



University of Stuttgart
Germany

Fakulty 6: Aerospace Engineering and Geodesy

Geodesy & Geoinformatics

Annual Report 2017



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 2017 activities and academic highlights of the Department of Geodesy and Geoinformatics of the University of Stuttgart. The Department consists of the four institutes:

- Institute of Geodesy (GIS),
- Institute for Photogrammetry (ifp),
- Institute for 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 and 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

We were able to welcome 58 new BSc students in winter term 2016/2017. The first BSc students graduated at the end of 2013. Until the end of 2017, we had in total 99 BSc graduates. The MSc program for Geodesy and Geoinformatics started with the winter term 2012. Currently 40 students are taking part in this Master of Science program and we have already 37 MSc graduates. The Diploma program has terminated on March 31 2017. All our Diploma students got their Diploma degree. Total enrolment, in both the BSc, MSc and the Diploma programs, is an amount of 189 students. Please visit our website www.geodaesie.uni-stuttgart.de for additional information on the programs.

In its 12th year of existence, our international MSc program Geomatics Engineering (GeoEngine) enjoys a gratifying demand. We register an enrolment of 31 students. We attract the GeoEngine student population from such diverse countries as China, Palestine, Iran, Ghana, Ecuador, Nepal, India, Canada and Japan.

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),
- Vexcel Imaging GmbH,
- Ingenieur-Gesellschaft für Interfaces mbH (IGI),
- DVW Landesverein Baden-Wurtemberg,

who support our programs and our students with scholarships, awards and travel support. Below is the list of the recipients of the 2016/17 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!

Uwe Sörgel Associate Dean (Academic)

Uwe.soergel@ifp.uni-stuttgart.de

Award	Recipient	Sponsor	Programme
Karl-Ramsayer Preis	Mr. W. Zhang	Department of Geodesy & Geoinformatics	Geodesy & Geoinformatics
BScThesis Award	Mrs. M. Xiao	F2GeoS	Geodesy & Geoinformatics
MScThesis Award	Mr. F. Kappel	F2GeoS	Geodesy & Geoinformatics
Vexcel Imaging Scholarship	Mr. D. Chen Mr. Y. Li Mr. Z. Xia	Vexcel Imaging	GeoEngine
Matching Funds	Mr. F. Shu Mrs. Y. Wang Mr D. Yi	DAAD	GeoEngine

Institute of Engineering Geodesy



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Head of Institute

Prof. Dr.-Ing. habil. Volker Schwieger

Secretary

Elke Rawe

Ute Schinzel

Emeritus

Prof. Dr.-Ing. Dr.sc.techn.h.c. Dr.h.c. Klaus Linkwitz (died on 11 June 2017)

Scientific Staff

M. Sc. Alexandra Avram	GNSS
M.Sc. Marko Gasparac	GNSS and Digital Map
M.Sc. Aiham Hassan	Monitoring
Dipl.-Ing. Patric Hindenberger	Location Referencing
Dipl.-Ing. Stephanie Kauker (until 14.03.2017)	Monitoring
M.Sc. Gabriel Kerekes (since 01.04.2017)	Terrestrial Laser Scanning
Dipl.-Ing. Otto Lerke	Machine Guidance
Dr.-Ing. Martin Metzner	Engineering Geodesy
M. Sc. Dung Trung Pham	Kinematic Positioning
Dipl.-Ing. Annette Scheider	Kinematic Positioning
M.Sc. Annette Schmitt	Multi-Sensor-Systems
M.Sc. Martin Wachsmuth (since 01.06.2017)	Digital Map
M.Sc. Jinyue Wang	Map Matching
Dr.-Ing. Li Zhang	Monitoring

Technical Staff

Andreas Kanzler
 Martin Knihs
 Lars Plate

External Teaching Staff

Dipl.-Ing. Jürgen Eisenmann	Geschäftsbereichsleiter Landratsamt Ostalbkreis, Geoinformation und Landentwicklung
Dipl.-Ing. Christian Helfert	Fachdienstleiter Flurneuordnung im Landkreis Biberach
Dipl.-Math. Ulrich Völter	Geschäftsführer der Fa. Intermetric
Dr.-Ing. Thomas Wiltshcko	Daimler AG, Mercedes-Benz Cars; Research and Development

Obituary for Prof. Klaus Linkwitz

Prof. Dr.-Ing. Dr.sc.techn.h.c. Dr.h.c. Klaus Linkwitz, former director of the Institute of Applications of Geodesy to Engineering (IAGB), now Institute of Engineering Geodesy, University of Stuttgart, died on 11 June 2017, shortly before his 90th birthday.

Klaus Linkwitz was born in Bad Oeynhausen and, after school, military service as air force auxiliary, captivity and internship, started in 1948 his studies in geodesy in Stuttgart and Munich. Since 1953, he worked in practice in numerous engineering projects and surveying expeditions mainly in Central Asia - at that time remarkable pioneering achievements. There, his focus was on Afghanistan where he was active as project manager in the field of road and tunnel construction.

In 1960, Klaus Linkwitz graduated with a dissertation on the subject of "Fehlertheorie und Ausgleichung von Streckennetzen nach der Theorie elastischer Systeme". In 1964, he was appointed full professor and director of the IAGB on the then Polytechnic University, now University of Stuttgart. For more than 31 years, he held this position and earned the institute a worldwide reputation for his research on engineering geodesy, photogrammetry, adjustment calculus and special applications in the construction industry.

Klaus Linkwitz was substantially involved with his institute in the planning for the Olympic roofs in 1972 in Munich; he developed new methods for its mathematical form finding and analysis: the so-called force-density method. He succeeded in further developing these methods within the special research area 64 "Weitgespannte Flächentragwerke" into a practicable process. Cooperation partners in this special research area were apart from Frei Otto the colleagues Fritz Leonhardt, Jürgen Joedicke, John H. Argyris, Jörg Schlaich, Gallus Rehm and others. In the special research area 230 "Natürliche Konstruktionen" following the

special research area 64, the cooperation with other disciplines was even more diversified. Klaus Linkwitz achieved great merits for the geodesy in Stuttgart by initiating between 1984 and 1995 the special research area 228 "Hochgenaue Navigation - Integration geodätischer und navigatorischer Methoden". As speaker, Klaus Linkwitz led this special research area to great success thanks to his integrating personality; apart from the geodesy colleagues Ackermann, Grafarend and Hartl with the colleagues Gilles, Mehring, Sorg and Tiziani, there also participated representatives of the Faculties of Physics, Mechanical Engineering and Process Engineering. By his activities within the special research areas, Klaus Linkwitz succeeded in giving the Geodesy importance in an interdisciplinary national and international way.

Beside his commitment to science, he was always seeking a connection to practice - one characteristic that particularly distinguished him and also gained him a high reputation. He also spared no effort in establishing connections to expert colleagues abroad. Two honorary graduations (ETH Zurich and TU Donetsk/Ukraine) substantiate his multifaceted commitment. Due to his speech clarity and the elegance of his argumentation, Prof. Linkwitz was always able to convince in the numerous boards and fields of work in which he was represented. At the University of Stuttgart, he played an active part in many boards; for example, he was member of the senate for a total of 9 years. Beyond University, it is particularly worth mentioning the presidency of the German Geodetic Commission (DGK) from 1980 to 1987.

Klaus Linkwitz retired in 1996. As professor emeritus, he continued to give scientific lectures in the field of form finding of shell structures at the University of Stuttgart and gave guest lectures in many countries.

General View

The Institute of Engineering Geodesy (IIGS) is directed by Prof. Dr.-Ing. habil. Volker Schwieger. It is part of Faculty 6 "Aerospace Engineering and Geodesy" within the University of Stuttgart. Prof. Schwieger holds the chair in "Engineering Geodesy and Geodetic Measurements". Since 2017, he is the Dean of Faculty 6.

In addition to being a member of Faculty 6, Prof. Schwieger is co-opted to Faculty 2 "Civil and Environmental Engineering". Furthermore, IIGS is involved in the Center for Transportation Research of the University of Stuttgart (FOVUS). Thus, IIGS actively continues the close collaboration with all institutes in the field of transportation, especially with those belonging to Faculty 2.

Since 2011, he is a full member of the German Geodetic Commission (Deutsche Geodätische Kommission - DGK). 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 Commission 5 "Positioning and Measurements" in the period from 2015 to 2018.

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" (Master and Bachelor courses of study) as well as for "GEOENGINE" (Master for Geomatics Engineering in English). In addition, the IIGS provides several courses in German for the curricula of "Aerospace Engineering" (Bachelor and Master), "Civil Engineering" (Bachelor and Master), "Transport Engineering" (Bachelor and Master) and "Technique and Economy of Real Estate" (Bachelor). Furthermore, lectures are given in English to students within the Master course "Infrastructure Planning". Finally, eLearning modules are applied in different curricula.

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 implemented in close cooperation with the industry and external research partners. The main research focuses on kinematic and static 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, architecture, and aerospace engineering.

Research and Development

Automated Multi-sensor Early Warning System on the Three Gorges Dam - DAAD PPP China

One Project-Based Personnel Exchange Program between the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart and the School of Geodesy and Geomatics (SGG) at the University of Wuhan was approved by the DAAD (German Academic Exchange Service) and CSC (China Scholarship Council) for the years 2017 and 2018.

The goal of this project is to realize an automated multi-sensor early warning system on the Three Gorges Dam. In August 2017, Prof. Volker Schwieger visited the SGG and discussed the measurement plan with the colleagues in Wuhan. Simultaneously, one Bachelor thesis on the optimization of the monitoring networks and one Master thesis about the integration of GNSS and TLS measurements started at the IIGS for the preparation of the measurements at the Three Gorges Dam. In September, Li Zhang and Annette Schmitt went to the Three Gorges Dam for the measurements (compare Figure 1).

There were discussions on the requirement analysis of the monitoring system and on the ground-based SAR for monitoring purpose during the visit of Prof. Yaming Xu, who was at the IIGS in June for one month, and Dr. Cheng Xing, who was here from June to September. From October to December, there were discussions with Prof. Jinjun Xu and Dr. Guanlan Liu



Figure 1: Ground-based SAR and GNSS measurement at Three Gorges Dam

on the analysis of the measurement. All participants have written a joint paper: “Towards integration of GNSS and GB-SAR measurements: Exemplary monitoring of a rock fall at the Yangtze River in China”; its abstract was accepted for FIG congress 2018 in Istanbul. The next measurement will be in March 2018.

DAAD Thematic Network Summer School on Geodetic Techniques for Global Change Monitoring

The Summer School on Geodetic Techniques for Global Change Monitoring that ran from 24 to 28 July 2017 was organized within the Thematic Network and successfully completed in Yichang, China. Prof. Dr. Nico Sneeuw, director of the Geodetic Institute of the University Stuttgart and the project manager of the Thematic Network, was also present. More than 60 participants including professors, researchers and PhD and MSc students joined this program. They came from the partner institutions of the DAAD (German Academic Exchange Service) Thematic Network on Geodetic Techniques for Global Change Monitoring: University of Stuttgart, Stuttgart, Germany; Wuhan University, Wuhan, China; Tongji University, Shanghai, China; German Geodetic Research Institute, Technical University Munich, Germany; University of Luxembourg, Luxembourg; Chinese Academy of Surveying and Mapping, Beijing, China.

On the first day, both Prof. Dr. Volker Schwieger (Director of the Institute of Engineering Geodesy) and Prof. Dr. Nico Sneeuw (Director of the Institute of Geodesy) from the University of Stuttgart gave a brief introduction on different aspects of global changes monitoring (see Figure 2). The Summer School continued with lectures and laboratories involving many seemingly different topics like satellite altimetry and time series analysis. The lecture given by Prof. Dr. Volker Schwieger was about deformation analysis using Kalman-filter methodology, which was followed by a laboratory about optimal state estimation using Kalman-filter. The students were always motivated to raise questions and to discuss their interested research topics with others. Obviously, this Summer School offers a great opportunity for every participant to learn about current issues and future directions in global change monitoring and to communicate research experiences closely with international colleagues.



Figure 2: Introductory talk by Prof. Dr. Volker Schwieger on the first day of DAAD-TN Summer School 2017

Development of Models to Predict the Movement Behaviour of a Surveying Vessel

Surveying vessels acquire data of the channel bottom of rivers and channels by echo sounders, e.g. by multi beam echo sounders. To create a three-dimensional model of the ground, the measured profiles have to be georeferenced. For this purpose, precise positions and orientations of the vessel must be known. The HydrOs system provides this data, also in areas with poor GNSS reception, by installing a multi-sensor system. The acquired data are processed by an Extended Kalman Filter. This filter requires an adequate system and observation model to estimate the actual state of the system.

Depending on the chosen configuration of the multi-sensor system, the system model is adapted by considering the available control inputs. For that purpose, several extensions of a basic model are defined to predict the movement behaviour of the vessel. The kinematic extension integrates accelerations and changes of turning rates directly as control inputs. Another extension models the dynamic relations. In this context, forces caused by the ship propulsion (F_{contr}), by current flow (F_{str}) and by additional forces F_{add} (waves, vibrations) are considered and the indicated accelerations are modelled. It is obvious that changes in F_{contr} influences the system behavior for multiple epochs. So the resulting accelerations $a_{contr,k}$ at epoch k have to contain the summarized effects $\delta a_{m,k}$ (with $m = k - \tau, \dots, k$) of the previous τ epochs. As an example, the modelled changes of a turning rate are shown in Figure 3.

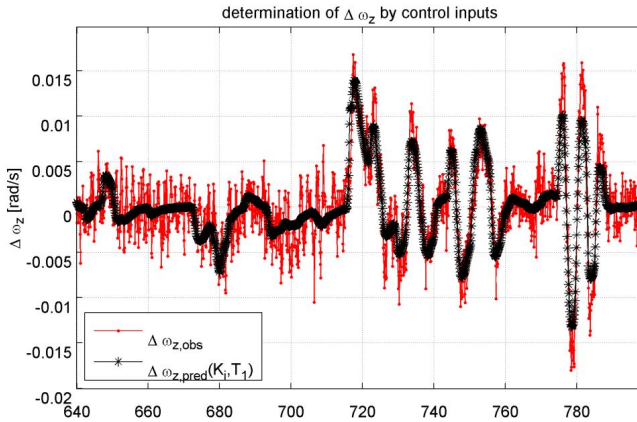


Figure 3: Determination of the change of turning rate ($\Delta\omega_Z$) caused by F_{contr} .

The accelerations a_{add} , caused by F_{add} , are calculated by a recursive approach. They are modelled by spherical harmonics. Information about the current flow can either be measured by a Doppler Velocity Log (control inputs a_{str}) or it can be derived from hydrodynamic models. Finally the turning rates ω and the velocities ν , resulting in a change of position and orientation, are calculated by

$$\begin{bmatrix} \hat{\omega}_{k+1} \\ \hat{\nu}_{k+1} \end{bmatrix} = \begin{bmatrix} \hat{\omega}_{k+1} \\ \hat{\nu}_{k+1} \end{bmatrix} + \mathbf{a}_{contr} + \mathbf{a}_{str} + \mathbf{a}_{add}. \quad (1)$$

Steering Method for Automatically Guided Tracked Vehicles

The steering method of a two-track crawler chassis is based on a skid-steer concept. Thereby the curve drive is achieved by adjusting different track velocities on the left and right track. The difference of the velocities from both tracks has a direct influence on the curve radius. The bigger this difference is, the smaller is the resulting radius.

The model crawler, operated by the Institute of Engineering Geodesy, has a two-stage continuous electric drive and can be automatically guided along predefined trajectories. The control of the model crawler is realized by a closed-loop-system. For the design of the steering method, the following three demands have been defined:

- the total speed during curve drives should remain stable,
- the tracks' rotational velocities must not be exceeded in order not to reach the maximum motor performance and thus not to damage the drive power unit,
- simple calibration procedure.

The steering angle of the model crawler is directly linked to the driving radius and thus with the velocities of the left and right track. The mathematical approach is based on the kinematic model for tracked vehicles according to Le (1991), where expression (2) has been used for further derivations:

$$R = \frac{-B(v_l + v_r)}{2(v_l - v_r)}, \quad (2)$$

with: R - radius, B - gauge of the crawler, v_l and v_r - velocities of left and right track.

Equation (2), which describes the relationship between radius and different velocities for the right and left track, has been modified and solved in a way that scaling terms could be derived. The expressions, $\frac{2n}{1+n}$ for the left track and $\frac{2}{1+n}$ for the right track, represent scaling terms for the machine's total velocity v_{total} during curve drives. The resulting equations for the left and right track are represented by the expressions (3) and (4).

$$v_l = v_{total} \cdot \frac{2n}{1+n} \quad (3)$$

$$v_r = v_{total} \cdot \frac{2}{1+n} \quad (4)$$

The functionality of the expressions (3) and (4) allows the compensation and balance of velocities for the inner and outer track during curve drives.

To prove the performance of the steering method, drives along predefined reference trajectories have been conducted. The quality, in the form of the root mean square (RMS) of the lateral deviation between the vehicle's position and the reference track, has been examined. The control and guidance performance by the use of the presented steering method reveals satisfactory results (2,7 mm weighted RMS). Moreover, the steering method satisfies the defined demands of stable speed during curve drives, considerate drive unit performance and simple calibration.

Optimization of the Positioning of Adaptive Supports

At the University of Stuttgart, the first adaptive double curved plane load bearing structure was developed. This structure is called Stuttgart Smartshell. It has got a base area of about 100 m² and a thickness of 4 cm, made of multilayer wood. Resting on three adaptive supports and one static support, the Stuttgart SmartShell offers the investigation of possibilities to reduce stress and structural vibration, while the weight of the structure is reduced drastically. Figure 4 shows the Stuttgart SmartShell.

In a former investigation, laser scanning data from 2012 was compared with a data set from 2015 of the initial position. The two data sets were transformed as well and compared. This comparison shows significant deviations at one support. Reasons for those deviations could be the ageing of the structure and the influence of the weather. These deviations led to a



Figure 4: Stuttgart SmartShell (©Bosch Rexroth)

fracture of the structure. After fixing the structure, a new CAD model was created from laser scanning data.

The optimization of the position of the adaptive support due to environmental influences is the main task of this project. Therefore, the geometrical behaviour due to temperature and humidity of fir plates is investigated in climate chambers. For these investigations, the laser tracker API Radian is used, because the expected deviations are too small to be detected by laser scanner. It is shown that the deviation due to humidity changes could be detected, while the changes due to temperature are not detectable for the used plates.

The next steps are the investigation of the plates under loads and the determination of the model to calculate the optimized position of the adaptive supports due to environmental influences.

GNSS Multipath Error Modelling and Simulation

Among the six main errors sources in the GPS positioning, multipath is an error which is highly dependent on the environment, therefore it is difficult to find a general model.

The purpose of this work is to determine the error envelope in a specific environment, at different velocities. The model which is simulated in a first step is fixed offset multipath. This model, although not applicable in the reality, offers the opportunity to study the injected error along the simulation time, allowing the understanding of this phenomenon. The whole chain: signal generation - channel model - receiver model are considered in order to have an understanding on how the multipath error is affecting the satellite-receiver link and how the receiver is dealing with the error.

The setup for the simulation consists of a GSS7000 Signal Generator, a MATLAB Implementation and a configurable software receiver IFEN SX3. The MATLAB implementation is used to determine the time delay and signal strength loss. With this input, a command file is created for the Spirent GSS7000 so that the multipath parameters obtained from MATLAB can be reproduced by the simulator. Only one GPS L1 C/A code satellite is programmed to be contained with multipath and the error will be studied in the output of the SX3 software receiver.

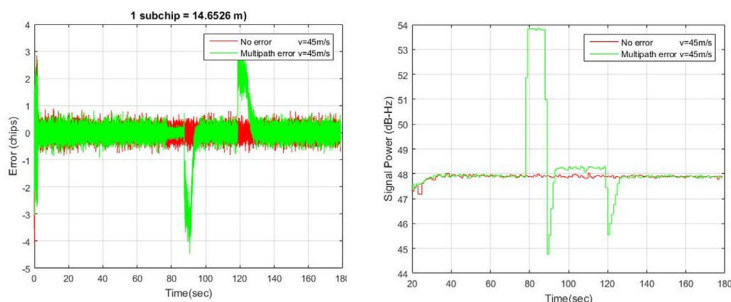


Figure 5: Delay Lock Loop (left) and signal strength of a GPS satellite (right)

The left plot (Figure 5) shows the output of a DLL (Delay Lock Loop) and the right one the signal strength of a GPS satellite after two simulations in the same conditions. The only difference is the existence of a fixed offset multipath of 20 dB power loss and 80 m path delay in the green plot. The multipath is programmed to occur after 1 minute and 30 seconds and to last 30 seconds. Both plots show the multipath signature in the tracking loop and in the signal strength. The tracking loop standard deviation is 0.3 subchip in a non-multipath scenario of 3 minutes, and it raises to 0.7 subchip if a 30 seconds multipath occurs within the 3 minutes of simulation. The DLL error is big in absence of the multipath. This is because of the receiver configuration. The effect of the multipath signature is present in the signal power as well. At the occurrence moment, the effect is perceived as a constructive interference, followed in the next second by a negative interference. This phenomenon is known as fading of the signal.

In the next steps, simulations with other velocities but the same multipath model will be performed to make a comparison between the error signatures. Additionally, different receiver configurations will be implemented and tested, as well as different multipath models with higher complexities.

Ghosthunter - Telematics System against Ghost Drivers using GNSS

The research project Ghosthunter aimed at developing a reliable wrong-way driving detection system using kinematic GNSS positioning technologies, digital road network data and map-matching technologies, so that the road safety in autobahn areas in Germany could be enhanced in an effective way. This project ran from August 2015 until November 2017, and it was successfully accomplished by the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart, the Institute of Space Technology and Space Applications (ISTA) at the University of the Federal Armed Forces Munich and the company NavCert.

Supported by:



Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

After the data quality evaluation of four different digital road maps (HERE, TomTom, OpenStreetMap and ATKIS-Basis-DLM) and the development of a weighting-function based map-matching algorithm based on standard map attributes in the previous phase, lane-level and ADAS (Advanced Driver Assistance Systems) attributes were investigated for potential use as additional information in the map-matching algorithm. The commercial map providers HERE and TomTom have almost similar sorts of the lane-level information. Relevant lane types are, for example, reversible lane, acceleration lane, deceleration lane and auxiliary. Afterwards a performance evaluation of the map-matching algorithm was done (Table 1), with the use of different sets of attributes.

Table 1: Performance evaluation of the proposed map-matching algorithm in summary

Map-matching	with lane-level attributes	with lane-level attributes and height data
Time consumption t for each epoch (1 Hz sampling rate)		
Maximum	0.173 s	2.329 s
Minimum	0.142 s	0.123 s
Mean value	0.146 s	0.541 s
Standard deviation	0.002 s	0.231 s

To assess its real-time performance, this map-matching algorithm needs to be integrated into the developed functional prototype for the desired wrong-way driver detection system and be tested in real time under real traffic conditions. Before that, the related map attributes like “street type” and “direction of travel” of entrance ramps of selected autobahn junctions had been swapped with their exit ramps. In this way, real wrong-way driving can be avoided while testing the map-matching algorithm. Warnings of wrong-way drivers will be raised, although the test vehicle travels in a correct direction.

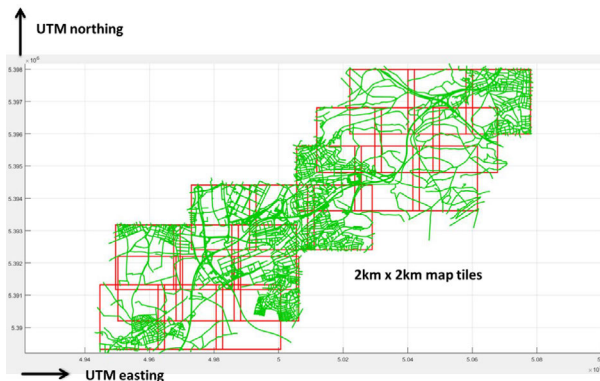


Figure 6: Division of large digital road map files into 2 km x 2 km map tiles

On the other hand, the map-matching algorithm had been optimized for high-performance by dividing large digital road map files into smaller tiles. One map tile is 2 km x 2 km (see Figure 6). Depending on the current vehicle position, the algorithm chooses the nearest map tile to it, and only digital road segments that lie completely within this tile or touch the tile borders are selected as possible candidates. According to the evaluation results of the algorithm performance in Table 2, the execution time of the proposed map-matching algorithm for a single vehicle position is drastically reduced by pre-processing the digital road map files with map tiles, from 0.137 s to 0.014 s in average.

Table 2: Performance evaluation of the proposed map-matching algorithm in summary

Map tiles	Pre-processing without map tiles	t_{\max} [s]	t_{\min} [s]	t_{mean} [s]	σ_t [s]
-	-	0.185	0.134	0.137	0.002
-	✓	0.113	0.035	0.065	0.020
✓	-	0.079	0.019	0.042	0.015
✓	✓	0.048	0.010	0.014	0.002

TransSec - Autonomous Emergency Manoeuvring and Movement Monitoring for Road Transport Security

The TransSec project addresses a new danger in European countries, which is the increasing number of terror attacks. Recent terror attacks with trucks in Nice and Berlin have drastically shown the damage a heavy truck can cause, how easy it is to misuse a truck for attacks and that newest safety systems cannot prevent these attacks. As a consequence, road transport safety has to be supplemented by road transport security. TransSec aims to initiate the development of such a security truck. The project objective is the development and evaluation of systems built-in or to be used by trucks for secure road transport and to prevent trucks to be misused for other purposes such as terror attacks. Specific objectives are:

- Precise vehicle positioning and navigation on road (lane) and off road
- Vehicle movement monitoring for dangerous goods with critical area alarm/eCall
- Vehicle communication security for critical information exchange
- Onboard precrash environment detection of vulnerable objects on/off road
- Non-defeatable autonomous emergency manoeuvring for crash prevention on/off road



The implementation is done in an explorative and incremental development cycle with early prototypes adding functionality step by step. Demonstrations with a truck on and off road will show the results. Testing and pilots on public roads and public areas will prove a higher level of security.

Several partners applied for funding this project in 2017, which will now start in February 2018 and will run until 2021. The partners involved are Daimler AG, TeleConsult Austria GmbH, Fundación Centro de Tecnologías de Interacción y Comunicaciones Vicomtech, Waterford Institute of Technology, Telecommunications Software & Systems Group and University of Stuttgart, Institute of Engineering Geodesy. The project is funded by the European Union within the research program of Horizon 2020.

Map-based Multi-GNSS Vehicle Positioning with Lane Identification Capability

Lane navigation plays a vital role in supporting the driver of a vehicle to take the correct lane on multilane roads, especially in roundabouts or motorway interchanges. Therefore, first of all an accurate vehicle localization is necessary. The precise point positioning (PPP) technique using the code and phase measurements of a GNSS receiver can obtain the required accuracy. In this case, not only GPS and GLONASS are used, but also the European Galileo satellite system. In the next step, the PPP solution is adapted to the road and lane, respectively. Common techniques like Fuzzy Logic or Hidden Markov Models are implemented for the map matching. The map is based on Navigation Data Standard (NDS), a physical storage format which aims to be a world-wide map standard. Nowadays, there is no map which provides worldwide lane information. The idea is to expand the road with map attributes like number of lanes and functional road class, and to derive the lanes out of this map information as well as the guidelines for road construction. Additionally, a camera can be used to get the correct lane width. Table 3 presents the values of the lane width at the beginning, in the middle and at the end of a lane marking on a German motorway. The laser scanner is used as reference measurement while the camera is used as additional sensor and the assumed value stands for the lane width which is coming from the German guidelines for road construction.

Table 3: Comparison between the reference laser scanning measurements compared with a camera and the guidelines for road construction

	Laser Scanner	Onboard Camera			Guidelines
	Measurement [m]	Round 1 [m]	Round 2 [m]	Round 3 [m]	Value [m]
L a n e	3.741	3.73	3.73	3.73	3.75
	3.738	3.72	3.72	3.73	3.75
	3.743	3.73	3.72	3.73	3.75

The implementation needs to work globally and in real-time. To establish a lane-precise navigation in shadowing areas and in tunnels, an Extended Kalman Filter will be used. In future work, several test drives need to be done to investigate the PPP algorithm, to prove the map matching algorithm in detail and to validate the lane-precise navigation.

Probability and Fuzzy Logic based dynamic Location Referencing Methods

Dynamic Location Referencing Methods are typically used for transferring Location References (LR) from one digital map to another in such cases where no common databases and/or common structures are available. This is done by a one-dimensional three steps process of encoding the LR in the sender system, transfer and decoding the LR in the receiver system without any iterations (Figure 7). The decoding step is hereby the critical one, i.e. to find the correct objects sent by the sender in the receiver system.

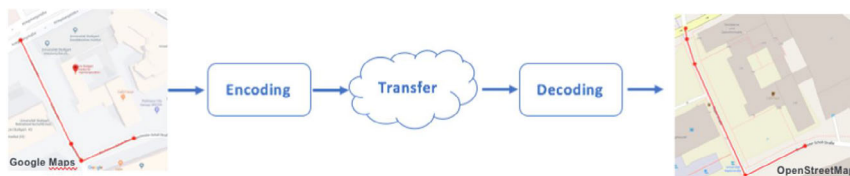


Figure 7: Process of Location Referencing

In the past, with nearly all known dynamic methods, an analytical power function (or cost function) - which will be maximized (or minimized) - has been used. Considering the fact that data linking from different sources has some uncertainty, the use of mathematical methods to handle such uncertainty by concepts like probability theory or fuzzy logic seems appropriate. Even if these methods have been used in various cases in the spatial context for data conflation/map matching, there is just one known method using a stochastic method (TPEG2-ULR with "Markov Chain").

Thus, there is some potential to do some further research and investigations in this field. As a base for this, statistical evaluations have been processed to find a valid base to estimate the probability distributions for the probability-based method and to define the fuzzy sets for the fuzzy-based method. As a result, the geometrical attributes follow an exponential distribution and all other attributes (topological, syntactical and semantical) are binomially distributed. These results have been published in the context of the Location based Service (LBS) conference which has been the first publication of such kind of statistical distributions for different attributes relating to Location Referencing.

Additionally, a first prototype (test environment) has been implemented which uses on the one hand the estimated probability distributions in a specific algorithm and on the other hand the defined fuzzy sets in a fuzzy logic inference system. Both methods show some first successful results.

Level Nonlinearity and Determination of Nonlinear Filtering Algorithms

The degree/level of nonlinearity can be measured by the coefficient of determination R^2 which describes the goodness-of-fit for mathematical models fitted to observation data by means of least squares regression. For multiple independent variables x_1, x_2, \dots, x_n , the linear regression model is given by

$$\hat{y} = b_0 + \sum_{i=1}^n b_i \cdot x_i \quad (5)$$

where b_0, b_1, \dots, b_n are regression coefficients. R^2 is then defined by (Helton and Davis, 2000)

$$R^2 = \frac{\sum_{i=1}^{nS} (\hat{y}_i - \bar{y}_i)^2}{\sum_{i=1}^{nS} (y_i - \bar{y}_i)^2} \quad (6)$$

If R^2 is close to 1, then the variation of observed data about the regression model is small or, in other words, the regression model can account for most of the uncertainty in variables. Conversely, if R^2 is close to 0, the variation of observed data about the regression model is large and the regression model fails to account for the uncertainty in variables.

The Kalman filter (KF) together with its modifications such as linearized KF by Authur (1974), extended KF by Anderson and Moore (1979) and unscented KF by Julier and Uhlmann (1997), are widely used. Besides, a promising solution utilized for the nonlinear model as well as the non-Gaussian noise was proposed by Gordon (1993). However, one of the main issues in our knowledge of nonlinear filters is a lack of determination of the nonlinear level.

In order to estimate accuracy of the filtering algorithm, the Root Mean Square Error (RMSE) of position is used as an accuracy parameter.

A kinematic model of straight line with five components of a state vector including coordinates (x and y), velocity (v), orientation (φ), and changed orientation ($\Delta\varphi$) can be seen as prediction model:

$$\mathbf{y} = [x \quad y \quad \varphi \quad v \quad \Delta\varphi]^T. \quad (7)$$

The observation vector consists of coordinates (X_{Ublox}, Y_{Ublox}) of low-grade GPS and the different distance and rotational angle ($\Delta s_{odo}, \Delta\varphi_{odo}$) of the Odometer sensor

$$l_{k+1} = [X_{Ublox,k+1} \quad Y_{Ublox,k+1} \quad \Delta s_{odo,k+1} \quad \Delta\varphi_{odo,k+1}]^T. \quad (8)$$

For the linear model, the distance and rotational angle measurements are assumed to be linearly related to the state vector. On the other hand, for the nonlinear model the distance and rotational angle measurements are nonlinearly related to the state vector defined by the following equations:

$$\Delta s = \sqrt{(x_{k+1} - \hat{x}_k)^2 + (y_{k+1} - \hat{y}_k)^2}; \Delta\varphi = \varphi_{k+1} - \hat{\varphi}_k = \text{atan}\left(\frac{y_{k+1} - \hat{y}_k}{x_{k+1} - \hat{x}_k}\right) - \hat{\varphi}_k \quad (9)$$

With (\hat{x}_k, \hat{y}_k) and $\hat{\varphi}_k$ are known coordinates and orientation at the last epoch k , respectively. (x_{k+1}, y_{k+1}) and φ_{k+1} are unknown coordinates and orientation at current epoch $k+1$, correspondingly.

R^2 is an indicator for selecting nonlinear filtering algorithms by using the relationship between the level of nonlinearity and the estimation accuracy. The EKF, UKF, and PF are a suitable choice for the linear observation model. On the other hand, the UKF and PF are possible solutions for the nonlinear observation model. In both cases non linear prediction is modelled. The results suggest that there should be further investigations on the relationship between the estimation accuracy and higher levels of nonlinearity as well as non-Gaussian noise.

Undergoing Research for Total Stations

Current research implied testing the non-reflector measurement mode (DR) of the Trimble S7 total station. Non-reflector measurements often occur on construction sites for certain points of interest, which are not accessible or involve a high risk for the operator. According to the technical specifications from Trimble, the non-prism distance measurement accuracy is the same with the one using a prism. To put these statements to a test, several scenarios have been created a measurements under different conditions have been conducted. As main parameters for the tests, distance and angle of incidence were taken into consideration. Laboratory conditions facilitated measurements for two chosen ranges of 5 and 30 meters. On the other side, field experiments involved slope distances from 30 to 456 m. As for the object of interest, 30 different materials like metals, polymers, ceramics and composites were used. The main criteria for selecting these targets, was their usage in the construction field, mostly for facade design. To eliminate any error sources that may come from a translated position of the material, a special adapter has been designed to constrain the sample to the same vertical axis of the prisms. Three different angles of incidence have also been used to see in which case the material offers reliable results. Exemplary results are presented for the 30m range in Figure 8.

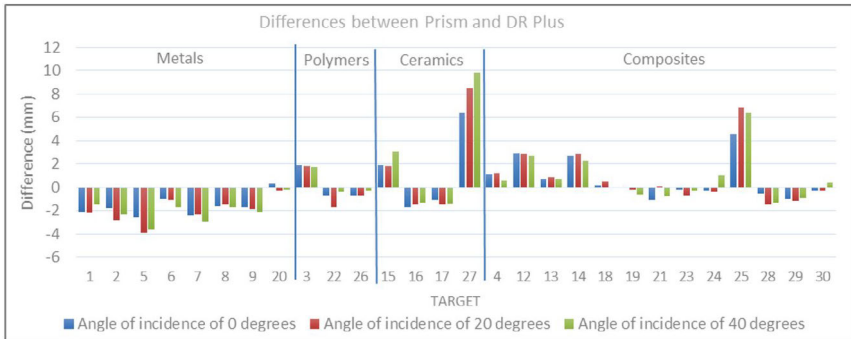


Figure 8: Differences at 30 m field range

Publications

Refereed Publications

- Kauker, S., Schwieger, V.: A synthetic covariance matrix for monitoring by terrestrial laser scanning. *Journal of Applied Geodesy*, Vol. 11, Issue 2, pp. 77-88, deGruyter, Berlin, 2017.
- Kauker, S.; Harmening, C.; Neuner, H.; Schwieger, V.: Modellierung und Auswirkung von Korrelationen bei der Schätzung von Deformationsparametern beim terrestrischen Laserscanning. In: Lienhart, W. (Hrsg.): Beiträge zum 18. Internationalen Ingenieurvermessungskurs in Graz 2017, pp. 321-336, Wichmann, Berlin.
- Rinke, N., v. Gösselen, I., Kochkine, V., Schweitzer, J., Berkhahn, V., Berner, F., Kutterer, H., Neumann, I., Schwieger, V.: Simulating quality assurance and efficiency analysis between construction management and engineering geodesy. In: *Automation in Construction*, Vol. 76, pp. 24-35, Elsevier B.V., Amsterdam.
- Wang J., Metzner M., Schwieger V.: Accuracy and Quality Assessment of Various Digital Road Maps for Wrong-Way Driving Detection on the German Autobahn. In: *Proceeding of FIG Working Week*, 29.05.-02.06.2017, Helsinki, Finland.
- Zhang, L., Schwieger, V.: Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System. In: *Proceeding of FIG Working Week*, 29.05.-02.06.2017, Helsinki, Finland.

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- Beckmann, H., Frankl, K., Schütz, A., Philips-Blum, A. Wang, J., Metzner, M., Schwieger, V., Pany, P., Eissfeller, B.: Performance Comparison of Different GNSS-based Multi-sensor Systems for Detecting Wrong-way Driving on Highways, 30th International Technical Meeting of the Satellite Division of The Institute of Navigation ION GNSS+ 2017, 25-29.09.2017, Oregon Convention Center, USA.
- Beckmann H., Frankl K., Pany T., Eissfeller B., Wang J., Metzner M., Schwieger V., Stapelfeld M., Grzebellus, M.: GNSS-based detection of wrong-way drivers with an automatic warning of other traffic, DGON Convent 2017,04./05.05.2017, Berlin.
- Haala, N., Schwieger, V.: UAV - Anforderungen und Möglichkeiten. 156. DVW-Seminar Unmanned Aerial Vehicles 2017 (UAV 2017), Stuttgart.
- Karpik, A., Musikhin, I. and Schwieger, V.: Research and Practical Trends in Geospatial Sciences: The Five to Seven Year Vision. Beiträge zu 19. Geodätische Woche Obergurgl 2017, Obergurgl - Ötztal -Tirol, 12.-18.02.2017, Wichmann Verlag im VDE-Verlag, Berlin.
- Lerke, O., Schwieger, V.: Steering Method for Automatically Guided Tracked Vehicles. In: Proceeding of FIG Working Week, 29.05.-02.06.2017, Helsinki, Finland.
- Maxim, A., Lerke, O., Prado, M., Dörstelmann, M. Menges, A., Schwieger, V.: UAV Guidance with Robotic Total Station for Architectural Fabrication Processes; 156. DVW-Seminar Unmanned Aerial Vehicles 2017 (UAV 2017), Stuttgart.
- Schmitt, A., Schwieger, V.: Estimation of wooden coefficient of expansion due to temperature and moisture with geodetic sensors. In: Kopáčik, Kyrnovič, Henriques (Hrsg.): INGEO 2017, 7th International Conference on Engineering Geodesy, Proceedings, 18.-20.10.2017, Lissabon, Portugal.

Presentations

- Schwieger V.: GEOENGINE - The University of Stuttgart International Master Program with more than 10 Years of Experience, GeoSiberia 2017, 19.-21.04.2017, Novosibirsk, Russia.
- Schwieger V.: Cost-Effective GNSS - FIG activities and IIGS Research, Workshop on Cost Effective Positioning and Geo Data, 20.04.2017, Novosibirsk, Russia.
- Schwieger V.: Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System, Workshop on Cost Effective Positioning and Geo Data, 20.04.2017, Novosibirsk, Russia.

Schwieger V.: Optimierte Positions- und Lagebestimmung für die Tiefenmessung mit HydrOs, Kolloquium der BFG "Geodätische Beiträge zum Systemverständnis für Bundeswasserstraßen und sonstige Gewässer", 10./11.05.2017, Koblenz.

Schwieger V.: Deformation Analysis using Kalman Filter, Summer School 2017 "Geodetic Techniques for Global Change Monitoring", 24.-28.07.2017, Yichang, China.

Wang J.: Deformation Analysis: optimal state estimate using Kalman filter, Summer School 2017 "Geodetic Techniques for Global Change Monitoring", 24.-28.07.2017, Yichang, China.

Wang J., Metzner M., Schwieger V.: Weighting-function based map-matching algorithm for a reliable wrong-way driving detection. In: Proceeding of 12th ITS European Congress, 19.-22.06.2017, Strasbourg, France.

Activities at the University and in National and International Organisations

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Doctorates

Al-Mistarehi, Bara' Wasfi: An Approach for Automated Detection and Classification of Pavement Cracks. Hauptberichter: Prof. Dr.-Ing. habil. V. Schwieger, Mitberichter: Prof. Dr. sc.-techn. D. Fritsch, PD Dr.-Ing. A. Reiterer.

von Gösseln, Ilka: Simulationsbasierte Effizienzoptimierung von Messprozessen am Beispiel der tachymetrischen Netzmessung Hauptberichter: Prof. Dr.-Ing. I. Neumann, Mitberichter: Prof. Dr.-Ing. habil. H. Kutterer, Prof. Dr.-Ing. habil. V. Schwieger, Prof. Dr.-Ing. habil. J. Müller.

Diploma Theses and Master Theses

Aichinger, Julia: Beurteilung von TLS-Aufnahmeparametern zur Deformationsanalyse mit Werkzeugen der Varianz-basierten Sensitivitätsanalyse (Schwieger)

Asomani, Alexander: Development of Android based application for locating a cell user (Metzner)

Dominguez, Luis Eduardo: Reliability and accuracy evaluation of the Direct Reflex Plus non-reflector measurement mode of the imaging/scanning total station Trimble S7 through scenario tests (Kerekes)

Fritsch, Benjamin: Tauglichkeitsuntersuchung der Leica Nova MS60 MultiStation für die messtechnische Überwachung von Bauzuständen im geschlossenen Tunnelbau (Metzner)

Gregotsch, Simon: Parametrisierung der Laserscanner-Waveforms unterschiedlicher Materialien unter unterschiedlichen Messbedingungen (Hassan)

Grellmann, Alix: Ermittlung von Bodenrichtwerten in kaufpreisarmen Lagen - Anwendung eines GIS-gestützten Verfahrens am Beispiel von Wohngebieten in Villingen-Schwenningen. (Schwieger)

Hambel, Tibor: Ableiten von Abschattungsdiagrammen vor GNSS-Beobachtungen auf Flüssen mit Hilfe von frei verfügbaren Daten (Metzner)

Kappeler, Marius: Erstellung eines CAD Modells einer Laderaupen und geometrische und stochastische Modellierung des Werkzeugs (Lerke)

SeydEshaghi, Masoud: Integration of Terrestrial Laser Scanning and GNSS for Monitoring the Hessigheim Wine Yard (Hassan, Schmitt, Zhang)

Szatkowska, Marta: Modify the shortest distance route to green route optimization for trucks (Trauter, Metzner)

Wenk, Maximilian: Untersuchung verschiedener Ansätze zur kinematischen Georeferenzierung für terrestrische Laserscanner (Scheider)

Bachelor Theses

- Ehmke, Svenja: Überprüfung der Messgenauigkeit verschiedener Laserscanner (Hassan)
- Guan, Ruomeng: Evaluierung der Qualität der Ublox LEA-M8T GNSS-Empfänger (Zhang)
- Huber, Christina: Gegenüberstellung und Vergleich verschiedener Ansätze zur Phototexturierung von Laserscans (Schmitt)
- Pfitzenmeier, Tobis: Untersuchung verschiedener Filterarten zur Extraktion von Geländepunkten aus full-Waveform-basierten Laserscannerpunktwolken zur Erstellung eines DGMs (Hassan)
- Stähle, Felix: Bewertung und Analyse des Flurneorderungsverfahrens Neuenstein-Neufels zur Verbesserung der Agrarstruktur wie auch der allgemeinen Landeskultur (Metzner)
- Xiao, Weixin: Investigation on the Quality of u-blox RTK application board package (Zhang)

Education

SS17 and WS17/18 with Lecture/Exercise/Practical Work/Seminar

Bachelor Geodesy and Geoinformatics (German):

Basic Geodetic Field Work (Schmitt, Kanzler)	0/0/5 days/0
Engineering Geodesy in Construction Processes (Schwieger, Kerekes)	3/1/0/0
Geodetic Measurement Techniques I (Metzner, Wachsmuth)	3/1/0/0
Geodetic Measurement Techniques II (Schmitt)	0/1/0/0
Integrated Field Work (Kerekes, Metzner)	0/0/10 days/0
Methods of Measurements and Analysis in Engineering Geodesy (Schwieger, Kerekes)	2/2/0/0
Reorganisation of Rural Regions (Helfert)	1/0/0/0
Statistics and Error Theory (Schwieger, Wang)	2/2/0/0

Master Geodesy and Geoinformatics (German):

Causes of Construction Deformation (Metzner, Wang)	1/1/0/0
Deformation Analysis (Zhang)	1/1/0/0
Industrial Metrology (Schwieger, Kerekes, Kanzler)	1/1/0/0
Land Development (Eisenmann)	1/0/0/0
Monitoring Measurements (Schwieger, Wang)	1/1/0/0
Monitoring Project (Lerke)	0/0/2/0

Terrestrial Multisensor Systems (Zhang, Lerke, Kerekes)	1/1/0/0
Thematic Cartography (Zhang, Wachsmuth)	1/1/0/0
Transport Telematics (Metzner, Scheider)	2/2/0/0

Master GeoEngine (English):

Integrated Field Work (Kerekes, Metzner)	0/0/10 days/0
Kinematic Measurement Systems (Schwieger, Lerke)	2/2/0/0
Monitoring (Schwieger, Wang)	1/1/0/0
Thematic Cartography (Zhang, Wachsmuth)	1/1/0/0
Transport Telematics (Metzner, Scheider)	2/1/0/0
Terrestrial Multisensor Systems (Zhang, Lerke)	2/1/0/0

Bachelor and Master Aerospace Engineering (German):

Statistics for Aerospace Engineers (Schwieger/Zhang, Hassan)	1/1/0/0
--	---------

Master Aerospace Engineering (German):

Industrial Metrology (Schwieger, Kerekes, Kanzler)	1/1/0/0
Transport Telematics (Metzner, Scheider)	2/2/0/0

Bachelor Civil Engineering (German):

Geodesy in Civil Engineering (Metzner, Scheider)	2/2/0/0
--	---------

Master Civil Engineering (German):

Geoinformation Systems (Metzner, Hassan)	2/1/0/0
Transport Telematics (Metzner, Scheider)	1/1/0/0

Bachelor Technique and Economy of Real Estate (German):

Acquisition and Management of Planning Data and Statistics (Metzner, Kanzler)	2/2/0/0
---	---------

Bachelor Transport Engineering (German):

Statistics (Metzner, Kanzler)	0.5/0.5/0/0
Seminar Introduction in Transport Engineering (Hassan)	0/0/0/1

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Research

Signature of ENSO on Boreal Catchment

Climate change brings more frequent extreme events and causes abnormal variation of terrestrial water cycle. The El Niño Southern Oscillation (ENSO) is one of the most important climate phenomena. Occurring every 2–7 years, it reflects ocean-atmosphere interactions over the equatorial Pacific. However, ENSO's reach is not limited to the Pacific but has global impact. ENSO dominantly influences rainfall in terms of moisture advection from ocean to land, consequently impacts on evaporation and runoff, and eventually affects terrestrial water cycle. Generally, terrestrial water storage reflects the water balance and, therefore, is influenced as well by global and regional climate change. After more than a decade of observations, the Gravity Recovery and Climate Experiment (GRACE) mission has been proved to be capable to monitor water mass variation and redistribution.

Climate warming has great impact on the Arctic, which leads to extreme events. Numerous studies indicate that the Arctic and Eurasia are mainly under the influence of the Arctic Oscillation and the North Atlantic Oscillation. However, whether the ENSO phenomenon also has a signature in boreal regions is still an unanswered question. A multivariate method, canonical correlation analysis (CCA), has been used to identify the teleconnection patterns between ENSO and terrestrial water variation. Because of the important role of SST on climate change and terrestrial water variation, we propose a comprehensive analysis to include SST as an intermedium.

In this study, we investigate the teleconnection pattern between ENSO and terrestrial water cycle in boreal region for the time period 2003 to 2014 using monthly spaceborne observations and reanalysis data sets. The correlated inter-annual variations have been identified in associated canonical modes by applying CCA on the data sets. The spatial pattern of terrestrial variables related to ENSO are obtained by projecting identified temporal modes in spatial domain.

In addition, we apply CCA as well on water storage fluxes to investigate the signature of ENSO on terrestrial water balance. Water mass derivative (dM/dt) is derived from GRACE observations. Figure 1 shows the ENSO related spatial patterns from terrestrial water storage, which has largest correlation with Nino 3.4. Results in Figure 1 reveal evident teleconnection between ENSO and terrestrial water cycle in boreal catchments, like Ob, Lena and Yenisei. Therefore, the signature of ENSO on boreal water cycle can be identified statistically with the aid of sea surface temperature.

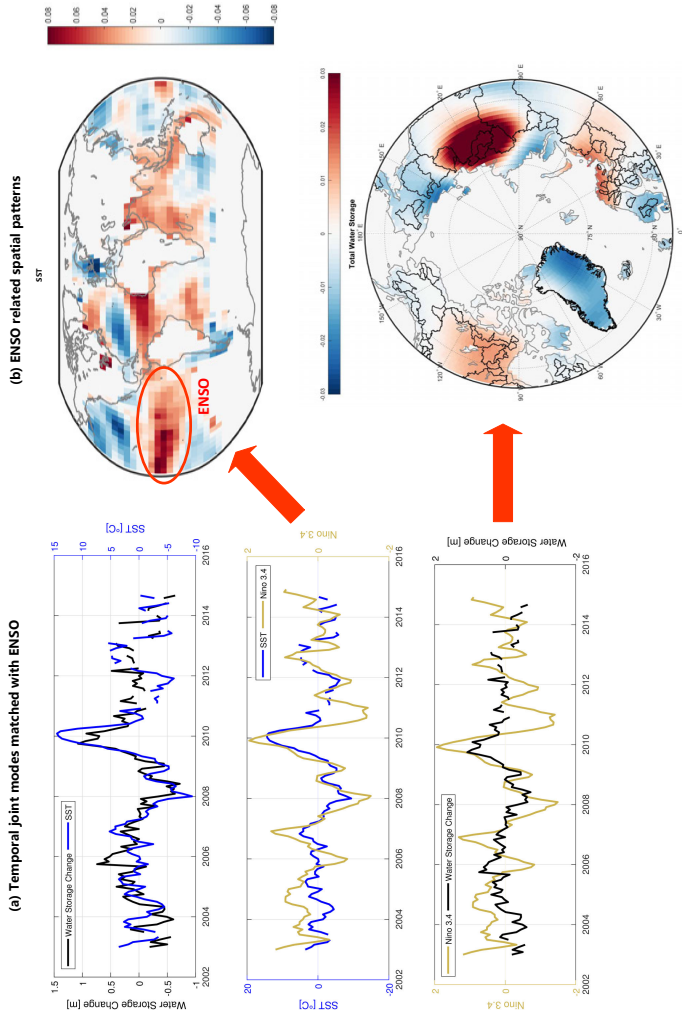


Figure 1: (a) Temporal joint modes from TWS and SST are matched with ENSO. (b) Associated spatial patterns of global SST and TWS in boreal region.

RASLyBoCa: Influence of Arctic river runoff variations on Arctic sea level, sea ice and circulation

The main objective of this project is to assess and quantify the response of Arctic sea ice and Arctic and North Atlantic sea level and hydrography to changes in river discharge into the Arctic Ocean.

However, as the availability of in situ observations of river runoff is on the decline since the late 1980s, the observational record of discharge into the Arctic Ocean is still too sparse to address important scientific questions relating to long-term behaviour. Therefore, we are improving the observational record of hydrological parameters over boreal catchments by geodetic spaceborne methods such as satellite altimetry and GRACE gravimetry. The goal is to achieve long time series (several decades) of runoff with a temporal resolution up to 5 days for all major catchments draining into the Arctic Ocean. Hereby, we are facing challenges including the correct interpretation of snow and ice reflected waveforms with appropriate altimetric retracking algorithms, the estimation of non-stationary runoff using multi-mission altimetric water level time series along each river as well as the combination of GRACE and altimetry based runoff estimates.

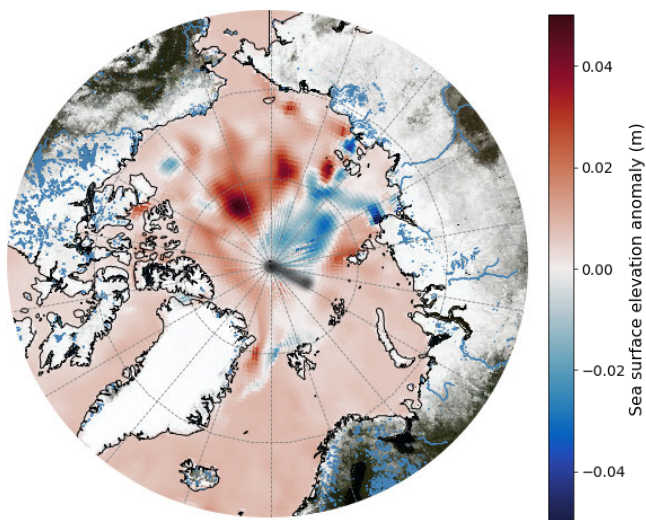


Figure 2: Sea surface elevation anomaly of simulations with CORE II runoff climatology and CORE II interannual runoff for August 2010. Red colours indicate higher sea level simulated with the runoff climatology and blue indicates where the sea level is lower compared to the interannual runoff.

For ice-ocean models, the scarcity of runoff information in the Arctic generally requires that the seasonal cycle of runoff is assumed to be a climatological mean. At the AWI Bremerhaven, our colleagues use the sea ice-ocean model MITgcm to determine the influence of using a high resolution time series of river discharge provided by our institute in comparison to runoff climatologies. Further, the people from AWI Bremerhaven will assess the influence of an increased river runoff and an increased freshwater content in the Arctic on the Arctic sea level, the Arctic sea ice and the North Atlantic sea level and overturning circulation. In addition to that, they will perform adjoint model simulations in order to assess the sensitivity of sea level and other important net quantities to river discharge relative to other freshwater sources. The adjoint model will be used to identify river catchments that are hotspots of sensitivity for the Arctic sea level to inform us where to focus our investigations.

First results suggest a measurable influence of using inter-annually varying runoff forcing in the model simulations on the freshwater content and the sea level in the Arctic (Figure 2). The difference in sea surface elevation for a simulation with the CORE II runoff climatology and a simulation with CORE II interannual runoff (monthly resolution) for August 2010 after 30 years of simulation imply systematic changes in the Arctic sea level of up to ± 5 cm. This can be quantified by current satellite altimetry missions.

Ocean Tide Aliasing in Spaceborne Gravimetry: Error Mitigation vs Parameter Estimation

Ocean tide constituents have fixed spectral lines, due to the relative motion of the Earth and the tide generating body, mainly the moon and the sun. Tidal aliasing errors due to the undersampling of the ocean tides can be estimated in the post-processing. Figure 3 (blue lozenges) shows the flowchart of the ocean tide mitigation. It can be accomplished as follows:

- deriving the residual fields by subtracting the reference models from the recovered gravity fields;
- evaluating the alias periods of each tidal constituent;
- calculating the alias errors by least-squares harmonic estimation on the alias periods with respect to the residual time series;
- subtracting the estimated alias errors from the recovered gravity field to derive the final de-aliased fields.

The alias errors can be used to estimate the tidal parameters as well rather than be discarded in post-processing. Figure 3 (blue and green lozenges) shows the flowchart of the tidal parameter estimation in post-processing mode. That means, after estimating alias errors with respect to each tidal constituent, the phase lags and amplitudes can be evaluated by LS-estimation. This procedure has the same idea as co-estimation and we do not discuss it in detail here. Comparing to the co-estimation, tidal parameter estimation in post-processing has following pros and cons:

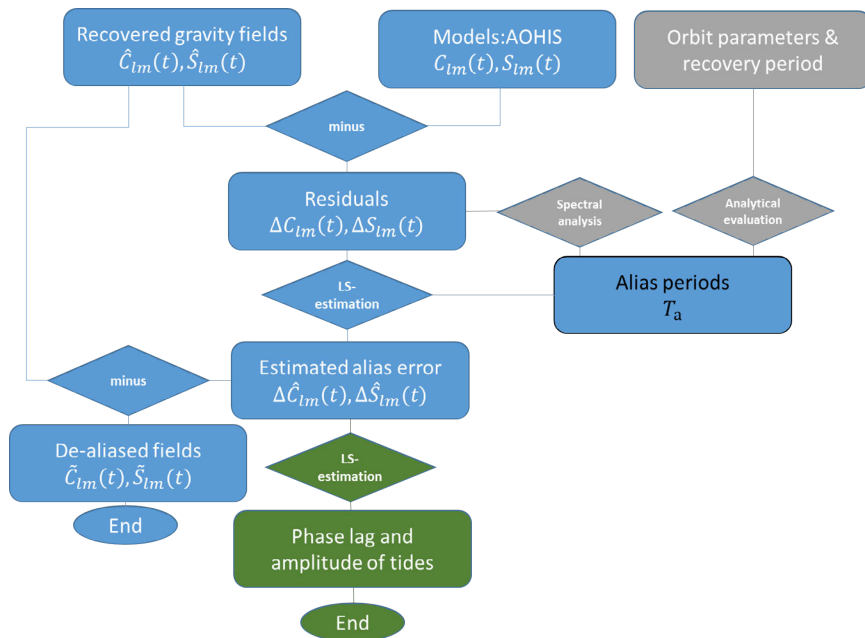


Figure 3: Flowchart of the ocean tide alias error mitigation and tidal parameter estimation in a post-processing mode. The blue lozenges show the main steps to mitigate the alias errors for the recovered gravity field. The grey lozenges indicate two different ways of estimating ocean tidal alias periods. The blue and green lozenges together give the main steps for tidal parameter estimation.

- less computation time with higher spatial resolution, while the estimated coefficients can be up to the same degree/order of the recovered gravity fields;
- reference temporal gravity field models are needed, which has a risk of introducing model errors in the estimated phase lag and amplitude of the tides.

In addition, longer time series are needed for both methods to gain a good estimation of the tidal parameters. Otherwise, the tides can only be partially estimated. Figure 3 shows that different alias spectra show up with different recovery periods T_r for the constituent M_2 . This demonstrates the complexity of the aliasing behavior induced by the spatial and temporal averaging during the gravity field retrieval. Without taking the retrieval procedure into consideration, the orbit sampling alone cannot give a comprehensive insight into tidal aliasing.

Characterizing storage-based drought

Drought is a natural recurring hazard with slow onset accompanied with effects that accumulate over a considerable period of time (e.g., weeks to months). It can virtually affect any climate region and has wide-ranging impacts on many sectors of society (e.g., agriculture, economics, ecosystem services, energy, water resources, human health, and recreation). Drought is a complex phenomenon and it can be classified according to three physically based perspectives: meteorological (lack of precipitation), agricultural (deficit in soil moisture and vegetation response) and hydrological (deficit in runoff, streamflow, or groundwater storage). The hydrology component of the ESA's Earth System Model for Gravity Mission Simulation Studies provides Total Water Storage Anomaly (TWSA) for every 6-hour from 1995 to 2006. ESM-EWH contains changes of storage (which is soil moisture, snow, and groundwater). As a result, it can be used as a source to investigate a new class of drought, which we call 'storage-based drought' as it comes from the change of total water storage.

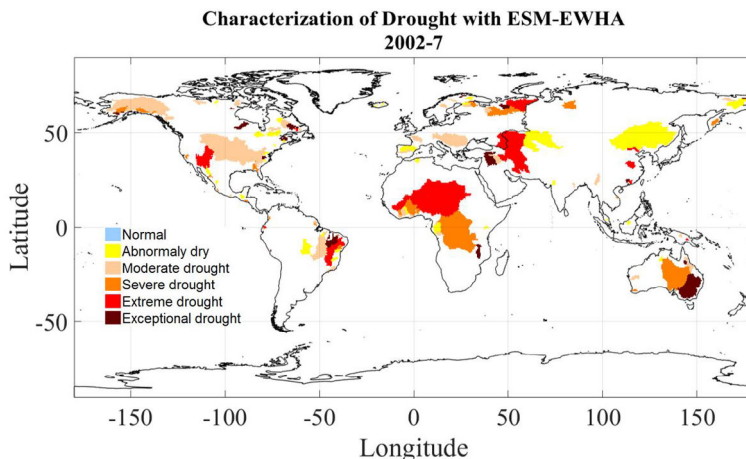


Figure 4: Spatial distribution of drought (July 2002)

As a part of ESA project ADDCON, we have investigated a new approach to characterize storage-based drought in ESM time series. The short time period of ESM-EWH —which is also the same issue for EWH time series from GRACE (Gravity Recovery and Climate Experiment)— for the characterization of drought has been investigated and using longer datasets (WGHM or the use of the integral of water balance fluxes) has been proposed for finding climatology. The results are shown both as time evolution of drought (Figure 5) and spatial distribution (Figure 4, 405 catchments).

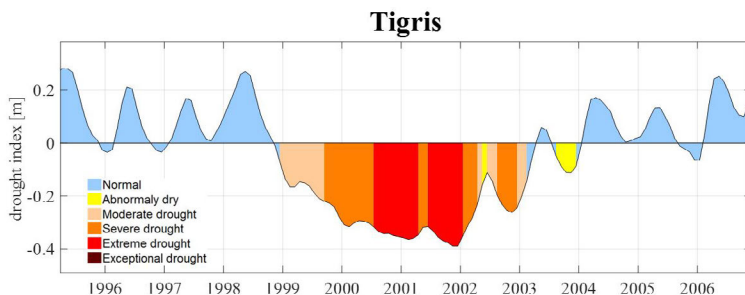


Figure 5: Time evolution of drought (Tigris catchment)

Markov Random Field based waveform retracking solved by the graph cuts technique

Satellite altimetry was initially designed for oceanography but it provided vast opportunities for hydrological studies as well. Over the past three decades, spaceborne altimetric measurements are widely used to monitor the fluctuations of inland water bodies. Over inland water bodies waveforms are damaged by noise mainly because of variations in the surface topography. Therefore, estimating an accurate surface water height requires a postprocessing algorithm known as retracking. The main outcome of retracking algorithms is the correction of the estimated range.

Most of the traditional retracking algorithms try to find the retracking gate just by considering the returned power of waveforms. In this study, we introduce a new retracking algorithm that benefits from both information about the returned power and the spatial correlation between adjacent waveforms. The procedure starts with generating a radargram by stacking all waveforms over a river section. Now, instead of defining retracking gates for different waveforms separately, we try to find a retracking line for the whole radargram. In other words, our aim is to segment the radargram into two distinct regions (before and after retracking line). Markov Random Fields (MRF) can express a wide variety of spatially varying behavior. Therefore, we define a MRF framework by specifying conditional distributions regarding the returned power and the labels. In order to find the retracking line in the radargram, the Maximum A Posteriori (MAP) estimate of the defined MRF must be sought. Since the high computational effort of finding a global solution is a serious concern, the problem is reshaped as an energy minimization problem. The minimum energy solution is found by the graph cuts technique, which is fast and able to find either the exact minimum or an approximate minimum solution. To generate water level time series over part of Amazon River (Figure 6a), we apply our method to waveforms of the Jason-2 mission for the period of 2008–2016. In Figure 6b, the strong spatial correlation between the neighboring waveforms located over the River is clear. Figure 6(c,d) presents the radargram of waveforms located over the river. The water level time series estimated by the proposed method is presented in Figure 6e. The comparison

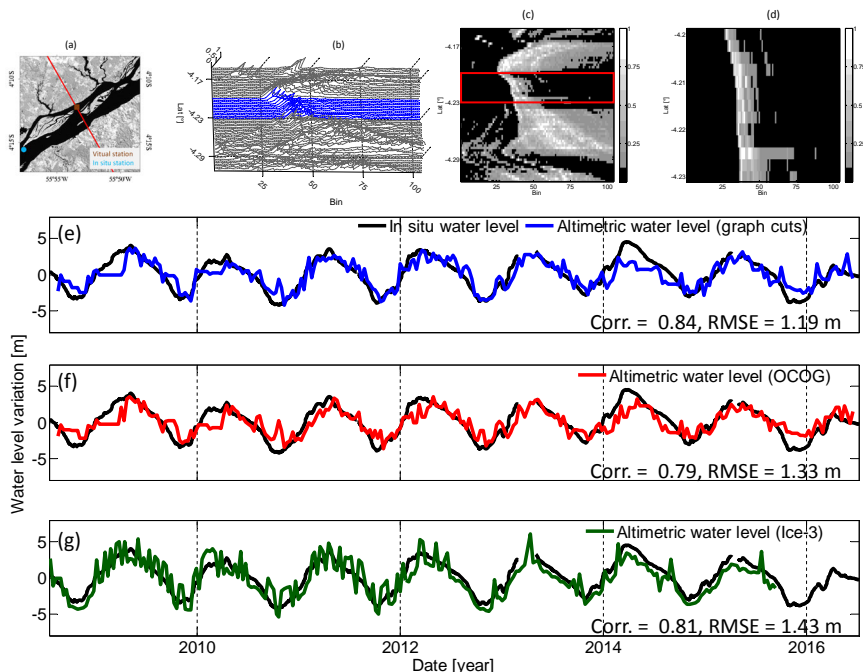


Figure 6: (a) is part of Amazon River used as case study, the track number 96 of Jason-2 mission is plotted over the River section, (b) is a three dimensions representation of waveforms. (c) is the generated radargram form the waveforms and in (d), just waveforms over the River are presented in the radargram. Time series in (e) is a comparison between water level estimated by the proposed retracker and in situ measurements. Time series in (f-g) are presented for comparing the performance of proposed retracker with two common retrackerers

between altimetric and in situ height measurements shows that the method can estimate the water level accurately. To assess the performance of the method, water level time series derived by two other retrackerers are also provided. This comparison shows that the proposed retracker can estimate water level more accurate than OCOG and Ice-3 retrackerers. The reason is clear since the proposed technique takes advantages of spatial correlation between neighboring waveforms apart from the returned power.

Data mining for GRACE monthly solutions

Recovered gravity field from GRACE satellite is represented in the form of spherical harmonics coefficients up to degree and order 90/90 for each month since 2002. So the total number of coefficients one need to recover is 8281. If we somehow reduce the number of coefficients to be recovered we can save some of the computing time, reduce the formal error and get the more stable gravity field solutions. In other words, we get the benefit of increasing the degree of freedom while reducing the number of recoverable coefficients.

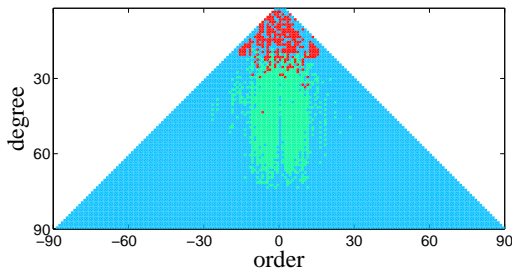


Figure 7: The plot represents the essential, non-essential and predicted classes in blue, green and red colors respectively.

Here in this study we present a method to reduce the number of coefficients. We achieve the goal using a two-step procedure, firstly, to classify the coefficients into essential and non-essential classes. According to the detail, we compute the yearly variance and select a value as the threshold. The coefficients having the variance below the threshold value are the non-essential class. Suppose we replace the non-essential coefficients with their yearly mean values. While doing it we are introducing a truncation error. The idea is to keep the truncation error within the standard deviations limits of the original GRACE monthly solutions, during the threshold selection procedure. We will not recover these coefficients during the recovery process. Secondly, we identify a set of coefficients among the essential coefficients which we can predict using neural networks. Since they can be predictable therefore they are also removed from the candidates list of the recoverable coefficients. Figure 7 shows the essential, non-essential and predictable coefficients of December 2010, in blue, green and red colors respectively.

Simulation shows that when we recover the reduced dataset of coefficients the formal error is decreased as compared to the case when we recover full dataset, as shown in the Figure 8.

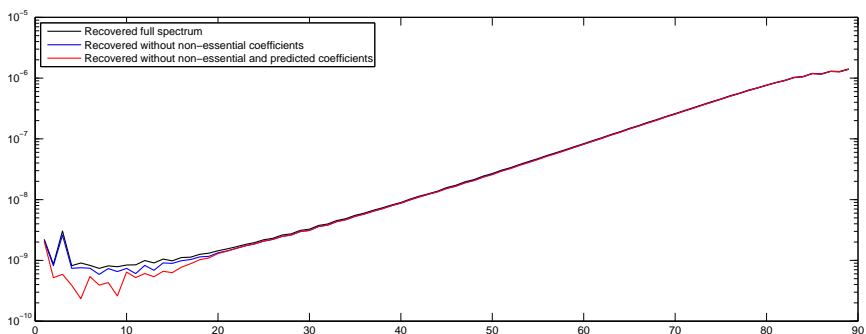


Figure 8: The plot shows the curves of the formal errors in cases if we recover 1) full spectrum (black curve) 2) the spectrum without the non-essential class (Blue curve) and 3) the spectrum without non-essential and predicted coefficients (Red curve) decreased as we reduce the number of coefficients to be recovered.

Summer School of the DAAD Thematic Network Geodesy in Yichang

Professors, researchers and students of the DAAD Thematic Network Geodetic Space Techniques for Global Change Monitoring came together in Yichang, China during 24.–28.07.2017. Especially the MSc and PhD students should benefit from the academic exchange in the field of geodetic methods for global change monitoring.

More than 60 professors, researchers, PhD and MSc students of the DAAD Thematic Network joined the Summer School in Yichang in China, which was co-organized by the Wuhan University and the University of Stuttgart. The Thematic Network consists of the host institutions of the Summer School, the Wuhan University and the University of Stuttgart, as well as the Tongji University in Shanghai, the Chinese Academy of Surveying and Mapping in Beijing, the German Geodetic Research Institute of the Technical University Munich and the University of Luxembourg. The program consisted of lectures covering a wide range of geodetic methods. The key topics of the lectures were satellite navigation (GNSS), satellite altimetry, satellite gravimetry, InSAR and deformation analysis, though transmitting methodological knowledge was another part of the curriculum, such as time series analysis, which can be applied to geodetic data. Furthermore the students dealt with the application of geodetic methods in hydrology and seismology, in which geodetic data provides essential data for meeting current global challenges like climate change and natural disasters such as earthquakes.

In this one-week event, the participants discussed the topics of the lectures and consolidated the content in computer laboratories. The social program included a field trip to the Three-Gorges-Dam, where geodetic methods also take effect. Besides the academic aspects, stu-



dents from all partner institutions benefited from the international atmosphere and enjoyed the intercultural exchange and interesting conversations with their foreign fellow students. Right after finishing the successful Summer School, the Thematic Network already started planning further joint events, exchange opportunities, so researchers and students can participate in research and study programs of the partner institutions. Furthermore the network provides a scholarship program for students of all levels. Another Thematic Network workshop is planned to take place in Luxembourg in summer 2018. More information about the Summer School and the DAAD Thematic Network is available online on the joint network website (<http://themnet.gis.uni-stuttgart.de/>) as well as on the website of the Wuhan University (<http://main.sgg.whu.edu.cn/daadtn/>).

Publications

(<http://www.gis.uni-stuttgart.de/research/publications/>)

Refereed Journal Publications

Devaraju, B. und N. Sneeuw (2017): The polar form of the spherical harmonic spectrum: implications for filtering GRACE data. In: *Journal of Geodesy*, S. 15. doi: 10.1007/s00190-017-1037-7.

Jiang, W., P. Yuan, H. Chen, J. Cai, Z. Li, N. Chao und N. Sneeuw (2017): Annual variations of monsoon and drought detected by GPS: A case study in Yunnan, China. In: *Scientific Reports* 7. Article no. 5874, S. 1–10. doi: 10.1038/s41598-017-06095-1.

Sjöberg, L., E. Grafarend und M. Joud (Jan. 2017): The zero gravity curve and surface and radii for geostationary and geosynchronous satellite orbits. In: *Journal of Geodetic Science* 7.1, S. 43–50. doi: 10.1515/jogs-2017-0005.

Tourian, M. J., C. Schwatke und N. Sneeuw (März 2017): River discharge estimation at daily resolution from satellite altimetry over an entire river basin. In: *Journal of Hydrology* 546, S. 230–247. doi: 10.1016/j.jhydro1.2017.01.009.

Varga, P. und E. W. Grafarend (Mai 2017): Influence of Tidal Forces on the Triggering of Seismic Events. In: *Pure and Applied Geophysics*. doi: 10.1007/s00024-017-1563-5.

Varga, P., E. W. Grafarend und J. Engels (März 2017): Relation of Different Type Love–Shida Numbers Determined with the Use of Time-Varying Incremental Gravitational Potential. In: *Pure and Applied Geophysics*. doi: 10.1007/s00024-017-1532-z.

Vishwakarma, B. D., M. Horwath, B. Devaraju, A. Groh und N. Sneeuw (2017a): A Data-Driven Approach for Repairing the Hydrological Catchment Signal Damage Due to Filtering of GRACE Products. In: *Water Resources Research*. doi: 10.1002/2017WR021150.

Xu, X., Y. Zhao, T. Reubelt und R. Tenzer (2017): A GOCE only gravity model GOSG01S and the validation of GOCE related satellite gravity models. In: *Geodesy and Geodynamics* 8 (4), S. 260–272. doi: 10.1016/j.geog.2017.03.013.

Books & Miscellaneous

Liu, W., N. Sneeuw, S. Iran Pour, M. J. Tourian und T. Reubelt (2017): "A Posteriori De-aliasing of Ocean Tide Error in Future Double-Pair Satellite Gravity Missions". In: *International Association of Geodesy Symposia*. Springer International Publishing, Switzerland, S. 1–7. doi: 10.1007/1345_2016_259.

Sadegh, M., C. Love, A. Farahmand, A. Mehran, M. J. Tourian und A. AghaKouchak (2017): "Multi-Sensor Remote Sensing of Drought from Space". In: *Remote Sensing of Hydrological Extremes*. Hrsg. von V. Lakshmi. Springer International Publishing, S. 219–247. isbn: 978-3-319-43744-6. doi: 10.1007/978-3-319-43744-6_11.

Tarpanelli, A., A. Domeneghetti, A. Getirana, O. Elmi, M. J. Tourian und S. Barbetta (2017): "The synergistic use of multiple sensors for hydrological purposes". In: *Inland altimetry*. Hrsg. von J. Benveniste, S. Vignudelli und A. G. Kostianoy. Springer-Verlag Berlin Heidelberg. isbn: 978-3-642-22678-6.

Conference Presentations

Cai, J., K. Qian und N. Sneeuw (26.–28. Sep. 2017): Revisiting of the determination of proper regularization parameter: α -Weighted BLE via A-optimal design and its comparison with numerical methods and ridge regression. Geodetic Week, Berlin, Germany.

Cai, J., K. Qian, N. Sneeuw, C. Wang und J. Wang (2. Aug. 2017): The optimal regularization (α -weighted BLE via A-optimal design) and its application in GNSS-based ionospheric tomography. IAG-IASPEI Symposium, Kobe, Japan.

Daras, I., P. Visser, N. Sneeuw, T. van Dam, R. Pail, T. Gruber, Q. Chen, W. Liu, M. J. Tourian, J. Engels, P. Saemian, C. Siemes und R. Haagmans (3. Aug. 2017): Near real-time gravity and its applications in the era of Next Generation Gravity Missions - Insights on the ESA-ADDCON project. IAG-IASPEI Symposium, Kobe, Japan.

Daras, I., P. Visser, N. Sneeuw, T. van Dam, R. Pail, T. Gruber, S. Tabibi, Q. Chen, W. Liu, M. J. Tourian, J. Engels, P. Saemian, C. Siemes und R. Haagmans (20.–24. März 2017): Impact of Orbit Design Choices on the Gravity Field Retrieval of Next Generation Gravity Missions - Insights on the ESA-ADDCON Project. ESA fourth Swarm science meeting, Banff, Alberta, Canada.

Dong, D., J. Cai und N. Sneeuw (26.–28. Sep. 2017): Converted Total Least Squares method and its application in coordinate transformation. Geodetic Week, Berlin, Germany.

- Elmi, O., M. J. Tourian und N. Sneeuw (20.–24. März 2017): Markov Random Field Based Waveform Retracking Solved by the Graph Cuts Technique. ESA CryoSat science meeting und geodetic missions, Banff, Alberta, Canada.
- Gao, Y., J. Cai und N. Sneeuw (26.–28. Sep. 2017): Analysis of coordinate transformation with different polynomial models. Geodetic Week, Berlin, Germany.
- Iran Pour, S., H. Mehrabi, B. D. Vishwakarma, M. Weigelt, A. Amiri-Simkooei und N. Sneeuw (19.–21. Sep. 2017): Land subsidence analysis by InSAR and GRACE time-series for two hydrological basins in West Iran. IAG Workshop SatGeo for Climate Studies, Bonn.
- Iran Pour, S., B. D. Vishwakarma, M. Weigelt, A. Amiri-Simkooei und N. Sneeuw (19.–21. Sep. 2017): Sampling geophysical signals: How the satellite groundtrack pattern can influence the quality of gravity field recovery for climate change studies. IAG Workshop SatGeo for Climate Studies, Bonn.
- Liu, W. und N. Sneeuw (3. Aug. 2017a): Ocean tide alias spectrum estimation for satellite gravity missions. talk. IAG-IASPEI Symposium, Kobe, Japan.
- Pail, R., M. Hauk, A. Purkhauer, P. Visser, N. Sneeuw, T. van Dam, T. Gruber, Q. Chen, W. Liu, M. J. Tourian, J. Engels, P. Saemian, C. Siemes und R. Haagmans (19.–21. Sep. 2017): Studies on next-generation gravity missions for climate-relevant applications. IAG Workshop SatGeo for Climate Studies, Bonn.
- Sneeuw, N. und B. Devaraju (3. Aug. 2017a): Amplitude-phase representation of GRACE spherical harmonic spectra. IAG-IASPEI Symposium, Kobe, Japan.
- Sneeuw, N. und B. Devaraju (2017b): Filtering GRACE gravity fields: anisotropy and other annoyances. Workshop 'Geomathematics Meets Medical Imaging', Speyer.
- Tourian, M. J., J. Reager und Sneeuw, N. (26.–28. Sep. 2017): The total drainable water storage of the Amazon River Basin: a first estimate using GRACE. Geodetic Week, Berlin, Germany.
- Tourian, M. J. und N. Sneeuw (3. Aug. 2017a): Spatio-temporal downscaling of GRACE water storage changes data at catchment scale. IAG-IASPEI Symposium, Kobe, Japan.
- Tourian, M. J. und N. Sneeuw (19.–21. Sep. 2017b): Spatio-temporal downscaling of GRACE water storage changes data at catchment scale. IAG Workshop SatGeo for Climate Studies, Bonn.
- Vishwakarma, B. D., M. Horwath, B. Devaraju, A. Groh und N. Sneeuw (23.–28. Apr. 2017b): Repairing signal damage in GRACE due to filtering: A comprehensive data-driven approach. PICO. EGU, Vienna, Austria.
- Zhang, J., M. J. Tourian und N. Sneeuw (19.–21. Sep. 2017): Can the teleconnection between ENSO and the boreal hydrological cycle be revealed by sea surface temperature anomalies? IAG Workshop SatGeo for Climate Studies, Bonn.

Poster Presentations

Devaraju, B., B. D. Vishwakarma, C. Lorenz und J. Müller (19.–21. Sep. 2017): Evolution of total water storage in Fennoscandia. IAG climate change workshop, Bonn, Germany.

Lin, Y., H. Ji, Q. Ye, J. Cai und N. Sneeuw (26.–28. Sep. 2017): Research on an Optimal ELM Classification Model for Remote Sensing Image with Artificial Fish-swarm Algorithm. Geodetic Week, Berlin, Germany.

Liu, W. und N. Sneeuw (23.–28. Apr. 2017b): Towards ocean tide alias error mitigation of GRACE-derived gravity field time series based on a data-driven method – a simulation study. EGU, Vienna, Austria.

Saemian, P., O. Elmi, B. D. Vishwakarma, M. J. Tourian und N. Sneeuw (19.–21. Sep. 2017): The desiccating Lake Urmia is restoring: A multisensor approach to investigate natural and human-induced reasons for increase of lake volume after 2014. IAG Workshop SatGeo for Climate Studies, Bonn.

Vishwakarma, B. D. und N. Sneeuw (23.–28. Apr. 2017): Comparing the data-driven and the model-dependent strategies for improving filtered GRACE signal. EGU, Vienna, Austria.

Theses

(<http://www.gis.uni-stuttgart.de/research/dissertations/>)

Shirzad Roohi: Performance evaluation of different satellite radar altimetry missions for monitoring inland water bodies

Bramha Dutt Vishwakarma: Understanding and repairing the signal damage due to filtering of mass change estimates from the GRACE satellite mission.

Master Theses

(http://www.gis.uni-stuttgart.de/edu/theses/finished_msc_theses/)

Osborn Agyei: Comparison of altimetric inland water level time series from different publicly available databases.

Zhongyi Chen: Analysing Normal Modes of the Earth from High-rate GNSS Time Series

Siyun Gu: A MATLAB Toolbox for the Scintrex CG-5 Gravimeter at GIS

Yuchen Han: Gravity inversion using point mass distribution

Abolfazl Mohammadnejad Madardi: A Estimation of river discharge from spaceborne observations : assessment of different models.

Bachelor Theses

(http://www.gis.uni-stuttgart.de/edu/theses/finished_bsc_theses/)

Roman Buss: Comparison between gravity gradients from dense CryoSat-2 altimetry and from shipborn gradiometry

Dalu Dong: Study on the converted Total Least Squares method and its application in coordinate transformation

Yueqing Gao: Analysis of coordinate transformation with different polynomial models

Qian Kun: On the determination of proper regularization parameter: α -weighted BLE via A-optimal design and its comparison with the results derived by numerical methods and ridge regression

Dennis Mattes: Estimation of atmospheric signals from daily gravity field solution

Tobias Schröder: Observing the gravitational constant G underneath two pump-storage reservoirs near Vianden (Luxembourg)

Tianshu Wang: Characterization of water storage behavior in boreal catchments

Isabel Wein: Digitalisierung und Bereitstellung von historischen Luftbildern des LGL

Zhuge Xia: Analysis of Helicopter-borne Gravity Gradiometry

Luolan Zhu: Stationarity analysis of runoff time series in Arctic basins

Guest Lectures and Lectures on special occasions

Lectures at other universities

Sneeuw N: Filtering GRACE gravity fields: anisotropy and other annoyances, Workshop "Geomathematics Meets Medical Imaging", Speyer (7.9.)

Sneeuw N: Future satellite gravimetry missions: recent developments as well as algorithmic aspects, Hohai University, School of Earth Sciences and Engineering, Nanjing, China (10.4.)

Sneeuw N: SVD based time series analysis, Summer School "Modern Geodetic Space Techniques for Global Change Monitoring, Yichang, China (24.-28.7.)

Tourian MJ: Satellite altimetry: basics and hydrology, Yichang, China (24.-28.7.)

Tourian MJ: River discharge estimation using satellite altimetry, TU München (6.7)

Tourian MJ: Application of spaceborne geodetic sensors for hydrology, University Oulu, Finland (6.6)

Tourian MJ: Hydro-geodesy: Application of spaceborne geodetic sensors for hydrology, Hohai University, Nanjing, China (7.4)

Activities in National and International Organizations

Grafarend E.

Emeritus Member German Geodetic Commission (DGK)
 Gauss Society, Göttingen
 Member of the "Leibniz Gesellschaft der Wissenschaften", Berlin
 Professor h.c., University of Navarra, Pamplona, Spain
 Professor h.c., University of Tehran, Iran
 Professor h.c., Wuhan University, China
 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
 Fellow International Association of Geodesy (IAG)

Sneeuw N.

Full Member Deutsche Geodätische Kommission (DGK)
 Member of AK7 (working group 7), Experimentelle, Angewandte und Theoretische Geodäsie, within DVW (Gesellschaft für Geodäsie, Geoinformation und LandManagement)
 Member of GGOS working group Committee on Satellite Missions Adjunct Professor of the College of Engineering, University of Tehran, 03.2015–02.2017
 Member Editorial Board of Studia Geophysica et Geodaetica
 Member Editorial Board of Surveys in Geophysics
 Fellow International Association of Geodesy (IAG)

Courses – Lecture/Lab/Seminar

Bachelor Geodesy and Geoinformatics (German):

Amtliches Vermessungswesen und Liegenschaftskataster (Steudle, Grams)	2/0/0/0
Ausgleichsrechnung I, II (Krumm, Elmi, Roth)	3/1/0/0
Einführung Geodäsie und Geoinformatik (Sneeuw)	2/2/0/0
Integriertes Praktikum/Integrated Field Work (Keller, Sneeuw)	10 days
Landesvermessung (Krumm, Antoni)	2/2/0/0
Physikalische Geodäsie (Sneeuw, Engels, Elmi, Tourian)	2/2/0/0

Referenzsysteme (Krumm, Sneeuw, Roth)	2/2/0/0
Satellitengeodäsie (Sneeuw, Tourian)	2/1/0/0
Wertermittlung I, II (Bolenz)	4/0/0/0

Master Geodesy and Geoinformatics (German):

Aktuelle Geodätische Satellitenmissionen (Sneeuw)	2/2/0/0
Amtliche Geoinformation (Heß)	2/0/0/0
Ausgewählte Kapitel der Parameterschätzung (Krumm, Engels)	2/2/0/0
Geodynamische Modelle (Engels)	2/0/0/0
Grundstücksbewertung (Bolenz)	1/0/0/0
Koordinaten- und Zeitsysteme in der Geodäsie (Sneeuw)	2/2/0/0
Physikalische Geodäsie (Engels, Elmi, Tourian)	2/2/0/0
Satellitengeodäsie (Sneeuw, Elmi, Tourian)	2/1/0/0

Master GeoEngine (English):

Advanced Mathematics (Keller, Antoni)	3/2/0/0
Foundations of Satellite Geodesy (Keller)	2/1/0/0
Integriertes Praktikum/Integrated Field Work (Keller, Sneeuw)	10 days
Map Projections and Geodetic Coordinate Systems (Krumm, Roth, Antoni)	2/1/0/0
Physikalische Geodäsie (Sneeuw, Elmi, Tourian)	2/2/0/0
Satellite Geodesy Observation Techniques (Keller, Tourian)	2/1/0/0
Statistical Inference (Krumm, Roth)	2/1/0/0

Bachelor and Master Aerospace Engineering (German):

Koordinaten- und Zeitsysteme in der Geodäsie (Sneeuw)	2/2/0/0
Erderkundung (Sneeuw)	2/2/0/0

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Dipl.-Ing. Bernhardt Schäfer	Navigation Systems
Dipl.-Ing. (FH) Martin Thomas	Laser Systems
Dr.-Ing. Aloysius Wehr	Laser Systems

EDP and Networking

Regine Schlothan

Laboratory and Technical Shop (ZLW)

Dr.-Ing. Aloysius Wehr (Head of ZLW)
 Technician Peter Selig-Eder
 Electrician Sebastian Schneider
 Mechanician Master Michael Pfeiffer

External teaching staff

Hon. Prof. Dr.-rer.nat. Volker Liebig - Directorate ESA
 Hon. Prof. Dr.-Ing. Hans Martin Braun - RST Raumfahrt Systemtechnik AG, St.Gallen
 Dr. Werner Enderle - Europäisches Satelliten Kontrollzentrum (ESOC), Darmstadt

Research Projects

Assembly, Soldering and Test of OPS-SAT Optical Communication PCBs

OPS-SAT is an ESA project and is a synonym for a laboratory in low earth orbit which will test and validate new techniques in mission control and on-board systems. OPS-SAT has been developed with the objective to be very flexible, to offer high performance and safety at low cost. Therefore, it was decided to develop OPS-SAT on the standards applied and approved of the well-known cubesats. This means, the used printed circuit boards (PCBs) have very limited dimensions in size and are assembled with off-the-shelf electronic components. OPS-SAT have been designed so that it can be used as a test-bed for on-board software applications, for advanced communication protocols, for compression techniques, for the demonstration of advanced software-defined radio (SDR) concepts, for the optical communication from ground to space and for various experiments with special hardware like cameras and attitude control systems and for procedures with regard for scheduling and autonomy.

In the course of this project the INS first demonstrated that it has got the proficiency in assembling and soldering the PCBs of the optical communication experiment of OPS-SAT and second to verify the functioning of critical components on the PCBs. A key item is a memory chip, which has got very small dimensions. In the OPS-SAT testbed environment the data communication of this chip is carried out via a bus interface linked with ARM dual-core Cortex-A9 MPCore. As INS did not have available the test environment of OPS-SAT, a special test bed (s. Figure 1) on basis of an ARDUINO and special test software in ARDUINO-C were realized. Applying these hard- and software it was possible to evaluate the performance of the component on the PCB and identify improvements concerning the PCB's layout.

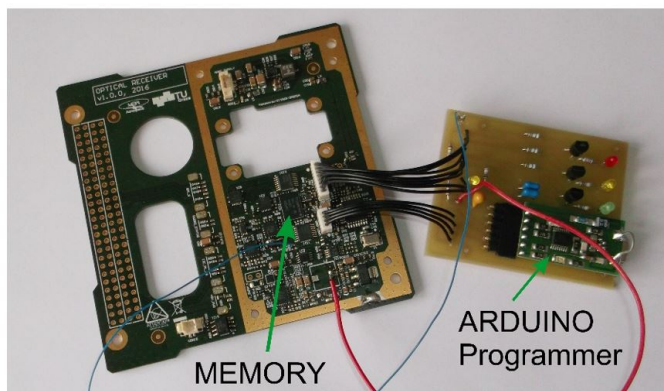


Figure 1: OPS-SAT Memory Test Bed.

The optical free space communication link of OPS-SAT will be coded by a pulse position modulation scheme (PPM) with 8 bit coding. To study and verify the software tools, which will be later implemented in the SDR, the INS developed and realized a test environment for this purpose on the basis on an ARDUINO. The transmitter comprises an ARDUINO extended with a special Arduino shield equipped with an ALTERA PGA (s. Figure 2) to make fast and robust communication possible. The receiver simulator uses an ARDUINO.

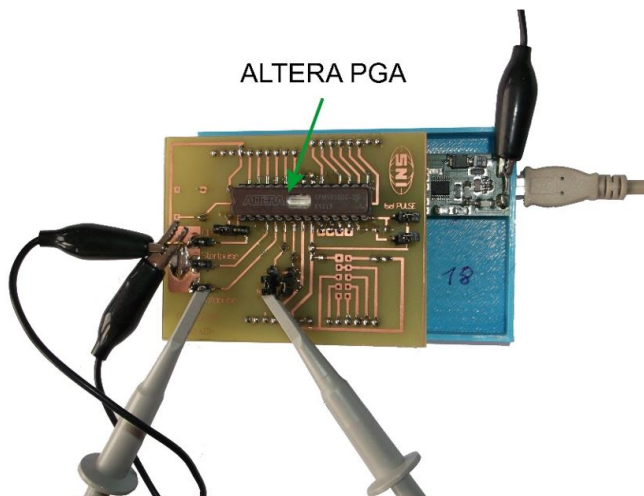


Figure 2: Coding Testbed (ARDUINO with ARDUINO Shield).

Modelling and Mapping Air Concentration and Atmospheric Deposition of Reactive Nitrogen Species in Baden-Württemberg for 2012 to 2016

The research project "Nitrogen background air concentration and atmospheric deposition Baden-Württemberg 2018 - Part 1: Regional scale modelling", funded by Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW) has been launched at the end of 2016.

A project consortium is set up for carrying out the joint research. It is consisting of EURAD group of Rhenish Institute for Environmental Research at the University of Cologne (RIU), Interra, Büro für Umweltmonitoring, Kenzingen, Meteotest, Berne (CH), and INS as project leader. Beyond that consortium close co-operation is arranged with LUBW, Karlsruhe, FVA-BW, Freiburg, Ingenieurbüro Lohmeyer, Radebeul, and TNO, Utrecht (NL).

Different modelling approaches, i.e. the chemical transport model (CTM) EURAD, and the GIS based Inferential Model PolluMap, INS geostatistical models, Interra regression models, respectively, are combined in order to derive high spatial resolution maps (1 ha grid) of air

concentration and atmospheric deposition of reactive nitrogen species. The model combination is outlined in Figure 3. Oxidised nitrogen (emitted NO_x and deposited NO_y , right side of Fig. 3) and reduced nitrogen (emitted NH_3 and deposited NH_x , left side of Figure 3) are modelled separately, due to different emission sources, different lifetime and in-atmosphere reaction with production of secondary nitrogen species with different behaviour.

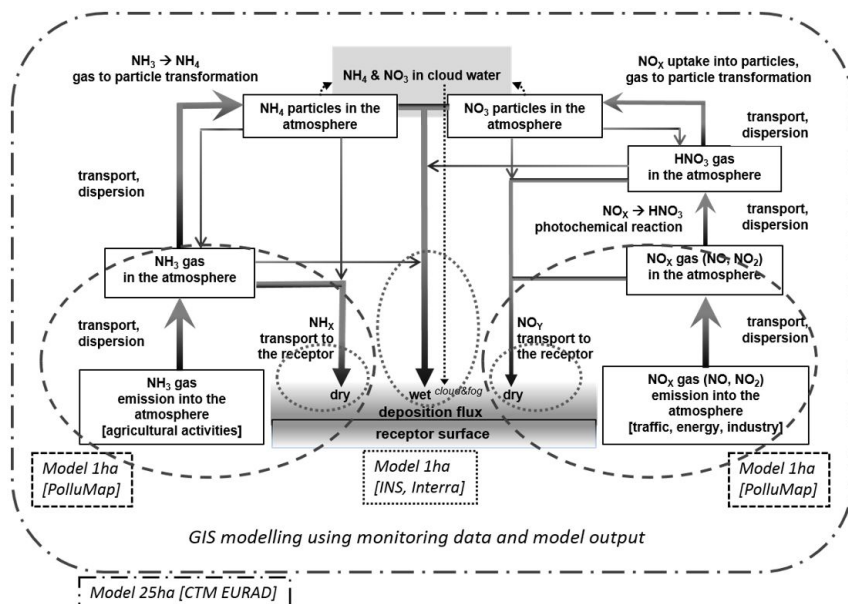


Figure 3: Air concentration and total deposition of reactive nitrogen in Baden-Württemberg is modelled using (CTM) EURAD (25ha grid resolution output), the Inferential model PolluMap, and GIS based geostatistical modelling by INS, and regression modelling by Interra, respectively (1ha grid resolution output). [Figure adopted from Hertel (2009); modified]

The whole atmospheric pathways of reactive nitrogen (N_r) from emission over transport and dispersion, including in-air physico-chemical reaction and transformation, leading to spatially differentiated ambient air concentration and wet and dry deposition fluxes onto the exposed receptor surfaces (i.e. buildings, vegetation, water, etc.) is differentially modelled using the CTM EURAD. The model calculations are carried out in hourly time steps. Four different spatial scales ranging from continental Europe down to a 25 ha grid resolution for Baden-Württemberg are successively modelled using nesting technique (Fig. 4 (1) to (4)). Emission input data, meteorological data, and land use data used, the latter depicting the receptor surface location at the ground, are provided in the respective spatial scale and resolution each.

The ecosystem level 1 ha grid is the highest model output resolution for concentration and deposition fluxes of reactive nitrogen (N_r) species, that is achieved by GIS implemented modelling. Where ever possible the use of measurement data is integrated into the modelling approach, in order to avoid contradictions between reliable monitoring data and modelling results.

The Inferential Model PolluMap (Meteotest, Berne) is modelling air concentration and dry deposition using 1 ha cadastral emission data, meteorological data, and very high resolution land use (cf. Fig. 4 (5)) along with CTM EURAD output data and point monitoring data of N_r on an annual base.

Wet deposition, which describes the N_r input with precipitation, and cloud&fog deposition, where cloud droplets containing N_r are directly deposited onto exposed surfaces, and dry deposition on forest are calculated using GIS procedures, mainly geostatistical modelling, carried out by INS based on an annual monitoring point data and modelled very high resolution fields (e.g. 1 ha precipitation, liquid water content data and land use, cf. Fig. 4 (5)). Moreover, GIS based regression modelling is applied in order to derive highest (≤ 1 ha) resolution precipitation data, N_r wet deposition and N_r dry deposition estimates for forest areas in Baden-Württemberg (Interra).

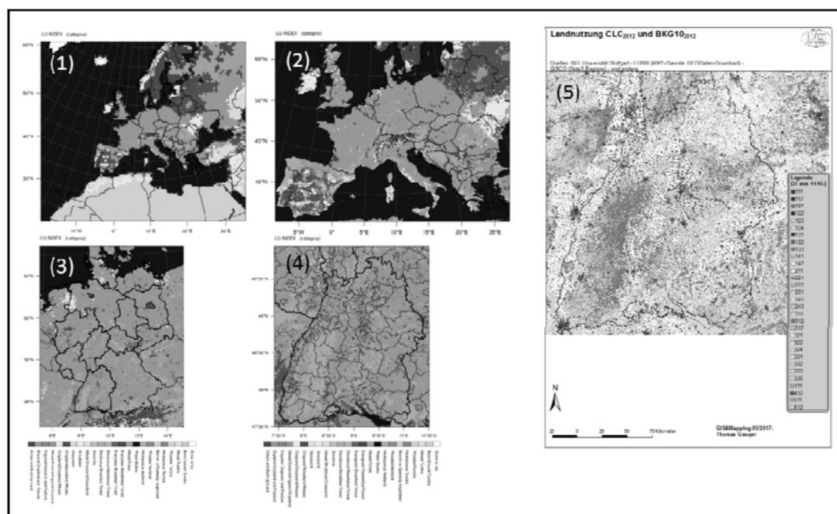


Figure 4: Illustration of 5 different spatial scales for modelling and mapping air concentration and deposition of reactive nitrogen in Baden-Württemberg. (1) to (4) are land cover data of the 4 nesting levels used by CTM EURAD (Continental Europe in 3900 km², Central Europe in 156 km², Germany in 2.5 km² and Baden-Württemberg in 25 ha grid resolution, resp.); (5) shows the Baden-Württemberg 1 ha target grid resolution achieved by final modelling using PolluMap and GIS application.

The project is part of StickstoffBW, an initiative of the federate state of Baden-Württemberg, elaborating basic information and data for regional politics and administrative execution with respect of ecological relevant nitrogen input. Project results are supporting EU and national regulations on air pollution control and emission abatement (EU NEC directive, BImSchG, TA-Luft), which are to be implemented on the sub-national level of the federate states of Germany. Moreover, scientific interest is supported by these data, e.g. when setting up flux assessment studies within ecosystems, ecological impact assessment, biodiversity, and nature protection. Administrative applications aiming at emission control and reduction of air pollutants are using the reactive nitrogen deposition data with reference to permission of projected animal husbandry, road construction, industrial settlements, and power plants, respectively. Hence the project results of nitrogen deposition are designated for public use and will be made accessible via the internet (see <http://www.fachdokumente.lubw.baden-wuerttemberg.de/servlet/is/91063/>).

Publications and Presentations

GAUGER, THOMAS: Reaktiver Stickstoff in der Atmosphäre von Baden-Württemberg. Interimskarten der Ammoniakkonzentration und der Stickstoffdeposition (Depositionsbericht 2017). Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg [Hrsg.]. AG1 Stickstoffdeposition in Zusammenarbeit mit Forschungseinrichtungen in Bern (Schweiz), Dresden, Freiburg, Köln, Stuttgart und Utrecht (Niederlande). ID Umweltbeobachtung U46-S7-J16. LUBW, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg, Karlsruhe. 2017.

Bachelor Thesis

Performance Analyse des Galileo Initial Service (SO) mit einem low-cost Empfänger (Becker).

Analyse und Visualisierung von Multi-GNSS (Becker).

Langzeitdatenanalyse einer GNSS-Referenzstation mit Schwerpunkt Signalverfügbarkeit und -qualität (Becker).

Master Thesis

Design of Steering Software for a GNSS Simulator Including Variations of the Simulated Ranges (Becker).

Height Estimation by Combining Pressure Observation Data with Inertial Navigation - Pixel based Classification of Multi-Temporal TerraSAR-X Data in Eastern Part of Kraichgau Region (Schäfer)

Untersuchung von Lagefiltern für inertielle Messeinheiten bei verschiedenen Anwendungsmodellen (Becker).

GNSS Processing with Dual-Frequency Pseudo Range Observations (Becker).

Study Thesis

Untersuchung der Orientierungsbestimmung einer Inertialmesseinheit mit Magnetfeldsensor am Beispiel BST BNO055 (Schäfer).

Activities in National and International Organizations

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

Education (Lecture / Practice / Training / Seminar)

Introduction of Geodesy and Geoinformatic (BSc) (Kleusberg, Schäfer)	2/2/0/0
Electronics and Electrical Engineering (Wehr)	2/1/0/0
Satellite Measurement Engineering (Wehr)	2/1/0/0
Parameter Estimation in Dynamic Systems (Kleusberg)	2/1/0/0
Navigation I (Kleusberg)	2/2/0/0
Inertial Navigation (Kleusberg, Schäfer)	2/2/0/0
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
Dynamic System Estimation (Kleusberg, Schäfer)	2/1/0/0
Integrated Positioning and Navigation (Kleusberg, Schäfer)	2/1/0/0
Satellite Navigation (Kleusberg)	2/1/0/0
Interplanetary Trajectories (Becker)	1/1/0/0
Geodetic Seminar I, II (Fritsch, Sneeuw, Keller, Kleusberg, Möhlenbrink)	0/0/0/4
Integrated Fieldwork (Schäfer)	(SS 2017)

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Prof. Dr.-Ing. Dieter Fritsch

Academic Staff

Dr.-Ing. Susanne Becker (until 8/2017)

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Dipl.-Ing. Patrick Tutzauer

Dr.-Ing. Volker Walter

MSc. Chia-Hsiang Yang

Hybrid GIS

Photogrammetric Calibration

Photogrammetric Systems

Laboratory, Computing Facilities

Photogrammetric Computer Vision

Classification in Remote Sensing

Laser Bathymetry

Modelling of Building Interiors

Facade Interpretation

Geoinformatics

Persistent Scatterer Interferometry

Stipendiaries and external PhD Students

MSc. Stefan Cavegn

MSc. Ke Gong

Dipl.-Ing. Wolfgang Groß

Dipl.-Phys. Hendrik Schilling

MSc. Mehrdad Nekouei Sharaki

Image-based Mobile Mapping

3D Reconstruction

Transformation of Hyperspectral Data

Classification of Hyperspectral Data

Photogrammetric Image Processing

Guests

MSc. Mateusz Karpina
 MSc. Rodolfo Lotte
 MSc. Jinghui Wang

Interpretation of 3D point clouds
 Image Processing
 Surface Motion Estimation

External Teaching Staff

Dipl.-Ing. Stefan Dvorak, Amt für Stadtentwicklung und Vermessung, Reutlingen

Research Activities in ifp organized in four thematic Groups

Geoinformatics
 Photogrammetric Computer Vision
 Photogrammetric Systems
 Remote Sensing

Dr.-Ing. Volker Walter
 apl. Prof. Dr.-Ing. Norbert Haala
 Dr.-Ing. Michael Cramer
 Prof. Dr.-Ing. Uwe Sörgel

Research Projects

Indoor change detection

A large variety of systems for mapping and interpretation of outdoor environments can process automatically updated 3D models. However, there is still ongoing research on processing similar models for indoor space. A challenging problem in the field of Building Information Modelling (BIM) is to maintain up-to-date models. Even though, not for every building a BIM model is available, for some of them older laser scanner point clouds are available which can be used as a reference for the comparison with a current model.

As a first step in automatic detecting of indoor changes, we used an indoor terrestrial laser scanner (TLS) point cloud composed of 31 individual scans. The available scans were saved in an octree structure. Considering the scanner positions, it was possible to use a ray-tracing algorithm in order to differentiate between three different states. Each octree cell is considered to be occupied if there are points inside. The cell is assigned as free if at least one ray is passing through it, or the state is considered to be unknown. Using this structure, it can be further investigated if the model is corresponding with a previous available model. Also the situation can be studied, when further changes occur and we are aware of them and of their approximate location. In this case, a low cost device with a range sensor (like Google Tango) could be used to monitor the changes. The octree structure will allow an update of the corresponding part of the model, by simply changing the state of the corresponding voxels.

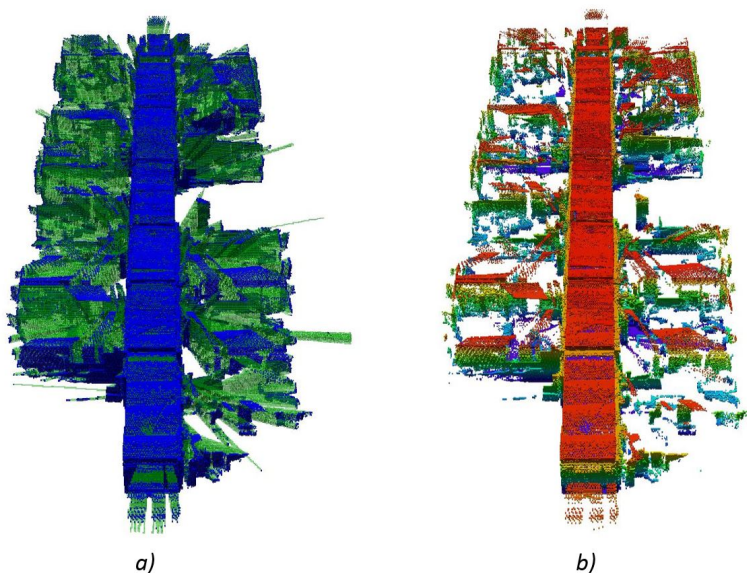


Figure 1: Occupancy map visualized with octovis: a) blue: occupied, green: free, transparent: unknown octree volumes; b) height map (color coded) (A. Hornung, K.M. Wurm, M. Bennewitz, C. Stachniss, and W. Burgard, „OctoMap: An Efficient Probabilistic 3D Mapping Framework Based on Octrees“ in *Autonomous Robots*, 2013)

Deep Learning based interpretation of publicly available facade imagery and perceptual rules for building enhancements

Enrichment of urban building models with semantics is an active research question in the field of geoinformation and geovisualization. Semantic information is not only valuable for applications like Building Information Modeling (BIM) but also offers possibilities to enhance visual insight for humans when interacting with such data. Presenting users the highest level of detail of building models is often neither the most informative nor feasible way - for instance, when using mobile apps, resources and display sizes are quite limited. A concrete use case is the imparting of building use types in urban scenes to users. In the first part of our work, we first try to determine use types of buildings by means of a Deep Learning approach. Once building categories are determined, the second part of our work focuses on embedding this knowledge into building category-specific grammars to modify automatically the geometry of a building to align its visual appearance to its underlying use type.

Deep Learning based interpretation of publicly available facade imagery

In order to enrich 3D urban models autonomously, we train Convolutional Neural Networks (CNNs) for classifying street-view images of building facades into five different use classes. The classes „commercial“ and „residential“ represent a singular use of a building, while the class „hybrid“ represents a mixture of these two use classes. The class „specialUse“ represents the remaining buildings not matching the other three classes, like e.g. schools and churches. Finally, the class „underConstruction“ contains buildings being under construction independently on their actual use.

CNNs are a data-driven end-to-end approach. Hence, there is no need for human-crafted features. Instead, the network learns decisive features during the training process. For this learning, a huge amount of labeled data (training set) has to be provided. I.e. for every street-level image of the training set, the ground truth class is known.

In our case, the ground truth data consists of the digital city base map provided by the City Survey Office Stuttgart linked with the respective street level images based on positions and headings as provided by the Street View API.

After training, the network can be applied to any previously unseen image. The network will output a probability density function over the five classes. As it is an end-to-end approach (i.e. a black box), humans cannot understand how CNNs classify the way they do.

With the help of so-called Class Activation Maps (CAMs) learned features can be localized and interpreted within input images. CAMs are heat maps that highlight image sections, which are decisive for the respective labeling. Thereof, a human operator can derive learned features, which are useful for understanding the networks decisions. Figure 2 shows correctly classified images and misclassified images overlaid by the associated CAMs, which highlight decisive image parts.

Another application of CAMs is their use as importance maps for non-photorealistic renderings. This process should maintain a high level of detail for important regions, while less important ones are abstracted. Thus, a CAM-based abstraction using the provided importance maps can help to focus a human viewer's attention to important regions for the visual discrimination of building categories. This abstract rendering is based on stippling, which is frequently used in architecture for sketching and illustration purposes. For matching the tone and texture of an image, visually similar point sets are created: in dark areas, many points are used and, conversely, only few points are used in bright regions. An increasing degree of abstraction is achieved by reducing the amount of points in the less important regions (provided by CAMs) while increasing the point size. In this way, smaller details are removed progressively. Figure 3 depicts a stippled result created without the usage of the corresponding CAM and the focus with a constant point size and no brightening (left) versus results created with our pipeline (right). The area in focus (bright regions in the grayscale CAM in the middle) is clearly distinguishable from the rest in our result.

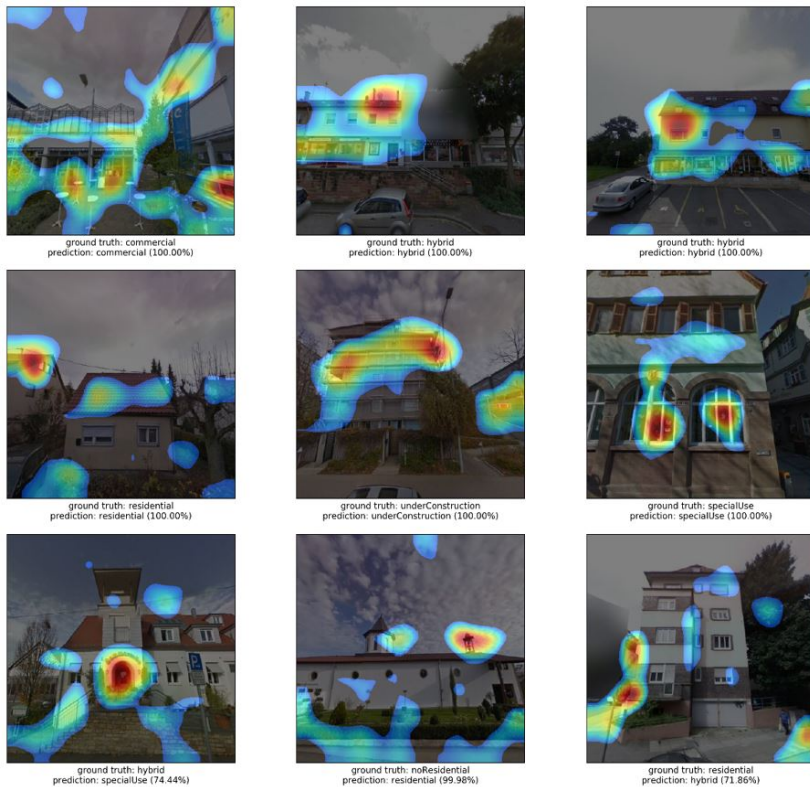


Figure 2: First two rows: Correct classifications of a CNN with overlaid CAMs. Bottom row: Misclassifications.

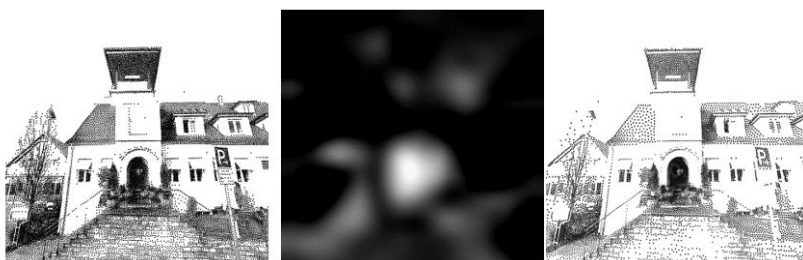


Figure 3: Created stipple drawings without (left) and with (right) usage of the grayscale CAM (center) to focus the user's attention. Focus in this example is on the door area.

Perceptual rules for building enhancements

Every building has a set of properties that refer to a certain use type. To generate virtual representations of buildings which are easily understandable for humans, we need to refine or abstract (in general - adapt) those buildings in a certain manner. Thus, specific rule sets were designed for each building category. These rule sets incorporate geometric and semantic constraints we extracted from our previous user studies by relating the features of ground truth buildings with as-perceived classifications by users - as an example - add balconies to a Residential Tower if they are not existent. We use those rules either to generate use-type specific buildings from scratch or to adapt existing ones. For the latter it is important to maintain the key characteristics of a building - therefore, we feed essential building elements of a previously parsed CityGML model into the modelling process. Figure 4 shows the application of building category-specific rules to a coarse building model. If a building category is not known beforehand or not inferable the way discussed in the previous section, we can use the parsed CityGML model to derive essential building features (such as building footprint, number of floors, floor height, ...). Mapping the model into building feature space and performing a nearest neighbor search returns the most probable building category. The class centers in feature space are mean buildings for each category that we computed based on data from previous user tests.

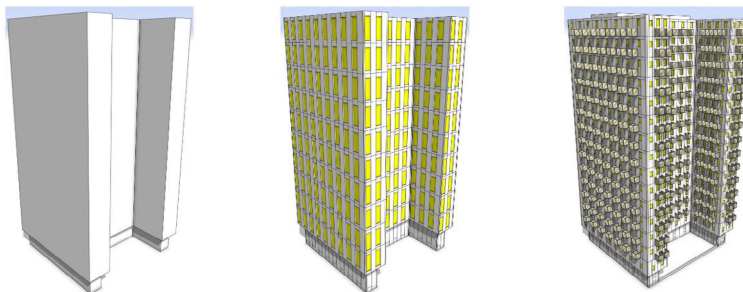


Figure 4: From left to right: Coarse model of a building tower; enhanced building with generic Office Building rules; enhanced building with generic Residential Tower rules.

Robust and accurate image-based georeferencing exploiting relative orientation constraints

Image-based mobile mapping systems featuring multi-view stereo camera configurations enable efficient data acquisition, for both outdoor and indoor environments. In order to obtain accurate geospatial 3D image spaces consisting of collections of georeferenced multi-view RGB-D imagery, which can be exploited for 3D mono-plotting applications as well as for 3D point cloud and mesh generation, depth maps of high quality need to be computed. These depth maps are preferably generated by performing multi-view stereo matching

using imagery captured at different epochs. In order to efficiently apply coplanarity constraints during dense stereo matching, sub-pixel accurate relative orientations of the image sequences are required. Since we rely on revealed trajectory discontinuities from direct georeferencing of up to 15 cm in urban environments, this can only be achieved by image-based georeferencing. This allows the elimination of trajectory offsets in the range of several decimeters leading to consistent image sequences, which might be captured at different days and daytimes.

In order to perform an integrated georeferencing, we extended the powerful incremental structure-from-motion (SfM) tool COLMAP, thus assuming initial values for exterior orientation parameters (EOP) from direct sensor orientation or SLAM (see Figure 5). First, we extract SIFT features in outdoor and DSP-SIFT in indoor environments with poor texture. Since we rely on prior EOP, we use the spatial feature matcher implemented in COLMAP, which only considers camera positions closer than a given maximum radius from the current image for search space reduction. Moreover, we added a maximum angle constraint in order to further speed up the process as feature matching is the most time consuming step in the COLMAP procedure. Feature extraction and matching is followed by geometric verification, resulting in a scene graph that serves as the foundation for the reconstruction stage.

Second, we triangulate 2D image features to natural 3D points incorporating all available images based on prior EOP, followed by bundle adjustment using Google's Ceres Solver library. Our bundle adjustment procedure not only minimizes the reprojection errors between the projected natural 3D points as well as ground control points (GCP) and its corresponding 2D measurements in image space, but it also minimizes differences of 3D projection center coordinates from direct georeferencing and photogrammetric reconstruction. Moreover, we constrain calibrated relative orientation parameters (ROP) or define constraints for ROP among cameras in bundle adjustment. Subsequently, COLMAP completes 3D point tracks, merges 3D points that are very close to each other, filters and re-triangulates observations before performing a new bundle adjustment computation. This iterative process is continued until convergence is reached.

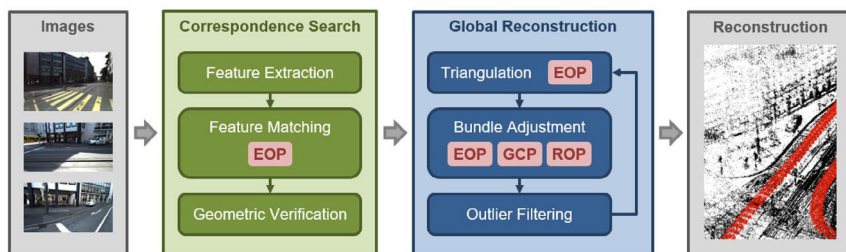


Figure 5: Adapted processing pipeline of COLMAP based on prior exterior orientation parameters and a limited number of ground control points as well as exploiting constraints for relative orientation parameters among all cameras.

We evaluated our integrated georeferencing approach on two data sets, one captured outdoors in Basel by a vehicle-based multi-stereo mobile mapping system and the other captured indoors in MuttENZ close to Basel by a portable panoramic mobile mapping system (see Figure 6). We obtained mean RMSE values for check point residuals between image-based georeferencing and tachymetry of 2 cm in an indoor area, and 3 cm in an urban environment where the measurement distances are a multiple compared to indoors. Moreover, in comparison to a solely image-based procedure, our integrated georeferencing approach showed a consistent accuracy increase by a factor of 2-3 at our outdoor test site. Due to pre-calibrated relative orientation parameters, images of all camera heads were oriented correctly in our indoor environment, even though they hardly overlap as well as they mainly contain homogenous surfaces or repetitive patterns. By performing self-calibration of relative orientation parameters among respective cameras of our vehicle-based mobile mapping system, remaining inaccuracies from suboptimal test field calibration were successfully compensated.

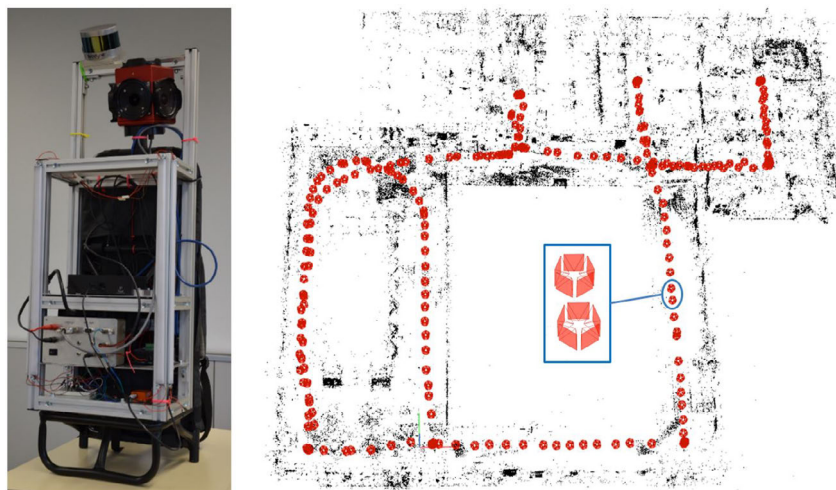


Figure 6: Sensor configuration of the portable mobile mapping system of the Institute of Geomatics (IGEO), University of Applied Sciences and Arts Northwestern Switzerland (FHNW) (left) as well as georeferenced mobile mapping images (red) and 3D tie points (black) at our indoor test site using our modified COLMAP processing pipeline (right).

On the potential of low-cost UAV camera systems

In former photogrammetry much effort was spent into the development of highly precise and stable camera systems, which are known since decades. Similar concepts have also been applied, when analog imaging moved into digital. With the advent of unmanned aircraft vehicles (UAV) this concept changed, mostly due to the limited maximum take-off-mass

(MTOM) of those systems. Typically an MTOM within 10kg should not be exceeded. This in a way prevents the use of stable, but also heavier and bulkier systems. This is, why regular consumer grade cameras are used quite often. Alternatively, manufactures combine their UAV-platform with proprietary cameras, which are often optimized for taking video sequences. Still, such commercial and quite low-cost UAVs increasingly are used for photogrammetric surveys. As an example the dji products of the Phantom or Inspire series could be mentioned, which have been established to map 3D structures of limited size. The wide distribution of such platforms is due to their easy use and attractive price. Many users, like engineering offices, who now have extended their terrestrial survey portfolio by UAV-based mapping, have invested in dji UAVs. As the classical photogrammetry has its clear focus on the precise geometric modelling of 3D objects, the geometric calibration and stability is one important part of the process flow. From this point of view, almost all UAV camera systems belong to the group of „partially metric cameras“ since the sensor matrix realizes a defined image coordinate system and the distortion parameters of the interior orientation can be assumed to be largely constant, while focal length and principal point position represent variable elements. From this, the necessity for camera calibration is obvious, which most often is carried out simultaneously within the bundle block adjustment of project data itself - this is called self- / or in-situ calibration, allowing the optimal estimation of camera calibration as part of the project itself. In order to analyze the potential of low cost UAV cameras, extensive tests have been made to estimate their geometric stability and performance. In order to have reproducible results most of these tests have been made in controlled laboratory environments. Figure 7 shows the 3D test field for geometrically camera calibration in the photogrammetric lab at the Institute for Photogrammetry (ifp). Such test site allows for the precise estimation of geometric camera calibration parameters. If such (geometric) calibrations is done several time, where the individual calibration runs are spread over a longer period of time, the geometrical stability of the camera system can also be evaluated. As it can be seen from Figure 7, additional Siemens star targets are distributed in addition to the coded targets. Such resolution targets are used to derive the true physical resolution of the sensor, which serves as an additional quality parameter of the camera system.

Figure 8 now depicts the change of the principal point coordinates of different camera models. The three dji systems Phantom 4, Phantom 4pro, MAVIC are compared against the Nikon D800 DSLR with 35mm lens as the reference system. As you can see, the results from multiple calibration runs are illustrated. These tests have been made on several days, sometimes the systems additionally have been warmed up or cooled down to simulate different environmental conditions. In addition the calibrations have been done using the original camera raw images (converted to TIF) and the JPG images, as provided by the camera directly. Every graph shows a 4 x 6 pixel wide area, except for the MAVIC system. Here the variations in the principal point are much larger. Thus a 12 x 9 pixel wide area is depicted here.

It is surprising to see, that the Phantom 4 camera shows the smallest variations within the different calibration runs. Except one measurement, where the principal point coordinates are little more far away, all other results are within one large cluster, which clearly indicates a quite stable camera configuration. The reason for this is the stable concept of the Phantom 4



Figure 7: 3D test site for geometrical camera calibration in the ifp measurement lab. In addition to the coded target, several Siemens stars are distributed in the test field to estimate the physical resolution of the sensor system.

camera, with fix mounted and focused lens, which is close to the classic concept of metric cameras. Then the D800 shows the most stable behavior followed by the Phantom 4pro camera. As already mentioned, the MAVIC performs worse. As it can be seen from the parallel use of RAW (converted into TIF) and JPG image formats, the selection of image formats also influences the results from calibration. In Figure 8 the estimated position of principal point differs depending on the use of RAW (blue) or JPG (red) image format. Obviously it is not only the (physical) image format which changes, internally the camera adds other corrections, when converting into JPG. This is also illustrated in Figure 9, where the estimated lens distortion is shown for the Phantom 4 and Phantom 4pro camera. Again the results from using the RAW (converted to TIF) data are compared to the JPG images. It is quite obvious, that not only the image is converted to another data format, an additional a priori distortion correction is also applied, when changing formats their internal RAW to JPG. When this pre-corrected image is not fulfilling the model of central perspective, this will influence the quality of later calibrations. Thus, the use of uncompressed RAW image data is of advantage and should be recommended. Unfortunately most of the cameras need more time for the capturing of RAW image formats, which in a way limits the flights especially when high forward overlap is required and the flight speed cannot be decreased accordingly.

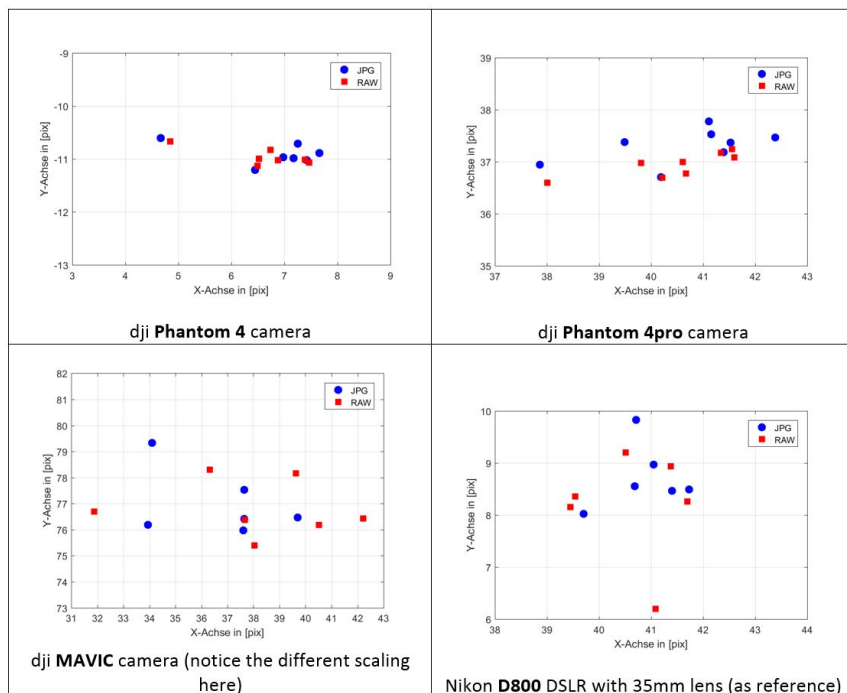


Figure 8: Estimated principal point coordinates from several different calibration runs. Each point depicts one estimated principal point coordinate. The changes in stability are projected into the change of coordinates. Additionally the calibration differences using different image formats are visible.

The a priori lab calibration of (UAV-based) camera systems in general is not necessary, as later empirical flights have been shown, that on-site camera parameters quite differ from the geometrical lab calibration. The calibration of the camera with the methods of in-situ or self-calibration is sufficient but only works if the block has sufficiently good block geometry. As a rule, all blocks with overlapping parallel flight lines or 360° circular image blocks with a large image overlap (the latter can be realized through copter flights) should fulfill these prerequisites. Possibly it is helpful not to start in-situ calibration from zero values, but to use the previous calibration as an approximation. Especially the distortion of the camera system changes little.

If unconventional block geometry (for example, individual flight lines for corridor applications) is present, a best pre-calibrated camera must be requested. Ideally, this camera is calibrated in a close temporal and spatial context nearby the mission area (i.e. by using a test area) and these parameters are then adopted. For such applications, cameras with the

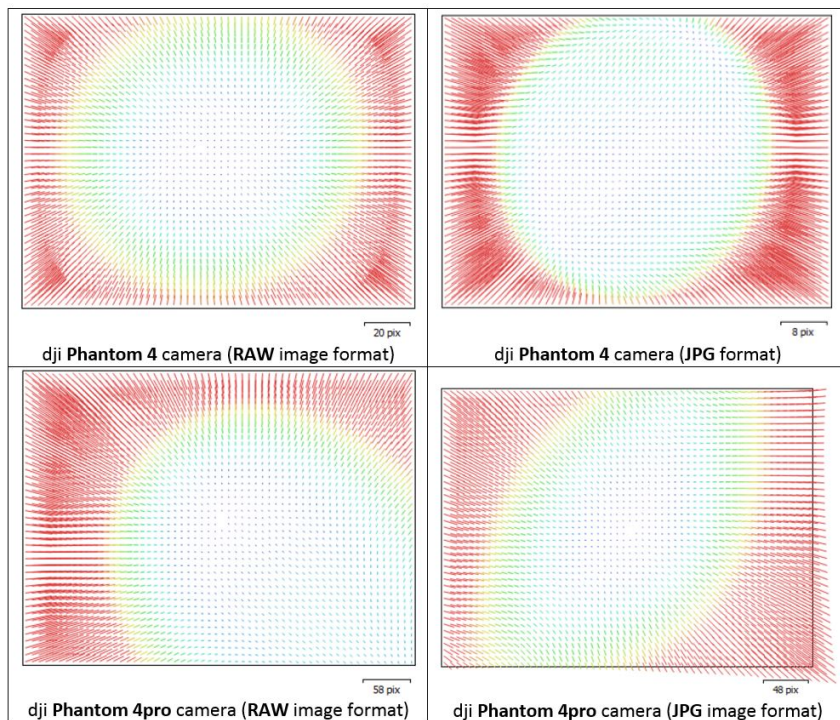


Figure 9: Estimated distortions using RAW and JPG image format. The distortions from JPG images are different to the RAW images. This clearly indicates, that a priori distortion correction is done in the camera when the JPG format is generated.

most stable camera geometry are preferred. In some circumstances, proprietary cameras, with fixed optics and fixed focus can be advantageous; alternatively specially developed (metric) cameras should be considered for these applications.

3D UAV flight planning for building reconstruction

Photogrammetric data capture of complex 3D objects using UAV imagery has become commonplace. Software tools based on algorithms like Structure-from-Motion and multi-view stereo image matching enable the fully automatic generation of densely meshed 3D point clouds. In contrast, the planning and execution of a suitable image network usually requires considerable effort of a human expert, since this steps directly influences the precision and completeness of the resulting point cloud. Planning of suitable camera stations can be rather complex, in particular for objects like buildings, bridges and monuments, which frequently

feature strong depth variations to be acquired by high resolution images at a short distance. We developed an automatic flight mission-planning tool, which generates flight lines while aiming at camera configurations, which maintain a roughly constant object distance, provide sufficient image overlap and avoid unnecessary stations. Planning is based on a coarse Digital Surface Model and an approximate building outline. As a proof of concept, we use the tool within our research project MoVEQuaD, which aims at the reconstruction of building geometry at sub-centimeter accuracy. The project is funded by the Federal Ministry of Economic Affairs and Energy and is furthermore partnered by the Geodetic Institute of the University of Hannover and Geo-Office-GmbH.

A georeferenced 2.5D DSM, along with a 2D polygon describing the building contours, serve as main data input (Figure 10). We generate a volumetric occupancy map of the environment of the building, which classifies voxels of user-defined size into the classes: free space, object of interest, and obstacle (Figure 11). Optionally, an additional set of polygons may be used during map generation to define no-trespass areas. This option allows compensating for unreliably reconstructed areas in the DSM, e.g. poles, lanterns, vegetation, etc.

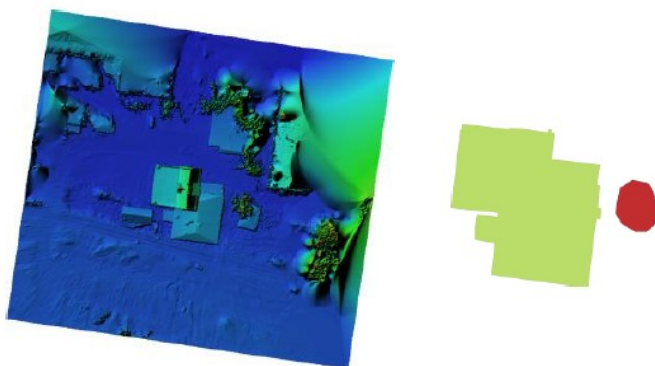


Figure 10: A DSM (left) and a polygon representing the building contour (green) is the main data input for mission planning. A single polygon (red) masks an imprecisely reconstructed tree close to the building.

Given a certain camera geometry, the camera should be positioned on the isosurface derived from „distance to object“ at value corresponding to the desired GSD. The viewing direction can be derived from the corresponding gradient. Intersection between the isosurfaces derived from „distance to occupied space“ and a safety distance removes unpassable parts. To ease these steps and the following ones, we perform these computations on z-layers of the volume, which correspond to fixed flight heights. The result is a set of trajectories for each flight height. Simple linking maneuvers connect these trajectories to a single mission (Figure 12).

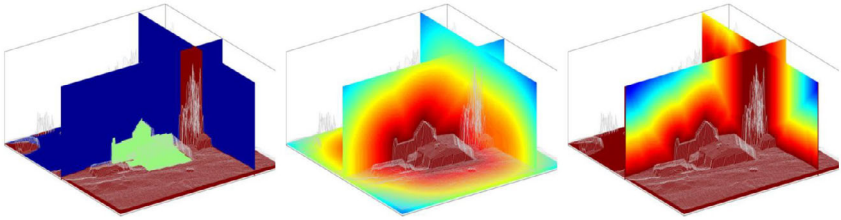


Figure 11: The volumetric map on the left segments space into the classes „object of interest“ (green), „obstacle“ (red) and „free space“ (blue). No-trespass areas create vertical obstacle areas. This map is combined with a three-dimensional scalar field, which holds distances to the object of interest (center). The result is a scalar field representing the distances to occupied space (right). It is used for obstacle avoidance during mission planning.

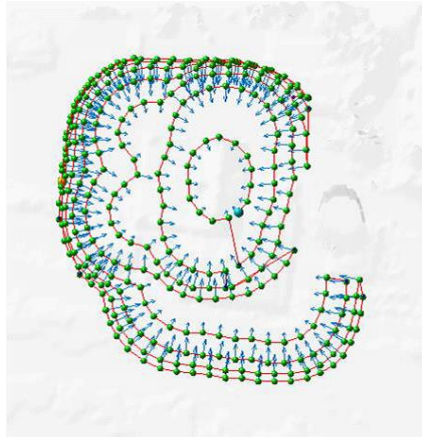


Figure 12: Top view of a flight plan. Green spheres with blue arrows indicate camera stations and corresponding camera alignment.

We developed a custom smartphone app to satisfy the particular needs of this project, which are primarily: assembling a flight mission, readable by the UAVs firmware, from given waypoints and viewpoints of the flight plan, transferring it to an UAV and controlling the execution. Other solutions available on the market have been lacking certain features; many apps are designed solely for nadir flights.

The system was tested on-site with a low-cost quadcopter (DJI Phantom 4 Pro). The resulting image distribution is homogeneous and covers the structures completely, while being well aligned towards the surfaces (Figure 14). Further, the number of captured images was reduced by more than 30% compared to a manual flight with time interval triggering. A comparison of time efficiency, however, is difficult, as the planned images were acquired

on a rather windy day. Neglecting interruptions, the average time interval between images is 4.9s in comparison to 2.9s for the manual flight. Extrapolation to the image number results in $\approx 43\text{min}$ compared to $\approx 38\text{min}$. De facto, a few interruptions are necessary to find good correction values for the trajectory, especially for the altitude, where the drone's self-localization deficiencies are most apparent. However, considering the larger area covered by the planned flights and the superior image distribution, we regard the test to be successful.

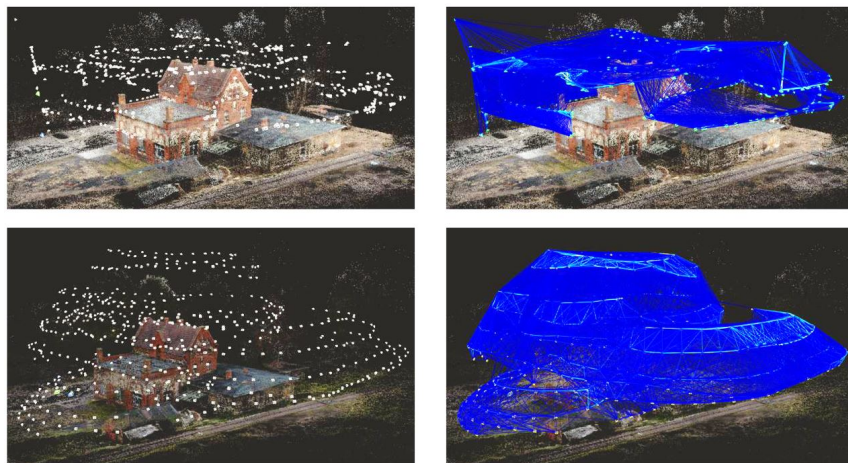


Figure 13: Comparison of image configurations resulting from a manually piloted attempt using time interval camera triggering (top) and from tests using our flight planning and assistance tools (bottom). In the former case, distances and viewing directions were not realised adequately. The distribution of camera stations (left) exhibits holes as well as clusters and results in suboptimal image connectivity (right). Using our approach, the results are significantly improved.

Close range photogrammetry for deformation measurement

Modern constructional steelwork is characterized by slim structures and production-optimized designs. Plates are often so slim, that they tend to bulge and bend under stress. The Institute for Construction and Design at the University of Stuttgart conducted large-scale experiments at the Materialprüfanstalt MPA in order to determine how accurate the theoretical description of these processes are. The examined steel beams are too large for a dense deformation tracking solely by local odometers etc. Therefore, we supported this project by implementing and operating a close range photogrammetric measurement setup and evaluation pipeline.



Figure 14: Meshed surface of the building, generated from UAV images. A precise, homogeneous and complete reconstruction was achieved with the well-distributed images of our flight planning and execution concept.

Four industrial IDS uEye provide the images. The cameras are mounted on individual tripods or installed into an aluminum profile frame with a fixed relative orientation, depending on the measured object. Baselines reach from 15cm to about 1.5m. Cables connect the cameras to a laptop directly via USB and indirectly via a microcontroller relay. We developed custom software for the operator to control the cameras. This configuration allowed reaching a deformation accuracy of ca. 0.1mm.

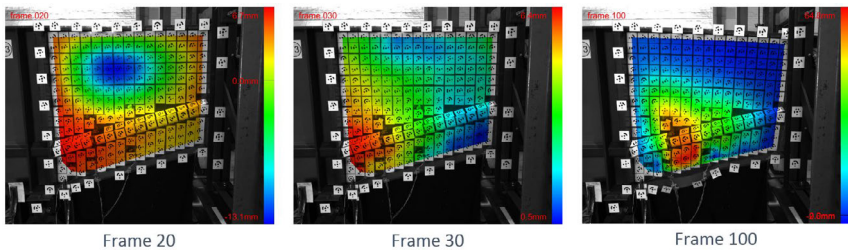


Figure 15: Frames showing the deformation of the outburst experiment.

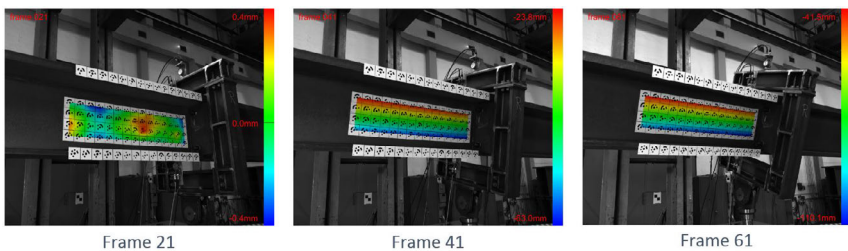


Figure 16: Frames showing the deformation of the twist and kink experiment.

Efficient engineer-geodetic monitoring of traffic structures

The lock Hessigheim is located at Neckar 143,01 km (see Figure 17) and built on unstable ground. Natural underground chambers arise due to eluviation of gypsum in the anhydrite layer. For this reason, the ground submerges continuously. The relative submergence of ground is about 1 mm/a up to 1 cm/a (relative to direct surroundings). The corresponding relative translatory movement is in the range of several mm/a. Absolute submergence is unknown. However, from a monitoring point of view relative movement is sufficient.



Figure 17: True Orthophoto (DOP) of the lock Hessigheim.

We monitor the lock in collaboration with the Bundesanstalt für Gewässerkunde (BfG) and the Amt für Neckarausbau Heidelberg (ANH).

The lock is monitored in a threefold manner:

- Engineer-geodetic monitoring (tachymeter, precise levelling, extensometer, alignment)
- Airborne monitoring (image matching, laserscanning)
- Satellite monitoring (persistent scatterer interferometry)

The objective of the project is to analyze different engineer-geodetic concepts for constructional questions. In particular, we analyze the potentials of area wide, permanent, high-frequency measurements for monitoring the lock.

Airborne monitoring (by image matching or laserscanning) and satellite monitoring (by persistent scatterer interferometry) are contactless measuring methods. Such remote sensing methods are capable to cover large areas in short time. In case of satellite sensors, temporal monitoring is possible. Depending on the repeat cycle of the satellite (usually between a few days up to weeks), time-series of imagery of high temporal density can be obtained.

Another aim of the project is to prove the efficiency for an area wide high-frequency monitoring regarding a high quality assurance. The subsequent aim is to apply the research findings/the concept to other traffic structures.

Engineer-geodetic monitoring

Engineer-geodetic monitoring is state-of-the art for highly accurate monitoring. However, the monitoring is only point based and very time-consuming. Furthermore, there are difficult geographic framework conditions at the lock that impede the monitoring. Common measurement tools are tachymeter, precise levelling, extensometer, and alignment.

Airborne monitoring (image matching, laserscanning)

The advantage of airborne imagery and airborne laserscanning is the generation of area wide, high-resolution point clouds. Furthermore, those points could be attached with semantic information. The standard multi-stereo image processing (matching, 3D reconstruction, DEM generation, generation of true orthophoto) has to be adapted to the challenging water surroundings. The same holds true for the standard laserscanning processing by the Laser Strip Adjustment. We seek to realize a ground sampling distance (GSD) of 3-5 mm and a minimal point density of 4 points per 10 x 10 cm. The combination of both methods generates a dense point cloud for every epoch. These point clouds can be used for generating difference models and, thus, for visualizing relative movements of objects.

Satellite monitoring (persistent scatterer interferometry)

We seek to detect movement of the lock with high accuracy and reliability based on Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR). We rely on TerraSAR-X and Sentinel 1 data. The main idea of Persistent Scatterer Interferometry is to detect pixels with a constant reflective behavior within a stack of radar images. Generally, these pixels correspond to rigid objects with smooth surfaces. Buildings are „natural“ persistent scatterers in urban areas. In addition, we mount artificial persistent scatterers near the lock. These so-called corner reflectors (see Figure 18) work like retro reflectors.

First results

We achieved object point accuracy of 3-8 mm with our first monitoring flight in January 2018. Figure 19 shows the result of the matching. Figure 20 shows a first evaluation of PSInSAR.

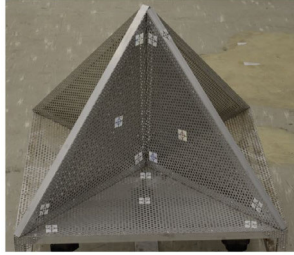


Figure 18: A corner reflector with targets for the determination of its phase center.

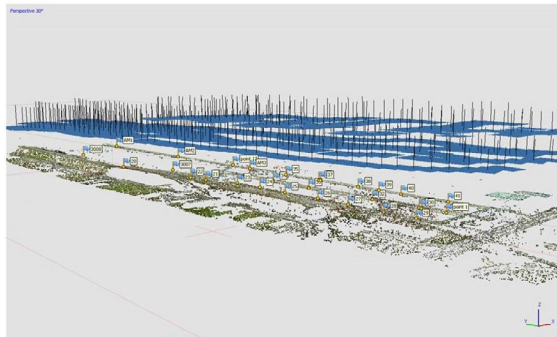


Figure 19: Result of the matching (thin point cloud and aligned images).

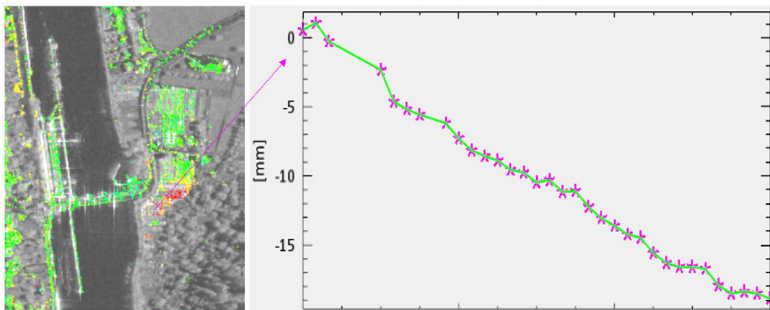


Figure 20: Left: Relative movement in the area near the lock Hessigheim (by PSInSAR). Red: high submergence, green: low submergence. Right: Accumulated displacement [mm] for one point (based on 33 TerraSAR-X images. Period: 27th November 2014 - 28th December 2015).

Adaptive 4D PSI-based change detection

Previously, we proposed a PSI-based 4D change detection to detect disappearing and emerging PS points (3D) along with their occurrence dates (1D). Such change points are usually caused by anthropic events, e.g., building constructions in cities. This method first divides an entire SAR image stack into several subsets by a set of break dates. The PS points, which are selected based on their temporal coherences before or after a break date, are regarded as change candidates. Change points are then extracted from these candidates according to their change indices, which are modelled from their temporal coherences of divided image subsets. Finally, we check the evolution of the change indices for each change point to detect the break date that this change occurred. The experiment validated both feasibility and applicability of our method. However, two questions still remain. First, selection of temporal coherence threshold associates with a trade-off between quality and quantity of PS points. This selection is also crucial for the amount of change points in a more complex way. Second, heuristic selection of change index thresholds brings vulnerability and causes loss of change points. In this study, we adapt our approach to identify change points based on statistical characteristics of change indices rather than thresholding. The experiment validates this adaptive approach and shows increase of change points by at most 29% compared with the old version. In addition, we also explore and discuss the optimal selection of temporal coherence thresholds.

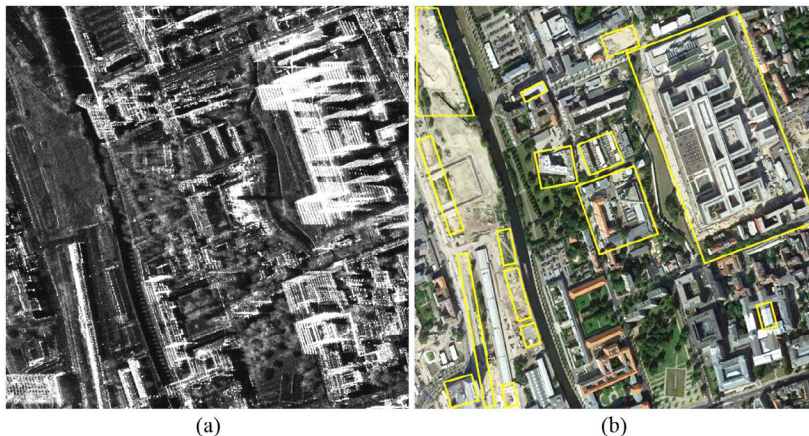


Figure 21: Study area at the north of Berlin central station. (a) Mean TerraSAR-X image. (b) Aerial image (Google Earth) acquired on September 5, 2014. Yellow square, building construction.

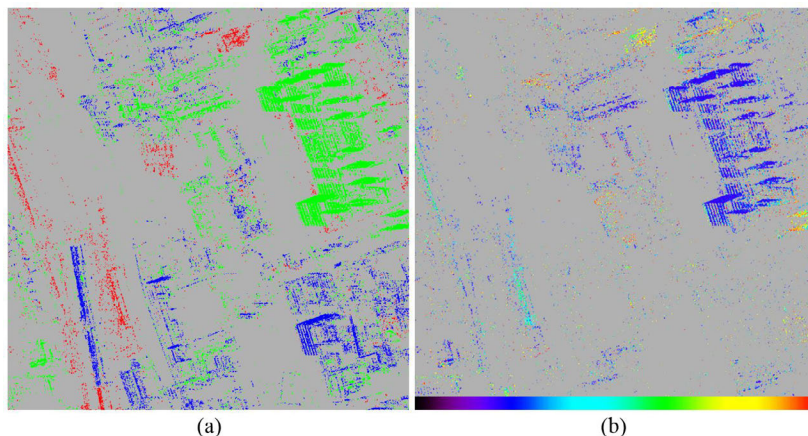


Figure 22: Spatiotemporal change detection result. (a) Steady, disappearing, and emerging structures represented by PS (blue), DBC (red), and EBC (green) points. (b) Occurrence dates: black to red, earliest to latest in 2013.

Modified epipolar resampling and orientation method for satellite imagery

Nowadays, high resolution satellite images have been commonly used for the point cloud and Digital Surface Model (DSM) generation or 3D reconstruction. Since we already have a completely workflow to process the satellite imagery, we focus more on the improvement of the pipeline.

New epipolar model

In order to get very dense point clouds, the modified Semi-Global Matching (tSGM) method is an efficient tool. Because the epipolar images will reduce the search range from 2D space to 1D space and largely decrease the processing time, epipolar resampling is required before the dense matching. As we know, the epipolar geometry of satellite pushbroom sensors only exists in small range areas, and the epipolar curve is more like a hyperbola line than a straight line. Many applications only carry out the epipolar resampling in small tiles. The present work aims at the epipolar resampling for the whole image without tiling. In our method, each epipolar curve is approximated by several segments. In order to get a proper epipolar segment length, we use the height range calculated from RPCs to define it. The sketch of the method is shown in Figure 23, and the main steps are:

- Select the points on the border as start points and calculate the epipolar line function
- Define the epipolar segment length and end point.
- Resample original image along the epipolar segment until it reach the end points
- Then choose the end point as the start point to derive new epipolar segments
- Repeat this procedure until the other border of the image is reached

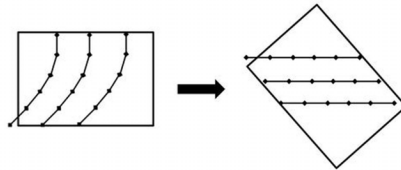


Figure 23: Epipolar curve approximation and resampling.

Epipolar curve approximation and resampling

All these steps are implemented with RPC projection trajectory method, and some evaluations have been done on QuickBird data that covers Melbourne. Twenty-five pairs of check points are selected to calculate the vertical parallaxes. The result is shown in Figure 24, all vertical parallaxes are smaller than one pixel and the root-mean-square (RMS) error is 0.499 pixels. This indicates that the piece-wise epipolar resampling method can reach sub-pixel level.

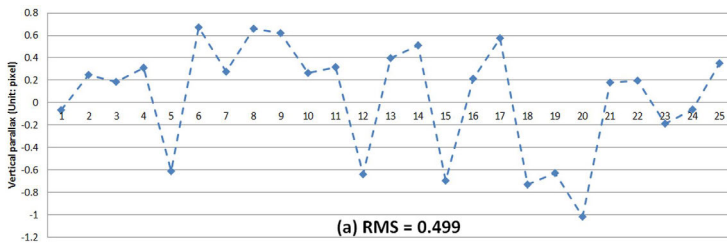


Figure 24: Vertical parallaxes of QuickBird Melbourne dataset.

Relative orientation without ground controls

From our experience, the Rational Polynomial Coefficients (RPCs) provided by the vendors are not always accurate enough. The corresponding points on matching image might not locate on the corresponding epipolar curve because of the lack of RPCs precision. Moreover,

users might not have ground control information for bundle block adjustment. Therefore, relative orientation is an important pre-procedure to generate high quality epipolar geometry. Some researches use an error vector to compensate the error in matching image space, but only for small tiles.

The present work introduces a relative orientation method for entire satellite images without tiling. This method doesn't need ground control information, but only use the tie points and rough RPCs. The tie points are generated half-automatically with the software ENVI, and their accuracy is considered as sub-pixel level. The method measures the difference between corresponding points and corresponding epipolar curves on the matching image. Then we estimate an affine model as a global correction to compensate the location error for the whole image. Twenty-four check points are selected from the Pleiades imagery to verify the quality of this global compensated relative orientation. Before processing, the location error is as large as ca. 10 pixels. After the orientation, the location error is less than 1 pixel. The result is shown in Figure 25. According to the experiments, proposed relative orientation method can achieve sub-pixel accuracy and provide a good geometry for following epipolar resampling.

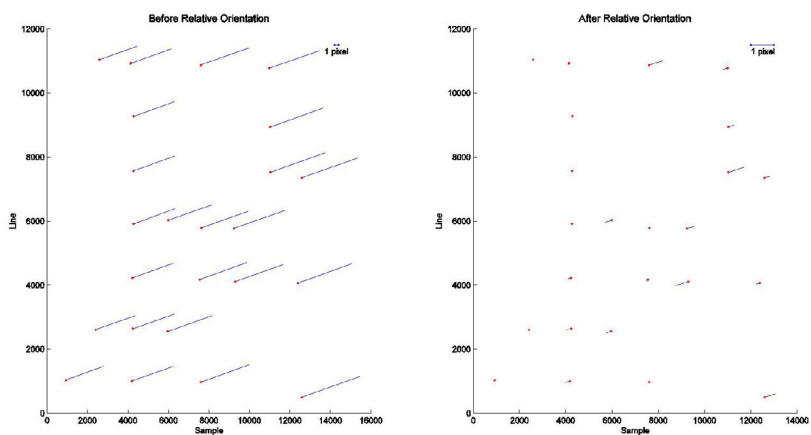


Figure 25: Location error of Pleiades Taipei dataset (the red points are the true corresponding points' location, blue lines are the distance between true location and the epipolar curve. The scale of the distance is shown in the right top of the figure).

Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery

Knowledge about the bathymetry of water bodies is of high economic, social, and ecological importance. Whereas charting bathymetry for navigational purposes is indispensable for ensuring safe shipping traffic, monitoring the quantity and quality of fresh water resources gains more and more importance, especially in the light of climate change. In the European context, three water related directives, namely the water framework directive (2000), the flood directive (2007), and the Fauna-Flora-Habitat directive (1992), request monitoring in a periodic cycle. Repeat acquisition of rivers and other inland water bodies is one of the essential tasks in fulfilling the above directives and requires efficient techniques for capturing bathymetry. The same applies to the coastal zone with applications in shore protection after storm events, monitoring of benthic habitats, etc.

Echo sounding is still the prime technique for capturing bathymetry. However, ship-borne sonar data acquisition is inefficient and even hazardous in shallow water areas. For surveying the bottom of the shallow riparian area, active and passive optical remote sensing techniques are employed. Three different approaches are in use: (i) Spectrally based depth estimation based on multi-spectral images, (ii) multi-media photogrammetry based on stereo images, and (iii) airborne laser bathymetry. Whereas the prior two are passive techniques using the reflections of solar illumination, the latter is an active method based on green laser radiation.

Exploiting the potential benefits of fusing concurrently acquired data from either data source (i.e. images and laser scans) is the topic of the German Research Foundation (DFG) project „Bathymetry by fusion of airborne laser scanning and multi-spectral aerial imagery“ that is work-in-progress at the Institute for Photogrammetry (project start: January 2017).

Modern airborne bathymetric sensors (e.g. Riegl VQ-880-G, Teledyne Optech CZMIL Nova, Leica/AHAB HawkEye III, etc.) incorporate laser scanners and multi-spectral cameras. This opens the floor for joint data processing of simultaneously acquired active and passive remote sensing data. Therefore, the following research topics are currently addressed at the IfP with the above-mentioned DFG project:

- Spectrally based depth estimation, through-water photogrammetry, and airborne laser bathymetry are used exclusively so far. It is expected that exploiting the complementary measurement techniques will result in more accurate, reliable, and complete Digital Terrain Models (DTM) of the submerged topography.
- Airborne Laser Bathymetry (ALB) is a monochromatic measurement technique operating in the green domain of the electro-magnetic spectrum. Especially for clear water, certain bands of multi-spectral or even hyper-spectral data may provide better water column penetration. This especially applies to the lower wavelength boundary of the visible spectrum (coastal blue-blue, $\lambda=430-500\text{nm}$).

- Depths derived from ALB constitute optimum reference data for calibrating models for spectrally based depth and/or substrate type estimation. This enables automated procedures for processing multi-spectral image data.
- The main advantage of ALB is that the derivation of depth relies on round-trip time measurement of a laser pulse and is, thus, independent from radiometric information (signal strength). Knowing the water depth reduces the unknowns for spectrally based techniques, which helps to distinguish substrate soil types, benthic habitats, etc. Fusion of passive image data and active laser scans should therefore improve the object classification (sand, gravel, rock, submerged vegetation, etc.).
- Existing state-of-the-art techniques like Conditional Random Fields can incorporate contextual information. Extending these techniques for the use with comprehensive active and passive remote sensing data as input should lead to better classification results.
- Whereas the laser footprint diameter fundamentally limits the spatial resolution of laser bathymetry, a much higher resolution in the range of the ground sampling distance of a single image pixel is achieved with Dense Image Matching. Embedding DIM in a multimedia-photogrammetry framework could potentially increase the DTM resolution of the littoral zone.

Following a literature research and an inspection of available laser and image data (coastal zone: German Baltic Sea; inland running waters: Pielach River, Austria), one of the main project activities in 2017 was planning and conducting a data acquisition campaign in the Stubai Alps (Tyrol, Austria). For this project, the IfP teamed up with the Unit of Hydraulic Engineering, University of Innsbruck (UIBK). The company Airborne Hydro Mapping (AHM) was commissioned to conduct a flight with a bathymetric laser scanner (Riegl VQ-880-G), a RGB camera (Hasselblad, 39 MP) and a separate Colour Infrared (CIR) camera for capturing two mountain lakes at the foothill of the Stubai glacier (Grünausee and Blaue Lacke). Both lakes are about 12m deep. In a first campaign in July 2017, the UIBK team measured the bathymetry of both lakes with a multi-beam echo sounder mounted on an inflatable dinghy. Within the same campaign, the IfP team (Gottfried Mandlbürger, Ke Gong) measured twenty photogrammetric control points with Leica GNSS receivers. The IIGS (Andreas Kanzler, Annette Scheider) thankfully aided campaign with equipment and data processing support.

While the lakes featured very clear water in July (Secchi depth Grünausee: > 8m), the instable weather conditions prevented flight operation. Airborne data acquisition took place one month later on August 22. Whereas sunny weather and almost no wind provided excellent conditions for the flight, which was still challenging due to the extreme topography with surrounding peaks higher than 3.000m above sea level, several heavy thunderstorms in the beginning of August had a negative impact on the clarity of the lakes (Secchi depth Grünausee on August 22: 2.4m). As turbidity is the limiting factor for any optical measurement technique, only the near-shoreline area could be analysed so far. Figure 26 shows impressions and first results from the field campaigns in July and August.

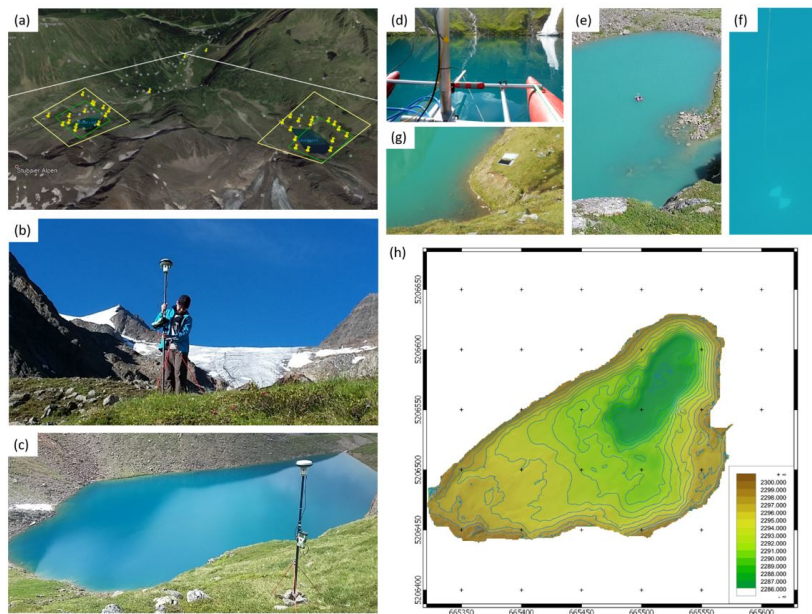


Figure 26: Study area Grünausee, Blaue Lacke, Stubai Alps, Tyrol, Austria; (a) flight planning; (b) Ke Gong (IfP) during GNSS surveying of a photogrammetric control point; (c) GNSS receiver in front of Blaue Lacke, July 2017; (d) multi-beam echo sounder mounted on inflatable dinghy; (e) sonar data acquisition of Blaue Lacke, July 2017; (f) Secchi depth measurement, Grünausee, July 2017 (> 8m); (g) radiometric control patches at the shore of Grünausee, August 2017; (h) submerged topography of Blaue Lacke derived from sonar data.

Apart from the Grünausee dataset, data from an existing flight in 2014 at the German Baltic sea, captured with a Leica/AHAB HawkEye III bathymetric laser scanner and an integrated RGBI camera (RCD30, 80 MPix) served as basis for a feasibility study on dense under-water matching. Figure 27 shows the first preliminary results, highlighting that the photogrammetric technique works well in shallow areas with calm water surface and high image texture, but fails in poorly textured areas with undulating water surface. A more sophisticated through-water dense image matching approach is currently work in progress, as are the remaining points from the above list of research topics.

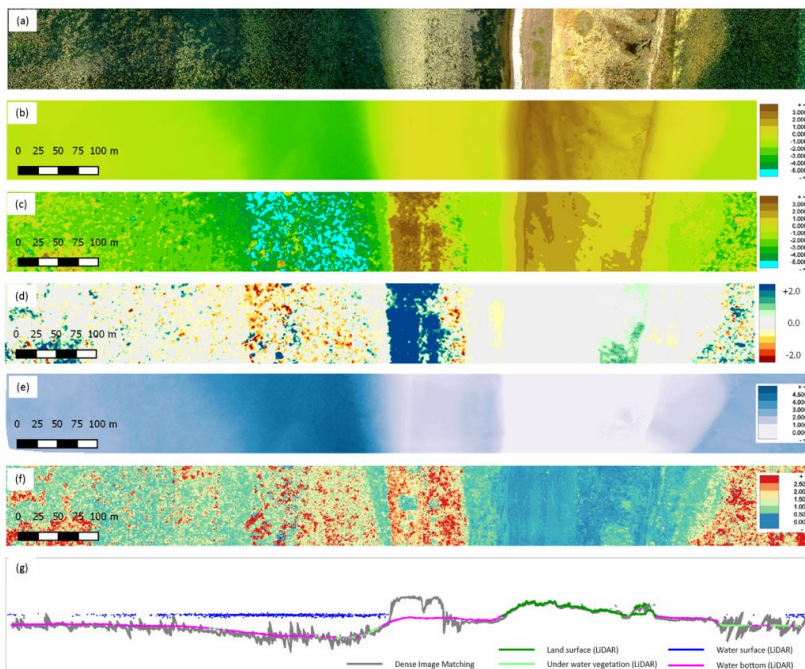


Figure 27: Study area Poel/German Baltic Sea; (a) coloured through-water DIM point cloud; (b) ALB DTM, colour coded elevation map; (c) DIM DTM, colour coded elevation map; (d) Colour coded DEM of Difference model (DIM minus LiDAR); (e) ALB derived water depth map; (f) RMSE of DIM point cloud (analysis unit: 25x25 cm²); (g) DIM-ALB DTM profile comparison, location of section in the centre of the Figure 2a-f, complete East-West-transect, heights exaggerated (max. water depth: ca. 5m).

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- Runceanu, L., Becker, S., Haala, N., Fritsch, D.: Indoor Point Cloud Segmentation for Automatic Object Interpretation. DGPF annual conference, Würzburg, Germany. *Publikationen der DGPF*, Band 26, 147-159.
- Schack, L., Sörgel, U., Heipke, C.: Assigning Persistent Scatterers of Regular Multi-Story Buildings to Optical Oblique Images. *PFG - Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 85(1), 67-74.

- Tutzauer, P., Haala, N.: Processing of Crawled Urban Imagery for Building Use Classification. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-1/W1, 143-149.
- Wieser, M., Mandlbürger, G., Hollaus, M., Otepka, J., Glira, P., Pfeifer, N. A Case Study of UAS Borne Laser Scanning for Measurement of Tree Stem Diameter. *Remote Sensing*. 2017, 9, 1154.
- Yang, C.H., Sörgel, U.: Urban Monitoring by 4D Change Detection Using Multi-temporal SAR Images. DGPf annual conference, Würzburg, Germany. Publikationen der DGPf, Band 26, 2017, 233-244.
- Yang, C.H., Sörgel, U.: Monitoring of Building Construction by 4D Change Detection Using Multi-temporal SAR Images. *ISPRS Annals of The Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-1/W1, 35-42.

Master Theses

- Adam, J.R.: Markov Marked Point Process zur Klassifizierung von Gebäuden in 2.5D-Punktwolken. Supervisor: Becker, S.
- Bashir, M.: Indoor Positioning for Warehouse Logistics. Supervisor: Walter, V.
- Cruz Rangel, C.C.: Comparison and Implementation of Open Source Web Mapping Libraries as a Visualization Tool for the Conflict in Colombia. Supervisor: Walter, V.
- Farmonov, E.: Implementation and Evaluation of a Crowd-based Approach for Georeferencing of Raster-Maps. Supervisor: Walter, V.
- Graner, M.: Google Tango as an indoor mapping device. Supervisor: Runceanu, L.
- Huang, X.: PCA-based change detection using multi-temporal SAR images. Supervisors: Yang, C.H., Sörgel, U.
- Hurt, P.: Qualification and accuracy analysis of modern vehicle localization processes with the help of the entropy. Supervisors: Schuster, F. (Daimler AG), Haala, N.
- Hüttl, P.: Structure from Motion for Oblique Aerial Imagery. Supervisors: Wenzel, K. (nFrames), Haala, N.
- Iftikhar, M.A.: Spatially Aware Conversational Agent. Supervisor: Walter, V.
- Ignat, P.: 3D indoor mapping using NavVis M3Trolley data - an empirical study. Supervisors: Runceanu, L., Cramer, M., Fitz, D.
- Jetter, M.: Überwachung von Veränderungen im urbanen Raum mittels SAR-Techniken - Fallbeispiel der Neuordnung des Bahnknotens Stuttgart. Supervisors: Yang, C.H., Sörgel, U.

- Karam, S.: 3D-Building Reconstruction with Different Height Levels from Airborne LiDAR Data. Supervisor: Partovi, T. (DLR), Reinartz, P. (DLR).
- Laupheimer, D.: Deep Learning for the Classification of Building Facades. Supervisors: Tutzauer, P., Haala, N.
- Li, J.: Filtering terrestrial LiDAR point cloud in forest areas. Supervisors: Haala, N., Coughenour, C., Xie, H. (SGG, Wuhan University).
- Li, P.: Evaluation and Improvement of a Dual-channel Method for Detection and Quantification of High-temperature Events Based on FireBIRD Data. Supervisor: Sörgel, U.
- Liu, A.: Photogrammetric Data Collection and Processing - An Android App. Supervisor: Fritsch, D.
- Lucaciu, F.: Estimating Pose and Dimensions of Parked Automobiles on Radar Occupancy Grids. Supervisor: Sörgel, U.
- Mawas, K.: Close Range Photogrammetry, Computer Aided Design for Heritage Sites. Supervisors: Haala, N., Coughenour, C.
- Moanta, A.M.: Camera-based Plough Control. Supervisors: Michalke, G. (Robert Bosch GmbH), Erz, M. (Robert Bosch GmbH), Haala, N.
- Nhattiala, D.: Quality Analysis and Integration of Spatial Data. Supervisor: Walter, V.
- Owda, A.N.: Digital Preservation of Calw Market Square - Im Zwinger by Means of Automated HDS and Photogrammetric Texture Mapping. Supervisors: Fritsch, D., Balsa-Barreiro, J.
- Pang, H.: Application of Machine Learning Algorithms for the Automatic Recognition of Characters in Scanned Survey Plans. Supervisors: Heuchel, T. (Trimble/inpho), Tutzauer, P.
- Pang, Y.: Time series change detection using SAR images: from pixel-based to object-based analysis. Supervisors: Yang, C.H., Sörgel, U.
- Rajagopal, K.: Sharpness Optimization of a 3D Scanner Using Modulation Transfer Function. Supervisors: Döring, D. (FARO Scanner Production GmbH), Pfeiffer, R. (FARO Scanner Production GmbH), Haala, N.
- Schmohl, S.: Study on Noise Robustness of 3D Shape Recognition with Convolutional Neural Networks. Supervisor: Sörgel, U.
- Schwämmle, K.: 3D Reconstruction and texturing of the Copan Ruinas (Honduras) site using photogrammetry and LiDAR. Supervisor: Coughenour, C.
- Shafaghi, Y.: A Geosocial Network for Refugees in Germany. Supervisor: Walter, V.
- Song, Y.: Fusion of Range Data from Multi-View Stereo and LiDAR for Volumetric Surface Reconstruction. Supervisor: Cefalu, A.

Tang, M.: Calibration of automotive fish-eye cameras with misaligned camera components.
Supervisors: Cramer, M., Singh, J. (Magna Electronics).

Thamarappilly, S.: Implementation of a GPS-based Android Game. Supervisor: Walter, V.

Vlachos, M.: Integration and Testing of Sequoia MS Camera with Various UAV Platforms.
Supervisor: Cramer, M.

Zhang, X.: Fusion of Range Data from Multi-View Stereo and LiDAR for Volumetric Surface
Reconstruction. Supervisors: Lombacher J. (Daimler AG), Broßheit, P. (Daimler AG),
Haala, N.

Bachelor Theses

Budde, L.E.: Fusion von 3D-Punktwolken aus Stereo-Bildzuordnung und Laserscanning zur
Verbesserung von digitaler Oberflächenmodellen. Supervisor: Mandlbürger, G.

Clauß, D.: Integration von mehrfach erfassten Polygonen mit Hilfe eines Rasterbasierten An-
satzes. Supervisor: Walter, V.

Hirt, P.R.: Klassifizierung von 3D-Objekten in Gebäudeinnenräumen. Supervisor:
Runcéanu, L.

Joachim, L.: Potenzial von 3D-Punktwolken-basierter Unkrautererkennung in Mais. Supervisor:
Reiser, D.

Lansche, L.: Untersuchung zur Qualität von DJI UAV-Kameras. Supervisor: Cramer, M.

Nied, F.: Band-zu-Band Registrierung UAV-gestützter MS-Kameras. Supervisor: Cramer, M.

Wiedemann, A.: Facade Detection in Urban Scenes using Semantic Image Segmentation.
Supervisor: Tutzauer, P.

Activities in National and International Organizations

Cramer, M.:

Co-Chair ISPRS WG I/9: Integrated Sensor Orientation, Calibration, Navigation and
Mapping

Englich, M.:

Webmaster ISPRS

Haala, N.:

Chair ISPRS WG II/2: Point Cloud Generation

Vorsitz DGPF Arbeitskreis Sensorik und Plattformen

Sörgel, U.:

Vice President German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF)

Chair ISPRS WG III/3: SAR-Based Surface Generation and Deformation Monitoring

Walter, V.:

National Correspondent of the ISPRS Commission IV

Education - Lectures/Exercises/Training/Seminars

Bachelor „Geodäsie und Geoinformatik“

Geoinformatics I (Walter)	2/2/0/0
Geoinformatics II (Walter)	1/1/0/0
Image Processing (Haala)	2/1/0/0
Integrated Fieldworks (Haala, Keller, Kleusberg, Sneeuw)	0/0/4/0
Introduction into Geodesy and Geoinformatics (Cramer, Keller, Kleusberg, Sörgel, Sneeuw)	4/2/0/0
Photogrammetry (Cramer)	2/1/0/0
Remote Sensing (Sörgel)	2/1/0/0
Signal Processing (Sörgel)	2/1/0/0
Urban Planning (Dvorak)	2/0/0/0

Master Course „Geodäsie und Geoinformatik“

Aerotriangulation (Cramer)	1/1/0/0
Computational Geometry (Walter)	1/1/0/0
Computer Vision for Image-based Acquisition of Geodata (Haala)	1/1/0/0
Databases and Geographical Information Systems (Walter)	1/1/0/0
Digital Terrain Models (Haala)	1/1/0/0
Fundamentals in Urban Planning (Dvorak)	2/0/0/0
Georeferencing of photogrammetric Systems (Cramer)	1/1/0/0
Modelling and Visualisation (Haala)	1/1/0/0
Pattern Recognition and Image Understanding (Haala)	1/1/0/0
Remote Sensing (Sörgel)	1/1/0/0
Scientific Presentation Seminar (Haala)	0/0/0/2
Topology and Optimisation (Becker)	1/1/0/0
Web-based GIS (Walter)	1/1/0/0

Master Course GEOENGINE

Airborne Data Acquisition (Cramer)	2/1/0/0
Geoinformatics (Walter)	2/2/0/0
Signal Processing (Sörgel)	2/1/0/0
Image-based Data Collection (Haala, Cramer)	2/1/0/0
Integrated Fieldworks (Haala, Sneeuw, Keller, Kleusberg)	0/0/4/0
Remote Sensing (Sörgel)	2/1/0/0
Topology and Optimisation (Becker)	2/1/0/0

Master Course „Infrastructure Planning“

Introduction to GIS (Walter)	2/0/0/0
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Master Course „Aerospace Engineering“

Image Processing (Haala)	2/1/0/0
Introduction into projective Geometry (Cramer)	2/0/0/0