Sensorik und Plattformen

Walter, V.:
- Nationaler Berichterstatter für die ISPRS Kommission IV

Education - Lectures/Exercises/Training/Seminars

Bachelor Geodäsie und Geoinformatik

Introduction into Geodesy and Geoinformatics (Cramer, Fritsch, Sneeuw, Keller, Kleusberg)	4/2/0/0
Adjustment Theory I (Fritsch, Sneeuw)	1/1/0/0
Adjustment Theory II (Fritsch, Sneeuw)	2/2/0/0
Geoinformatics I (Fritsch, Walter)	2/2/0/0
Geoinformatics II (Walter)	1/1/0/0
Image Processing (Haala)	2/1/0/0
Photogrammetry (Cramer)	2/1/0/0
Signal Processing (Fritsch)	2/1/0/0

Diplomstudiengang Geodäsie und Geoinformatik

Aerotriangulation and Stereoplotting (Cramer)	2/1/0/0
Advanced Projects in Photogrammetry and GIS (Cramer, Haala, Walter)	1/2/0/0
Animation and Visualisation of Geodata (Haala, Kada)	1/1/0/0
Cartography (Urbanke)	1/0/0/0
Close Range Photogrammetry (Fritsch)	2/1/0/0
Databases and Geoinformation Systems (Walter)	2/1/0/0
Digital Image Processing (Haala)	2/1/0/0
Digital Terrain Models (Haala)	1/1/0/0
Geodetic Seminar I, II (Fritsch, Sneeuw, Keller, Kleusberg)	0/0/0/4
Integrated Fieldworks (Fritsch, Sneeuw, Keller, Kleusberg)	0/0/4/0
Pattern Recognition and Image Based Geodata Collection (Haala)	2/1/0/0
Urban Planning (Dvorak)	1/0/0/0

Master Course GEOENGINE

Airborne Data Acquisition (Fritsch, Cramer)	1/1/0/0
Geoinformatics (Fritsch, Walter)	2/1/0/0
Signal Processing (Fritsch)	2/1/0/0
Topology and Optimisation (Fritsch)	2/1/0/0
Integrated Fieldworks (Fritsch, Sneeuw, Keller, Kleusberg)	0/0/4/0

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

Introduction to GIS (Walter)	2/0/0/0
Advanced GIS (Walter)	2/0/0/0

Diplomstudiengang Geographie Tübingen

Practical Training in GIS (Walter)	0/0/4/0

Diplomstudiengang Luft- und Raumfahrttechnik

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