The Department of Geodesy and Geoinformatics

Stuttgart University

2014

editing and layout:
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Dear friends and colleagues,

It is our great pleasure to present to you this annual report[1] on the 2014 activities and academic highlights of the Department of Geodesy & Geoinformatics of the University of Stuttgart. The Department consists of the four institutes:

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

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

Research

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

Teaching

We were able to welcome 41 new BSc students in Winter Term 2014/2015. The first BSc students graduated at the end of 2013. Until the end of 2014 we had in total 26 BSc. graduates. The MSc program for Geodesy and Geoinformatik started with the winter-term 2012. Currently 20 students are taking part in this Master of Science program and we have already 5 MSc graduates. The Diploma program is slowly being phased out. Total enrolment, in both the BSc, Msc and the Diploma programs, is stable at about 160 students. Please visit our website *www.geodaesie.uni-stuttgart.de* for additional information on the programs.

In its 9^{th} year of existence, our international MSc program *Geomatics Engineering* (GeoEngine) enjoys a gratifying demand. We register an enrolment of 42 students. We attract the GeoEngine student population from such diverse countries as China, Palestine, Iran, Pakistan, Nigeria, India, Romania, Poland, Nepal, Syria, Russia, and Ghana. Please visit *www.geoengine.uni-stuttgart.de* for more information.

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

Awards and scholarships

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

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

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

Below is the list of the recipients of the 2013/14 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!

Wolfgang Keller
Associate Dean (Academic)
wolfgang.keller@gis.uni-stuttgart.de

Award	**Recipient**	**Sponsor**	**Programme**
Karl-Ramsayer Preis	M. Küver	Department of Geodesy & Geoinformatics	Geodesy & Geo-informatics
BSc/MSc Thesis Award	R. Thor	F2GeoS	Geodesy & Geo-informatics
MS Photogrammetry / Vexcel Imaging Scholarship	L. S. Garoiu T. Wang	MS Photogrammetry / Vexcel Imaging	GeoEngine
IGI Scholarship	A. Owada B. R. Zhu	IGI mbH	GeoEngine
matching funds	C. B. Berdanoglu W. Huang M. Nanic Y. Wang M. Alhajaj Lafte A. Liu	DAAD	GeoEngine

Institute for Engineering Geodesy

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Head of Institute

Prof. Dr.-Ing. habil. Volker Schwieger

Secretary

Elke Rawe
Ute Schinzel (since 01.10.2014)

Emeritus

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

Scientific Staff

M.Sc. Ashraf Abdallah	GNSS Positioning
M.Sc. Bara' Al-Mistarehi	Construction Process
M.Sc. Shenghua Chen (until 30.09.2014)	Kinematic Positioning
M.Sc. Aiham Hassan	Monitoring
Dipl.-Ing. Stephanie Kauker (since 15.03.2014)	Monitoring
Dipl.-Ing. Otto Lerke	Machine Guidance
M.Sc. Xiaojing Lin	Machine Guidance
Dr.-Ing. Martin Metzner	Engineering Geodesy
Dipl.-Ing. Annette Scheider	Kinematic Positioning
M.Sc. Pham Trung Dung (since 01.11.2014)	Kinematic Positioning
M.Sc. Annette Schmitt	Multi-Sensor-Systems
M.Sc. Rainer Schützle	Location Referencing
Dipl.-Ing. Li Zhang	Monitoring
Dipl.-Ing. Bimin Zheng	Monitoring

Technical Staff

Andreas Kanzler
Martin Knihs
Lars Plate

External teaching staff

Dipl.-Ing. Jürgen Eisenmann	Landratsamt Ludwigsburg - Fachbereich Vermessung
Dipl.-Ing. Christian Helfert	Fachdienstleiter Flurneuordnung im Landkreis Biberach
Dipl.-Math. Ulrich Völter	Geschäftsführer der Fa. Intermetric
Dr.-Ing. Thomas Wiltschko	Daimler AG, Mercedes-Benz Cars; Research and Development

General View

The Institute of Engineering Geodesy (IIGS) is directed by Prof. Dr.-Ing. habil. Volker Schwieger. It is part of the Faculty 6 „Aerospace Engineering and Geodesy“ within the University of Stuttgart. Prof. Schwieger holds the chair in „Engineering Geodesy and Geodetic Measurements“. In 2012 he was elected Vice Dean of Faculty 6.

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

Since 2011 he is 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“ for the period 2015-2018.

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 language). In addition, the IIGS provides several courses in German language for the curricula of „Aerospace Engineering“ (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. In 2014, teaching was still characterized by the conversion of courses from Diploma to Bachelor and Master degree, now with the special focus on the Master degree. This process is now coming to an end.

The current research and project work of the institute is expressed in the course contents, thus always presenting the actual state-of-the-art to the students. As a benefit of this, student research projects and theses are often effected in close cooperation with the industry and extenal 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 modeling. 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

International Workshop 14./15. April 2014 on „Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects“

The former Siberian State Academy of Geodesy (SSGA), (today Siberian State University of Geosystems and Technologies) and the Institute of Engineering Geodesy Stuttgart (IIGS) concluded a cooperation agreement on 18 April 2012. The objectives of the agreement were the intensification of the exchange in joint research subjects, teaching and further development of bilateral relations. Within the scope of these agreements an international workshop took place in Novosibirsk, Russian Federation on 14. to 15. April 2014. Beside SSGA and IIGS, researchers from the Leibniz University Hannover, Technical University of Munich, Technical University of East Kazakhstan, as well as University of Applied Sciences Karlsruhe and Beuth University of Applied Science Berlin, joined the workshop. The workshop was co-funded by the DFG (Deutsche Forschungsgemeinschaft). Numerous scientific presentations were held during the workshop. The articles are published and available on the internet.

The object of interest can be monitored with a specific measurement technique at specific chosen points and at specific times. The point-based methods provide highly precise information for individually characterized points. The area-based methods provide the complete shape of the object with a high resolution but very often with a reduced accuracy. The accuracy and reliability of the area-wise measurement method should be improved through the precise point wise measurement method.

The key issues of the workshop were „Objects under Observation“, „Methods of Observations and Measurements“ and „Monitoring Data Processing and Interpretation“.

Objects under observation

This issue deals with different monitoring objects from industrial and civilian fields. Among them one can find public utilities (hydro technical constructions, atomic and thermal power plants), mining plants, shafts, tunnels, linear structures (highways, roads, pipelines, power transmission lines), landslides (Figure 1), glaciers, etc.

Figure 1: Landslide (CGEOS, 2014).

Methods of observations and measurements

Once the monitoring object is defined, diverse techniques and methods are required for the measurement implementation. The implementation includes the measurement concept as well as the choice of instruments. Tachymetry, Levelling and GPS can be used as well as Laserscanning (Figure 2) or Photogrammetry. Before measurements can be performed, an appropriate measurement concept has to be established and measurands have to be defined, e.g. position changes of a point. Geodetic networks also play an important role including proposed accuracies and resolutions. These aspects are defined by the specific monitoring tasks.

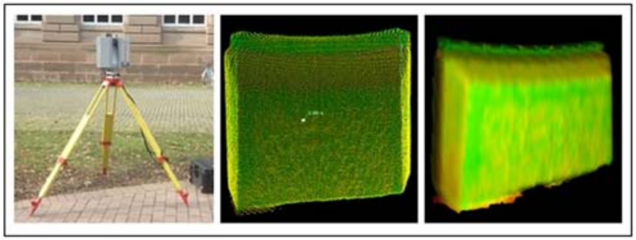

Figure 2: left: Laserscanner HDS7000; center: detected point cloud; right: derived surface structure (IIGS 2014).

Monitoring data processing and interpretation

During the measurements, especially during long term observations, a big amount of data is generated. This data must be processed in a way that conclusions about geometric changes can be stated. Geometric changes might come from deformations, position changes or structural alterations. For the interpretation of such collected data a mathematical and statistical analyses are necessary. Such analyses (Figure 3) help to learn more about the characteristics of deformations and their probabilistic aspects.

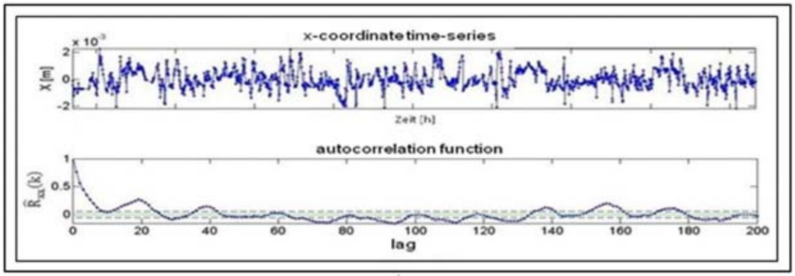

Figure 3: Time series and related empirical autocorrelation function (Wang, 2012).

During the workshop numerous monitoring objects and specific measurement techniques as well as area-wise evaluation methods were presented and discussed. Keywords like multi-sensor integration, change detection, geometric, semantic and dynamic modelling could be identified as future research fields and potential cooperation topics.

Comparison of Different Shieldings of Low-Cost GPS Receivers

It is well-known that the accuracy of GNSS receivers is affected by multipath effects, even in shadowing free environment. The multipath effects are the dominant errors for short baselines. In the Institute of Engineering Geodesy at the University of Stuttgart (IIGS), the low-cost single frequency GPS receiver (u-blox receiver) has been studied for a long time. To improve the accuracy of measurements, different shieldings such as ground plate and choke ring ground plate are constructed to reduce undesirable multipath effects (Figure 4).

The depths of the choke rings should be about 1/4 of the wavelength of the signal, for the frequencies of L1 and L2 they are approximately 4.7 cm and 6 cm. The commercial choke rings have depth of about 5.6 cm, which is a compromise between L1 and L2 and so the multipath effects are not reduced optimally for single frequencies. A so-called L1-optimized choke ring ground plate, which has a depth of 4.5 cm, is constructed at IIGS. Its performance is compared to the same antenna without shielding, to the normal ground plate and to the Leica antenna. Figure 1 shows the antenna and shielding combinations:

Figure 4: Four Antenna and Shielding Combinations.

- ▷ Trimble Bullet III GPS antenna without shielding + GPS L1 receiver U-blox LEA-6T;
- ▷ Trimble Bullet III GPS antenna with ground plate (GP) + GPS L1 receiver U-blox LEA-6T;
- ▷ Trimble Bullet III GPS antenna with L1-optimized choke ring ground plate (CRGP) + GPS L1 receiver U-blox LEA-6T;
- ▷ Leica AX1203 GNSS antenna without shielding + Leica GNSS GX1230 receiver

The antennas are measured with different shieldings at the same position for about one day. Table 1 shows the results of the comparison.

Receiver		Ubox LEA-6T GPS L1 Receiver			Leica GX1230 GNSS Receiver	
Antenna		Trimble Bullet III			Leica AX1203	
Shieldings		-	GP	CRGP	-	-
Frequency		GPS-L1	GPS-L1	GPS-L1	GPS-L1	GNSS
Accuracy	s_E [mm]	7.2	5.8	3.7	4.0	3.6
	s_N [mm]	10.8	8.6	5.7	6.4	4.7
	s_h [mm]	18.3	14.2	9.6	11.0	10.1
	s_{3D} [mm]	22.4	17.6	11.7	13.3	11.7

Table 1: Accuracy of different antenna and shielding combinations.

The accuracy is given as standard deviation of the coordinates. It is calculated for different coordinates' components east s_E, north s_N, height s_h and the whole position

$$s_{3D} = \sqrt{s_E^2 + s_N^2 + s_h^2} \tag{1}$$

Table 1 shows that the choke ring ground plate is the best shielding for the TBIII antenna. Its accuracy is improved about 50% and 35% compared to the same antenna without shielding and with ground plate and it is almost the same with the Leica geodetic receiver and antenna.

HydrOs - Optimization of Positioning in Areas of GNSS Shadowing Along Inland Waterways

In cooperation with the Federal Institute of Hydrology (BfG), the positioning of surveying vessels shall be improved. Currently the particular position of a surveying vessel is determined by kinematic GNSS measurements (RTK-solution). But there are two types of problems: Firstly, GNSS signals cannot be received in some (shadowed) areas. In addition, the RTK solution cannot be computed if there is an outage of the correction signal. Therefore the trajectory of the vessel may contain gaps or positions with low geometric accuracy. So a multisensor system and an evaluation software are developed within the project HydrOs to overcome these gaps.

Currently the following sensors are connected to the HydrOs system: GNSS receivers, Inertial Measurement Unit (IMU) and a Doppler Velocity Log (DVL). As additional sensor a total station shall be integrated into the system. Besides, the ability of a total station to measure from a moving platform (Figure 7) was tested and an evaluation model was stated.

The HydrOs software records measurement data from all connected sensors and processes within a filter module. The filtering process is currently realized in a post-processing mode. All measurement data are interpolated to a common time stamp and are integrated into an Extended Kalman Filter (EKF). The system time is synchronized to GNSS time to avoid drift behaviour.

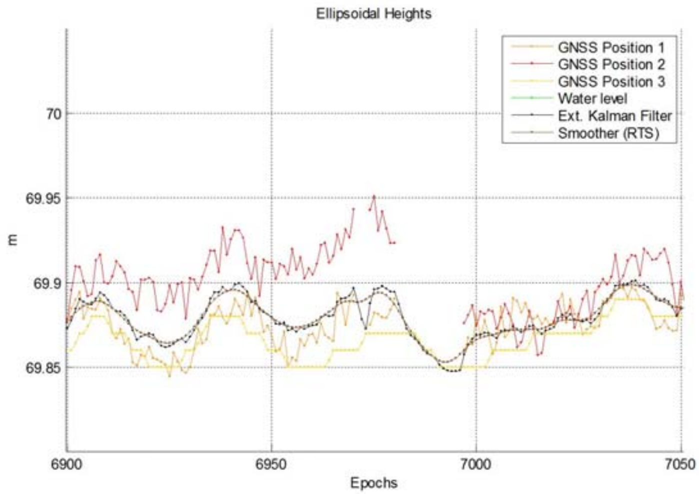

Figure 5: Ellipsoidal heights - GNSS measurements and EKF results.

As a result, the turning rates, velocity components, orientation angles and the coordinates of any defined particular reference point on the vessel are estimated. To receive reliable results, the estimated parameters and the measurement data are tested with global and local statistical outlier removal tests. So it is possible to estimate reliably the position of the vessel even in case of an outage of the RTK measurements up to a time interval of one minute.

Not only sensors but also some existing hydrological models can be integrated into the system: Information about the predicted water level in the measuring area can be used to stabilize the predicted heights. Next to the above-mentioned state variables also an improved water level can be estimated. As a precondition for the estimation of this parameter, the actual influence of the squat effect to the vessel must be known. Therefore a vessel-specific squat characteristic diagram was created based on measurements with different velocities (compared to water) and under keel clearances.

The results, especially the orientation angles and the coordinates, can be saved in a file and also be considered in specific figures (Figure 5).

First measurements on the vessel were undertaken on the rivers Rhine and Ruhr close to Duisburg: Measurement data were recorded and evaluated by HydrOs software. Some extreme scenarios were driven to test the performance of the filtering module. Thereby, the system, especially the system noise, has been adapted to the circumstances on the surveying vessel „Mercator" (Figure 6).

Figure 6: Surveying Vessel „Mercator".

Figure 7: Total stations on a moving platform.

Kinematic Precise Point Positioning Solution for Hydrographic Applications Using Bernese Software

The GNSS Precise Point Positioning (PPP) technique is one of the most challenging surveying methodologies to achieve a high accurate positioning. Therefore, the research is needed to investigate the accuracy of PPP solution, especially in the field of the kinematic measurements. Bernese software contains a group of different tools to complete the processing for double-difference (Differential GNSS) or zero-difference (PPP) mode. The estimation of the two techniques has the same processing schedule in most of the pre-processing stages. The change appears later within the parameter estimations section. Figure 8 shows the processing flow chart using Bernese software V. 5.2.

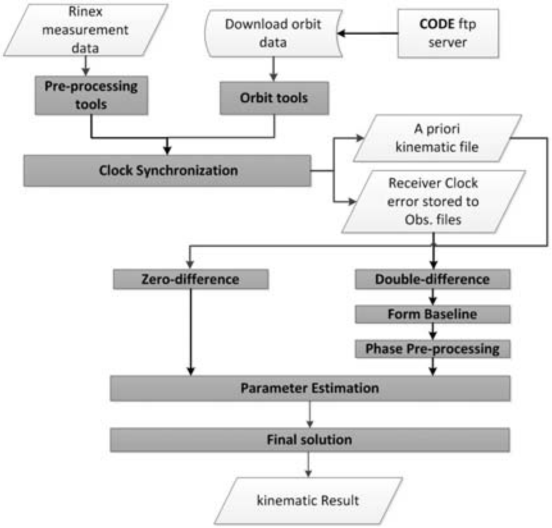

Figure 8: Bernese software processing schedule.

Figure 9: LEIAX1203+GNSS Antenna on the vessel.

A kinematic trajectory has been observed on the Rhine River, Duisburg, Germany as a part of project „HydrOs - Integrated Hydrographical Positioning System“. This project is launched in co-operation between the department M5 (Geodesy) of the German Federal Institute of Hydrology (BfG) and the Institute of Engineering Geodesy at the University of Stuttgart (IIGS). The main goal of the study was to investigate the kinematic PPP solutions for the hydrographic applications. Additionally, it aims at evaluating the suitability of using Bernese software for kinematic PPP solution for the hydrographical applications.

An antenna LEIAX1203+GNSS and a receiver LEICA GX1230+GNSS are located on the surveying vessel to collect the GNSS data with an interval of 1 second, as to be seen in Figure 9. The kinematic PPP errors relative to the differential GNSS solution from Bernese software V. 5.2 is illustrated for East, North, and ellipsoidal height directions in Figure 10.

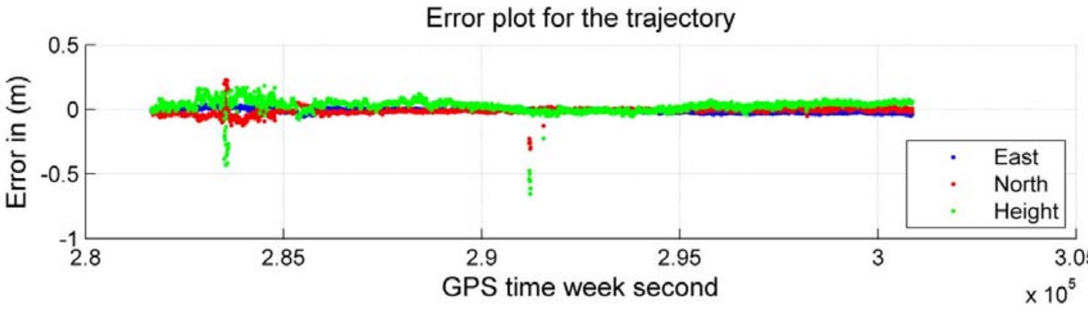

Figure 10: Kinematic PPP solution.

As shown in Table 2, the maximum and minimum values for the error range are reported in the East, North and height directions. From the table below, we can see that the RMS error from the solution is equal to 2.10 cm and 2.90 cm in East and North respectively. Moreover, it shows a RMS error of 5.60 cm in height. The standard deviation (SD) for these PPP errors is set out additionally in Table 2. This SD value is definitely improved after elimination of 5% of the PPP errors as outliers. The standard deviation of a confidence level of 95% ($SD_{95\%}$) shows 1.5 cm in East and North and 3 cm in height.

	East [m]	North [m]	height [m]
Max.	0.064	0.228	0.180
Mean	-0.012	-0.012	0.026
Min.	-0.064	-0.307	-0.655
RMS	0.021	0.029	0.056
SD	0.017	0.026	0.049
$SD_{95\%}$	0.015	0.015	0.030

Table 2: Statistical results of the trajectory.

IMCAD - Integrated Spatio-Temporal Modeling Using Correlated Measured Values for the Derivation of Surveying Configurations and Description of Deformation Processes

This project is founded by the Deutsche Forschungsgemeinschaft and is realized in cooperation of the Institute of Engineering Geodesy, University of Stuttgart with the Department of Geodesy and Geoinformation, Vienna University of Technology.

As part of this project a new non-linear space-temporal method for modeling a time-varying object surface will be developed. The result of this project shall provide a method to model and determine deformations of any point on an object surface.

Traditionally, deformation processes are mostly detected point-wise, e.g. by means of a total station. Consequently, information about the surface of the monitored object is lost since only clearly reproducible points or signalized points can be measured. Nowadays, buildings can be measured area-wise, e.g. by means of a terrestrial laser scanner (TLS). The relations among the measured point cloud and the deformation parameters are non-linear. The measured data is highly correlated.

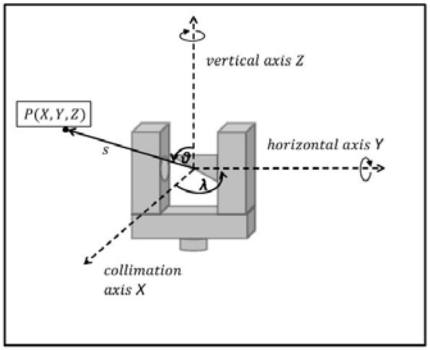

Figure 11: Construction elements of a TLS.

Figure 11 shows the main construction elements of a terrestrial laser scanner and its corresponding observables, such as horizontal and vertical angle and slope distance. In Figure 12, the main sources of errors of a TLS are shown: collimation axis, horizontal axis and vertical axis. Besides, there are atmospheric sources of error such as air temperature, pressure and partial water vapour pressure which affect a 3D point cloud. In addition, monitored objects provide sources of errors such as reflectivity, angle of incidence, and so on.

Calculating the synthetic covariance matrix of the measured values requires the elementary error model. This model consists of three types: non-correlating, functional correlating and stochastic correlating errors. The impact of elementary errors on correlations is given as follows:

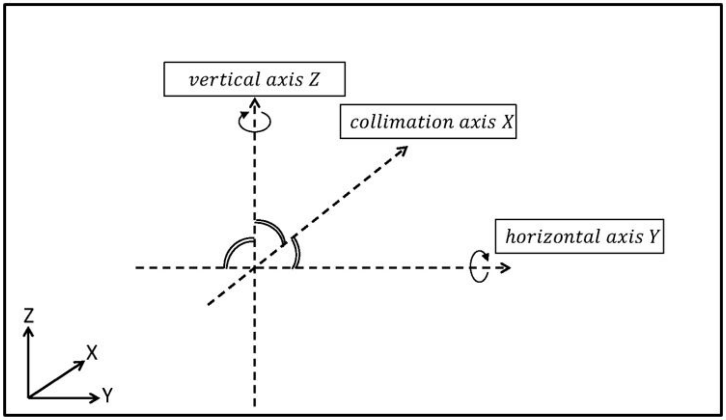

Figure 12: Main sources of errors.

- ▷ p non-correlating error vectors δ_k,
- ▷ m functional correlating errors ξ_j,
- ▷ q stochastic correlating error vectors γ_h .

Transforming the elementary errors into the observation space requires an influencing matrix for each type of correlations:

- ▷ p matrices D_k for the non-correlating errors,
- ▷ one matrix F for the functional correlating errors,
- ▷ q matrices G_h for the stochastic correlating errors.

As result, the random deviation ϵ is calculated directly as the sum of all elementary errors. Hereby, the projection into the observation space is considered.

$$\epsilon = \sum_{k=1}^{p} D_k * \delta_k + F * \xi + \sum_{h=1}^{q} G_h * \gamma_h \tag{2}$$

Consequently, the substantial TLS errors mentioned above can be classified into three groups. Table 3 shows the classification of the error sources.

Thus, a corresponding synthetic covariance matrix can be determined.

$$\Sigma_u = \sum_{k=1}^{p} D_k * \Sigma_{\delta\delta,k} * D_k^T + F * \Sigma_{\xi\xi} * F^T + \sum_{h=1}^{q} G_k * \Sigma_{\gamma\gamma,h} * G_h^T \tag{3}$$

group	error source	correlation	group	error source	correlation
systematic	rangefinder error	functional	atmospheric	pressure	stochastic
	zero point error			partial water vapour pressure	
	collimation axis error		object	colour	stochastic
	horizontal axis error			roughness	
	vertical index error			reflectivity	
	tumbling error			penetration depth	
	eccentricity of the collimation axis			angle of incidence	functional
atmospheric	temperature	stochastic		edges	

Table 3: Correlations for TLS measurements.

The covariance matrices for the elementary errors are defined as follows:

- ▷ $\Sigma_{\delta\delta,k}$ for the non-correlating errors,
- ▷ $\Sigma_{\xi\xi}$ for the functional correlating errors,
- ▷ $\Sigma_{\gamma\gamma,h}$ for the stochastic correlating errors.

For future work, the impact of meteorological conditions will be modelled. Additionally, object based variances have to be defined in order to compute the synthetic covariance matrix. On this basis, the generated synthetic covariance matrix shall be evaluated by empirical investigations.

Automated Detection of Pavement Cracks

Considerable developments and improvements have been made in the field of automated crack detection in the last years. Digital image processing techniques for crack detection are already widely adapted on large highways maintenance projects. No standard scenario of digital image processing algorithms for crack detection is available and guarantees the crack detection in all cases of pavement images. Previously several image processing algorithms for crack detection were suffering from various shortcomings on the part of crack detection. This work provides an automated image processing crack detection algorithm. The goal is to extract the linear crack from sequence pavement images of different streets automatically.

A new methodology for analysing pavement images is presented. The algorithm presents an effective solution able to fuse different algorithms for crack extraction. Moreover, it achieves an increase in automation in order to meet the requirements of the end-user. Figure 13 illustrates the processing and evaluation methodology for crack detection. The proposed automated crack detection algorithm provides the possibility to detect the linear crack from sequence pavement images with different lighting conditions.

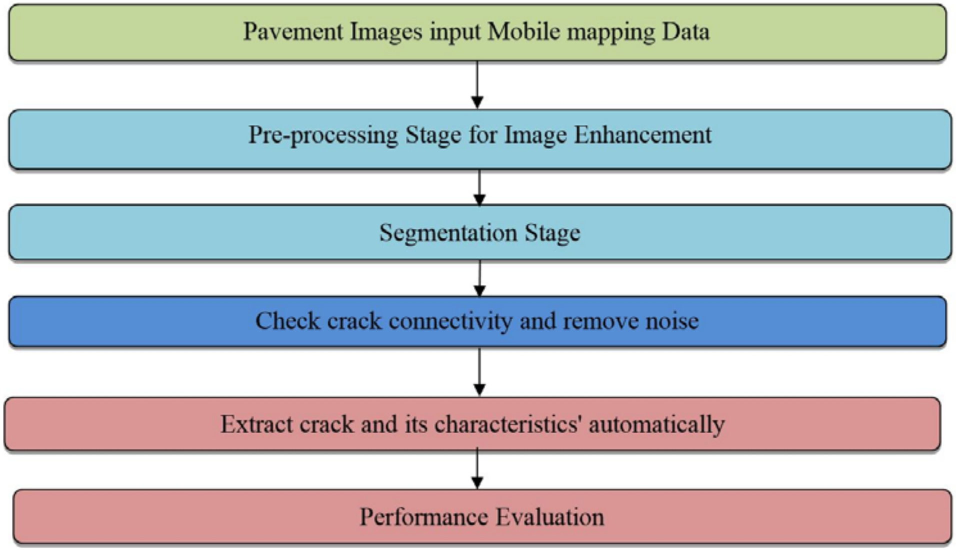

Figure 13: The Processing and Evaluation Methodology for Crack Detection.

The overall proposed algorithm is used for testing various pavement crack images from different countries. The performance is checked by comparing the results with well-known crack detection algorithms. The developed algorithm deliver an average processing time of 3.8 min and the false detection rate is 1.06%. Figure 14 illustrates the processing methodology for crack detection.

Figure (14a) presents the original image (crack marked by red rectangle), in (b) the resulting image after applying a pre-processing stage is visible, (c) shows the image after applying adaptive local threshold algorithm (segmentation stage), (d) shows the image after applying Sobel edge detector, (e) is the image after applying Hole pixel initial algorithm including several dilation process, in (f) the image after applying labeling connected components algorithm is visible; (g) shows the image after applying contouring algorithm, (h) shows the final image after applying modified binary mask detection algorithm to detect cracks and their characteristics’.

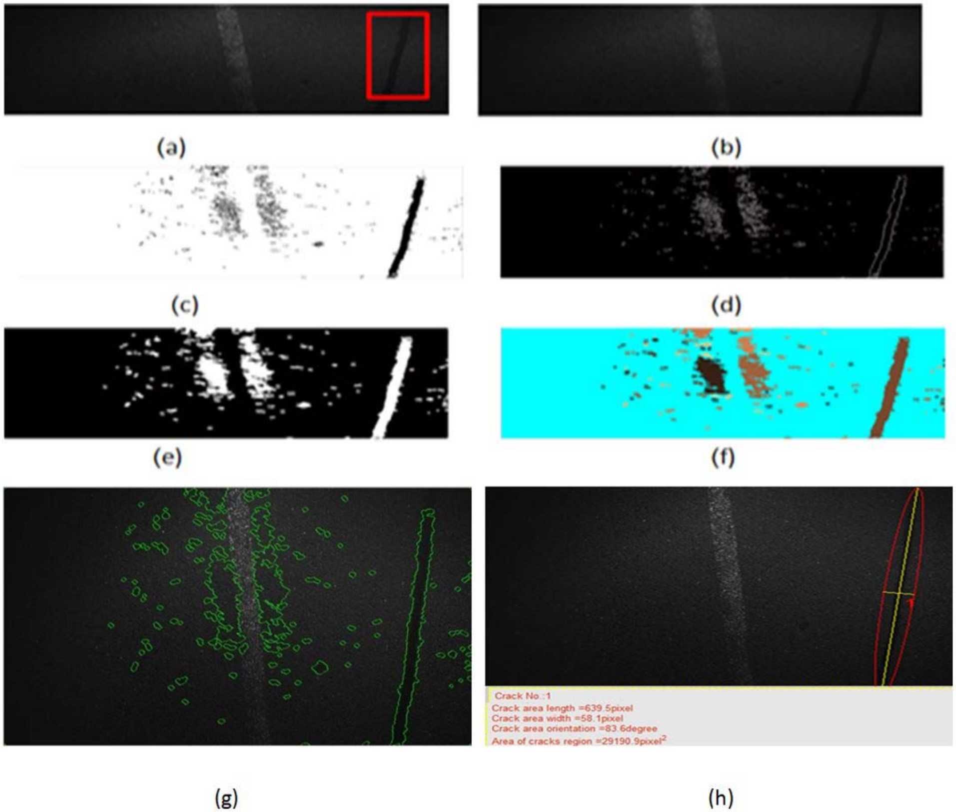

Figure 14: Behavior of Proposed Algorithm Stages for Crack Extraction within Image.

Filter Development for Point Clouds of Aggregate Elements

In the concrete real situation point clouds are often disturbed by noise because of complex measuring environment. It is necessary to remove the noise before further processing of the point cloud data. In order to test several commonly used filtering algorithms, a set of point cloud data with noise for different reasons is processed using the Point Cloud Library (PCL) platform. The dataset is a star-shaped aggregate element that is comprised wood (Figure 15). Since the structure of this component is quite complex with many edges, there is a lot of noise caused by „cometary tail“ phenomena. Moreover, the branches of the component are too thin with only approximately 5mm. Therefore the construction of the correct shape of this component is difficult with these point cloud data.

Figure 15: Aggregate Element and Aggregate Structure.

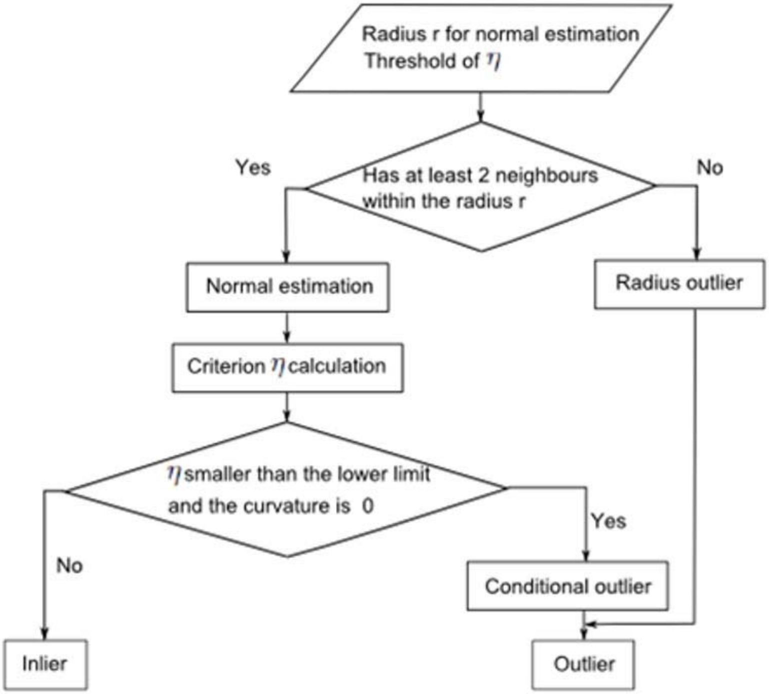

Figure 16: Cometary Tail Removal.

Radius outlier removal and statistical outlier removal are suitable for most types of noise in a 3D point cloud, so they are used for filtering this point cloud. Furthermore, considering that almost all noisy points are at edges and caused by the „cometary tail“ phenomenon, the algorithm „cometary tail“ removal is tested for this point cloud (Figure 16). The normal vectors and curvatures of the points are estimated. The angle between normal vector and camera view direction is considered as selection criterion for the filtering result.

Processing using at first the „cometary tail“ removal filter and in the next step once more the statistical outlier removal might be presumably appropriate (Figure 17).

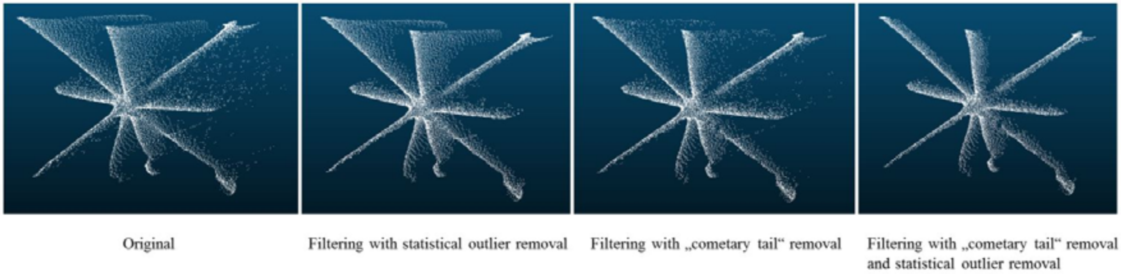

Figure 17: Filter combination.

The new filter „comet tail“ removal should be further developed to make it applicable for registered point clouds and improved to let the filter result more satisfactory. Moreover, it needs to be tested in more point clouds of different material, different colors and with different shapes.

Robotics in Timber Construction

In co-operation with the Institute for Computational Design, the Institute of Building Structures and Structural Design, industrial partners and partners from the state Baden-Württemberg, the project *Robotic Fabrication in Timber Construction* was realized. The goal of this project was to combine robotic fabrication with computational design, simulation processes and 3D-surveying.

The result of this project is a demonstrator pavilion, shown in Figure 18, for the state horticultural show *Landesgartenschau 2014* in Schwäbisch Gmünd. The pavilion is made of 243 wooden plates which was produced by industrial robots. The plates, which consist of plywood with a thickness of 50 millimetres, are preformatted by a CNC-machine and afterwards processed by the robots.

The surveyor’s part in this project was the quality control of the elements and the deformation analysis using laser scanning data. The quality control is done by the laser tracker. The results of the laser tracker measurements was compared to the given design model.

Figure 18: Pavilion (ICD/ITKE/IIGS Universität Stuttgart, 2014).

For the quality control of the plates a laser tracker API Radian was used together with the API IntelliProbe360™. The quality control was done by sampling; this means that out of 243 elements 24 were measured. Only the edges of the plates were measured and compared to the CAD models. A 2D fabrication accuracy of 0.42 mm was reached and only 3% of deviations were significant. Four plates were measured three times; within these additional measurements no significant changes of the plates were detected.

Second part of surveyor’s work in this project was a deformation analysis of the demonstrator. For that reason a geodetic network was set up around the demonstrator and laser scans were done. The demonstrator was scanned three times, first time after completion in May 2014, second time eight weeks later and the third time in October 2014. The deformation analysis itself was made with the commercial software Geomagic Quality 2012. For the comparison of the epochs triangulated irregular networks (TIN) are used. Between the first and the second epoch there are no significant deformations. The result of deformation analysis between the first and the third epoch shows no significant deformations, too

Publications

Refereed Publications

Abdallah, A., Schwieger, V.: Accuracy Assessment Study of GNSS Precise Point Positioning for Kinematic Positioning. In: Schattenberg, J., Minßen, T.-F.: Proceedings on 4th International Conference on Machine Control and Guidance. TU Braunschweig, Braunschweig, 2014.

Beetz, A., Schwieger, V.: Ein Simulationskonzept für die Integration von Positionssensoren in einen Regelkreis zur hochgenauen Führung eines Hecklenkers. In: Wieser, A. (Hrsg.): Ingenieurvermessung 14. Wichmann, Berlin, 2014.

Jafari, M., Schwieger, V., Saba, HR.: Dynamic approachs for system identi?cation applied to deformation study of the dams, ActaGeodaetica et Geophysica, DOI:10.1007/s40328-014-0091-3, 2014.

Krieg, O., Schwinn, T., Menges, A., Li, J.-M., Knippers, J., Schmitt, A., Schwieger, V. (2014): Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design. In: Block P., Knippers, J. Mitra, N., Wang, W. (Editors): Advances in Architectural Geometry 2014. Springer, London, 2014.

Kuhlmann, H., Schwieger, V., Wieser, A., Niemeier, W.: Engineering Geodesy - Definition and Core Competencies. Journal of Applied Geodesy, Heft 4, S. 327-334, de Gruyter, 2014.

Non-Refereed Publications

Breitenfeld, M., Wirth, H., Scheider, A., Schwieger, V.: Development of a Multi-Sensor System to optimize the Positioning of Hydrographic Surveying Vessels. In: Schattenberg, J., Minßen, T.-F.: Proceedings on 4th International Conference on Machine Control and Guidance. TU Braunschweig, Braunschweig, 2014; und Interexpo Geo-Siberia, Novosibirsk, Russia, 16.-18.04.2014.

Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Kuhlmann, H., Schwieger, V.: Mobile Messroboter. Akademie Aktuell. Zeitschrift der Bayerischen Akademie der Wissenschaften. Ausgabe 04, München, 2014.

Kuhlmann, H., Schwieger, V., Wieser, A., Niemeier, W.: Engineering Geodesy - Definition and Core Competencies. FIG International Congress, Kuala Lumpur, Malaysia, 16.-21.06.2014.

Lin, X. Beetz, A., Schwieger, V.: Evaluation of Control Quality using GNSS-RTK for an Outdoor Construction Machine Simulator. In: Schattenberg, J., Minßen, T.-F.: Proceedings on 4th International Conference on Machine Control and Guidance. TU Braunschweig, Braunschweig, 2014.

Metzner, M.: Time Series Analysis for Construction Monitoring. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Metzner, M., Schwieger, V.: Analyse von Messreihen im Zeitbereich. 129. DVW-Seminar: Zeitabhängige Messgrößen - Ihre Daten haben (Mehr-)Wert. Hannover, 26.-27.02.2014.

Scheider ,A.: Detecting and Modeling Fine Structures from TLS Data. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Scheider, A., Schwieger, V.: Optimierung eines Multisensorsystems zur hydrographischen Positionsbestimmung. In: Wieser, A. (Hrsg.): Ingenieurvermessung 14. Wichmann, Berlin, 2014.

Scheider, A., Wirth, H., Breitenfeld, M., Schwieger, V.: HydrOs - An Integrated Hydrographic Positioning System for Surveying Vessels. FIG International Congress, Kuala Lumpur, Malaysia, 16.-21.06.2014.

Schmitt, A.: Combining Laser Tracker and Laser Scanner Data. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Schwieger, V.: Kinematic and Dynamic Deformation Modelling. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Schwieger, V.: Qualitätsmanagement und Qualitätssicherung in der Ingenieurgeodäsie. Allgemeine Vermessungsnachrichten, Jahrgang 121, Heft 11-12, S. 371-376, 2014.

Schwieger, V.: Qualitätsmanangement und -sicherung. In: Kummer, K.,, Kötter, T., Eichhorn, A. (Hrsg.): Das deutsche Vermessungs- und Geoinformationswesen 2015, Unterkapitel zu Forschung in der Ingenieurgeodäsie. Wichman Verlag, Berlin, 2014.

Schwieger, V., Sternberg, H.: Multi-Sensor-Systeme in der Ingenieurgeodäsie - Grundlagen und Realisierungen. 138. DVW-Seminar: Multi-Sensor-Systeme - Bewegte Zufallsfelder. Hamburg, 18.-19.09.2014.

Zhang, L.: Time-Spatial Analysis for Low-Cost GPS Time Series. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Zheng, B.: TLS for Calibrating Finite Element Models. In: Karpik, A., Schwieger, V., Novitskaya, A., Lerke, O. (Hrsg.): Proceedings on International Workshop on Integration of Point- and Area-wise Geodetic Monitoring for Structures and Natural Objects. SSGA, Novosibirsk, Russia, 2014.

Books and Book Contributions

Kuhlmann, H., Schwieger, V.: Ingenieurgeodäsie. In: Kummer, K.,, Kötter, T., Eichhorn, A. (Hrsg.): Das deutsche Vermessungs- und Geoinformationswesen 2015. Wichman Verlag, Berlin.

Presentations

Schwieger, V.: Recent Automation Developments in Surveying. Summer School at University of Stuttgart. Initial Training Network for Digital Cultural Heritage, Stuttgart, 21.10.2014.

Schwieger, V.: Map Matching Applications. Seminar SE 3.05 „GPS/INS-Integration und Multisensor-Navigation“, Carl-Cranz-Gesellschaft e.V., Oberpfaffenhofen, 12.11.2014.

Zhang, L.: Raum-zeitliche Analyse von Low-Cost GPS Zeitreihen. DGK Doktorandenseminar Bonn, 06.06.2014.

Zheng, B.: Kalibrierung von Finite Elemente Modellen mittels TLS Messungen. DGK Doktorandenseminar Hannover, 23. bis 24.05.2014.

Activities at University and in National and International Organisations

Volker Schwieger

Vice Dean of Faculty of Aerospace Engineering and Geodesy, University of Stuttgart
Spokesperson of Centre for Transportation Research at University of Stuttgart (FOVUS)
Executive Board of Cooperation German Rail (DB) and University of Stuttgart
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Head of Working Group III „Measurement Methods and Systems“ of Deutscher Verein für Vermessungswesen (DVW)
Chief Editor of Peer Review Process for FIG Working Weeks
Member of Editorial Board Journal of Applied Geodesy
Member of Editorial Board Journal of Applied Engineering Science
Member of Editorial Board Journal of Geodesy and Geoinformation

Martin Metzner

Member of the NA 005-03-01 AA „Geodäsie“ at the DIN German Institute for Standardization

Li Zhang

Vicechair of Administration of FIG Commission 5 „Positioning and Measurement“
Member of Working Group III „Measurement Methods and Systems“ of Deutscher Verein für Vermessungswesen (DVW)

Diploma Theses and Master Theses

Abusharkh, Mohammed: Analysis of damage dynamics on the North-East facade of the HFT-Stuttgart using finite element method (FEM). (Supervisor: Zheng)

Anamelechi, Falasy Ebere: Creation of a digital elevation model which can be used by a field robot for navigation and localization. (Supervisor: Metzner)

Drogeanu, Florentin-Alexander: Deformation Analysis for Composed Structures Based on Volume Comparison. (Supervisor: Scheider/Zheng)

Ghalawinji, Ibrahim: Development of a Kalman Filter for Dead Reckoning of Paver, Curb and Gutter Applications. (Supervisor: Lerke)

Gaube, Matthias: Parametrisierung und Vergleich verschiedener Trassierungsarten. (Supervisor: Metzner)

Haji Sheikhi, Meysam: Accuracy Analysis for the low-cost GPS antennas with different shieldings (Supervisor: Zhang)

Han, Xiaoqian: Detection of thin limitation surfaces in TLS-point clouds with regard to quality assurance timber construction elements. (Supervisor: Schmitt)

Hanlioglu, Ayse Ecehan: Accuracy Estimation for Railway Clearance Determination using Laser Scanner Based Multisensorsystem. (Supervisor: Schwieger)

Jose Pullamthara, Jiny: Implementation of GNSS in Realtime-Positioning for an Outdoor Construction Machine Simulator . (Supervisor: Lin)

Kauker, Stephanie: Detektion von Ortungslücken bei kinematisch erfassten GNSS-Messungen. (Supervisor: Scheider)

Kerekes, Gabriel Adrian: Evaluation of the Control Quality for a Construction Machine Simulator using the Laser Tracker API Radian. (Supervisor: Lerke)

Lai, Yi-Chen: Implementation of a Realtime Multisensor System. (Supervisor: Schützle)

Samad, Rokshana Binta: GIS based Analysis for Developing Residental Land Suitability. (together with the Institute of Regional Development Planning Supervisor: Fina/Schwieger)

Giannoulakis, Michail: GIS Methodologies as an Input to Strategic Railway Planning: A Case Study in Greece (Fina / Schwieger)

Schilling, Jan: Erstellung eines Algorithmus zur Validierung von Objekten, die mittels Ultraschall erkannt werden. (Supervisor: Metzner)

Schmid, Dominik: Detektion von verbauten Holzelementen in Laserscans. (Supervisor: Schmitt)

Wilhelm, Johannes: Deformationsanalyse eines Holzpavillons. (Supervisor: Schmitt)

Study Theses and Bachelor Theses

Friedrich, Janina: Integration von Tachymetern in ein hydrografisches Ortungssystem. (Supervisor: Scheider)

Fritsch, Benjamin: Vergleich von gescannten komplexen Strukturen mit CAD-Modellen. (Supervisor: Scheider)

Karaca, Mehmet: Vergleich der GNSS-Auswertesoftwarepakete Bernese und Wa1. (Supervisor: Abdallah/Zhang)

Laatsch, Stephan: Bestimmung der Bauwerksverformung des ICD/ITKE Forschungspavillions. (Supervisor: Scheider)

Schirmer, Isabella: Kinematische Positionsbestimmung mittels auf einer bewegten Plattform befestigter Tachymeter. (Supervisor: Scheider)

Zhang, Lifan: Implementation and Comparison of Different Filters for TLS Point Clouds. (Supervisor: Zheng)

Zhang, Wei: Zeitreihenanalyse und Analyse der räumlichen Korrelation für Low-Cost GPS Empfänger. (Supervisor: Zhang)

Education

SS14 and WS14/15 with Lecture/Exercise/Practical Work/Seminar

Bachelor Geodesy and Geoinformatics

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

Master Geodesy and Geoinformatics

Deformations Analysis (Schwieger, Zhang)	1/1/0/0
Industrial Metrology (Schwieger, Kanzler, Schmitt)	1/1/0/0
Land Development (Eisenmann)	1/0/0/0
Monitoring Project (Lerke)	0/0/2/0
Monitoring Measurements (Schwieger, Lerke)	1/1/0/0
Project Management in Engineering Geodesy (Wiltschko, Völter)	2/0/0/0
Causes of Construction Deformation (Metzner/Scheider)	1/1/0/0

Transport Telematics (German) (Metzner, Scheider)	2/2/0/0
Thematic Cartography (German) (Zheng)	1/1/0/0
Terrestrial Multisensor Data Acquisition (German) (Zheng, Schmitt)	1/1/0/0

Master GeoEngine

Integrated Field Work (Metzner, Kauker)	0/0/10 days/0
Kinematic Measurement Systems (Schwieger, Lerke)	2/2/0/0
Monitoring (Schwieger, Lerke)	1/1/0/0
Thematic Cartography (Metzner, Kauker)	1/1/0/0
Transport Telematics (Metzner, Scheider)	2/1/0/0

Bachelor Aerospace Engineering

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

Master Aerospace Engineering

Transport Telematics (German) (Metzner, Scheider)	2/2/0/0

Bachelor Civil Engineering

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

Master Civil Engineering

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

Bachelor Technique and Economy of Real Estate

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

Bachelor Transport Engineering

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

Master „Infrastructure Planning“

GIS-based Data Acquisition (Zheng, Schmitt)	1/1/0/0

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Head of Institute

Prof. Dr.-Ing. Nico Sneeuw

Emeritus

em. Prof. Dr.-Ing. habil. Dr.tech.h.c.mult. Dr.-Ing.E.h.mult. Erik W. Grafarend

Academic Staff

Dr.-Ing. Markus Antoni	physical geodesy, satellite geodesy
Prof. Dr. sc. techn. Wolfgang Keller	physical geodesy, GNSS
Dr.-Ing. Friedrich Krumm	adjustment theory, mathematical geodesy
Dr.-Ing. Mohammad Tourian (since 1.4.)	satellite geodesy, hydrology
Dr.-Ing. Tilo Reubelt (until 1.4)	satellite geodesy
Dipl.-Ing. Matthias Roth	physical geodesy, satellite geodesy

Research Associates

M.Sc. Abbas Abedini (until 18.11)	satellite geodesy, hydrology
M.Sc. Qiang Chen	satellite geodesy
M.Sc. Balaji Devaraju (until 31.10)	physical geodesy, hydrology
M.Sc. Omid Elmi	remote sensing
Dr.-Ing. Siavash Iran Pour	future satellite missions
M.Sc. Muhammad Javaid	satellite geodesy
M.Sc. Huishu Li	satellite geodesy
M.Sc. Wei Liu (since 1.10)	satellite geodesy
M.Sc. Shirzad Roohi	altimetry, hydrology

M. Tech. Bramha Dutt Vishwakarma	hydrology, filter methods
M.Sc. Geli Wu (until 30.6)	satellite geodesy, hydrology
M.Sc. Zhourun Ye (until 31.10)	satellite geodesy
M.Sc. Jinwei Zhang	satellite geodesy, hydrology

Administrative/Technical Staff

Dipl.-Ing. (FH) Thomas Götz	IT system, controlling
Dipl.-Betriebsw. (FH) Wanda Herzog (since 1.11)	study course management
Dipl.-Ing. (FH) Ron Schlesinger	IT system, technical support
Anita Vollmer	Secretary

Guests

BSc. Sujata Goswami, Roorkee/India, IIT-Master-Sandwich DAAD (14.10.13 – 28.03.14)
Prof. Dr. E. Issawy, Cairo/Egypt (30.5. – 11.6.)
Assoc. Prof. Yi Lin, Tongji/China (18.09.14 – 15.09.15)

Additional Lecturers

Dipl.-Ing. Steffen Bolenz, Stadtmessungsamt, Stuttgart
PD Dr.-Ing. habil. Johannes Engels, Stuttgart
Dipl.-Ing. Dieter Heß, Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg, Stuttgart
Dipl.-Ing. Günther Steudle, Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg, Stuttgart

Research

Genetic-Algorithm Based Search Strategy for Optimal Scenarios of Future Dual-Pair Gravity Satellite Missions

Research into time-variable gravity field recovery by future satellite missions is currently focusing on the use of double satellite pairs in a so-called Bender constellation. The primary objective is to achieve higher temporal and spatial resolutions. However, the search space for finding optimal scenarios of double pairs is vast as the performance of the mission scenarios is a function of the orbital parameters of both pairs. The inclination of each pair, the temporal evolution of ground-track pattern of the missions, missions' altitudes, relative ascending node angles of the pairs and inter-satellite distances within each pair have important impacts on the gravity recovery quality of the mission scenarios.

This work employs genetic algorithms on top of the expertise from previous studies to find optimal scenarios for retrieving the geophysical signals. This means that the genetic algorithm approach is used as the main search strategy tool of this research, where restrictions from our previous experiences are considered in the running process as well. The main performance criterion of our genetic algorithm method is the global (accumulated) geoid height error RMS. That means, our main concern in running the algorithm, mapped into a fitness function, is to minimize the global geoid height error RMS, i.e. the constellations which provide the minimum error in terms of global geoid height RMS are desirable. In this way, the error in a specific time interval is defined as difference between mean of geophysical signals and the gravity solution (output of simulation). Of course, it could be possible to think of a more complex fitness function where the function is a weighted average of different performance criteria. However, the main reason to take such a simple performance criterion here was to avoid the complexity of a weighting procedure, where not enough knowledge over the weighting calculation is provided.

The result of our GA approach (Figure 1) for maximum SH degree and order 100, indicates a high stability of the scenarios' fitness values w.r.t. the choice of the orbital parameters of the constellations. Looking into the orbital parameters of individual scenarios, we found that most of the variations within the grey band of Figure 1 (top) are caused by $\Delta\Omega$ while the fitness is insensitive to the changes in differential ΔM (Figure 1 bottom).

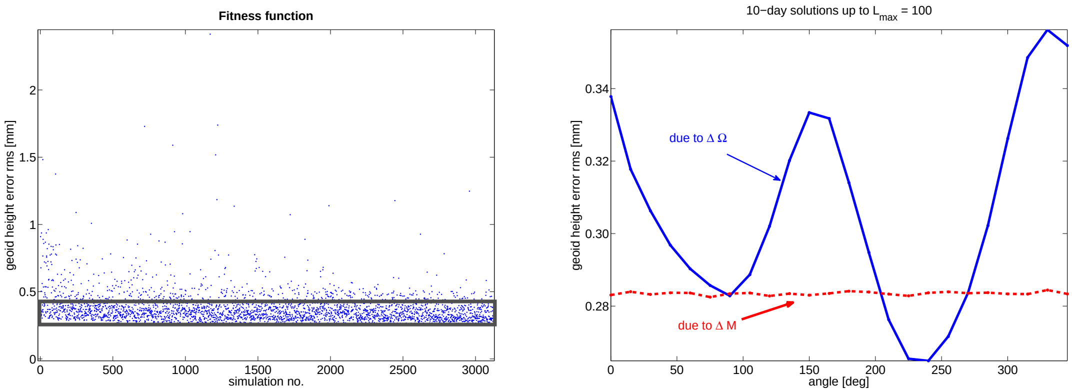

Figure 1: Fitness function values (in global geoid height error RMS) from genetic algorithm for the satellite scenarios (top) and dependence of the solutions of the grey band on $\Delta\Omega$ and ΔM (bottom); The results are based on 10-day solutions up to maximum degree $L_{\max} = 100$.

From the results above, one can conclude that the parameters $\Delta\Omega$ and ΔM should be excluded from the parameters optimization process or the search space. For the parameter ΔM, it is clear since there is almost no influence by parameter change on the results. For $\Delta\Omega$, however, that is different. In fact, we know that the orbits are drifting within the time, where the drifting rate for each pair within a mission scenario is different. This fact also reveals a disadvantage of employing GA

scenario	β/α [rev./day]	inclination [deg.]	altitude [km]	sub-cycle [day]	ρ [km]
baseline	$172/11$	92	361.9	3	100
	$460/29$	115	342.5	7	

Table 1: Baseline constellation as a result of GA approach and sampling behaviour of the single pairs.

approach for solutions of only one time interval where the quality change within the time-series cannot be seen.

Considering ground-track gap evolution of the single pairs and the results from our genetic algorithm approach, one scenario is selected as the near-optimal or baseline constellation (Table 1), where its global geoid height error RMS is 0.28 mm.

For comparison and as an example, the geoid height error RMS per degree of one year time-series of 10-day gravity solutions up to $L_{\max} = 130$ for the baseline constellation as well as a GRACE simulation scenario is illustrated in Figure 2.

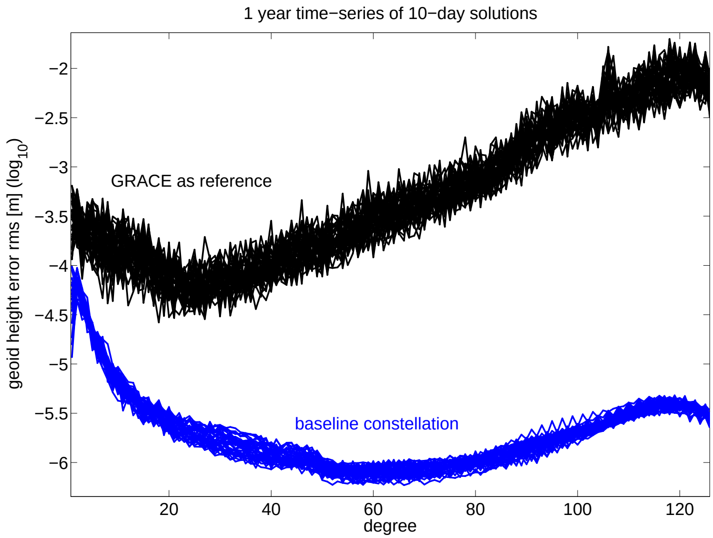

Figure 2: 36 time-series of 10-day solutions of the baseline constellation and GRACE simulation as reference ($L_{\max} = 130$). Please note that the decay of the error spectrum from around degree 115 onwards is due to the smoothing (Gaussian filter of 150 km).

River Water Level Time Series Estimation from Satellite Altimetry (ENVISAT) with Optimized Spatial Coverage and Temporal Resolution Densification
Case Study: Po River (Italy)

Satellite altimetry, one of the key space geodetic data sources for hydrological purposes, is a technique that can determine the water surface height of inland water bodies at an accuracy of several dm (rivers, small lakes, reservoirs) or even sub-dm (large lakes) Being a profiling method, satellite altimetry has a relatively poor spatial sampling that corresponds to the ground-track pattern, wherever it crosses hydrological objects (so-called virtual stations). The time resolution at the virtual stations is dictated by the repeat period of the satellite orbit, which is typically 10 days (TOPEX- and Jason-series) or 35 days (ERS- and Envisat-series, SARAL/Altika). The problem of temporal resolution is even more pronounced in the case of CryoSat-2 mission as its repeat cycle is 369 days. The upcoming Sentinel-3 mission's orbit is a near-polar, sun-synchronous orbit, with a repeat cycle of 27 days (14+7/27 orbits per day, 385 orbits per cycle).

The current limitations in both temporal and spatial resolution inhibit the operational use of altimetry into hydrological models, because river network dynamic behaviour is inadequately captured. However, it has been demonstrated that altimetry-derived water height over rivers can sensibly be used for hydrological studies. Previous researches were motivated to a large extent by the premise that satellite altimetry may fill the gaps left by the decline of gauge stations database. Surprisingly, other hydrological data like discharge is available in the open domain globally to a larger extent than in situ water level data. Since it cannot realistically be expected that the distribution and availability of global in-situ water level stations will be improved in the future, with regional exceptions, research on the use of geodetic satellite data needs to be expanded.

We have investigated a method for full-catchment water level estimation, coping with the limitations of temporal and spatial resolution of satellite altimetry. Our approach to this challenge would hydraulically and statistically connect all virtual stations in a given catchment, using the data of several satellite altimeters (Figure 3). Developing such an algorithm based on current satellite altimetric data e.g. ENVISAT would be highly beneficial for future altimetry satellites, including the operational Sentinel-3 series (3A to be launched 2014) and JASON-CS (launch 2017) of the European Copernicus program.

We deal with the critical issues of temporal resolution and spatial coverage at the same time. To this end, we first treat the inter-satellite biases between different satellites. Afterwards, we need to connect the time series to each other, for which we need to estimate the time lag between the defined virtual stations. In order to define the time lag, we estimate average and time variable slope along the river and we assess the reliability of each. After defining the time lag, we connect the time series through

1. Normalization: we first normalize the data from each virtual station, in which the 10th percentile falls on 0 and the 90th percentile on 1

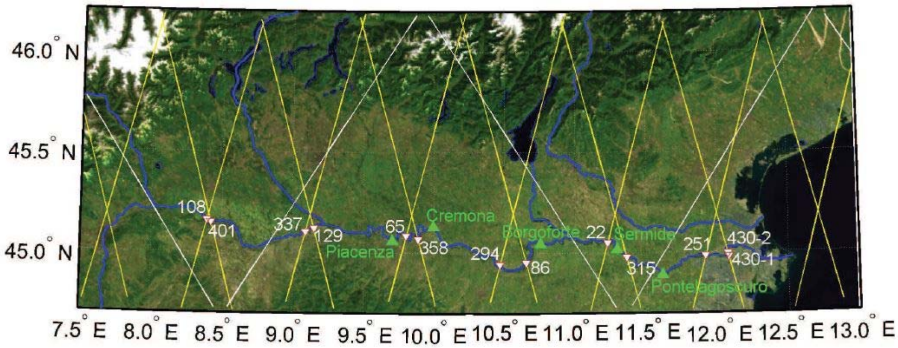

Figure 3: Po River in northern Italy with the ENVISAT (yellow) and TOPEX/Jason 1-2 (white) ground tracks. The green triangles show the location of gauging stations, over which daily in situ water level and discharge are available. The white triangles denote the location of defined virtual stations.

2. Confidence limit definition: we define confidence limits of 99% using Student's t-test for a sliding 1-month time window
3. Outlier identification and rejection by an iterative data snooping method and updating the confidence limits
4. Rescaling: scaling back the combined altimetric measurements to the considered virtual station
5. Constructing the time series using a) simply connecting the measurements and b) a 3-point distance weighted moving averaging

Figure 4 shows the dense time series obtained at the location of virtual station 86 together with its original time series. Comparing the coarse temporal resolution of original time series with the obtained ~ 5-day interval time series highlights the improvement in temporal resolution.

We validate the dense water level time series against available daily in situ data. Figure 5 shows the *in situ* water level time series at Borgoforte station together with the obtained dense water level time series from satellite altimetry derived from two averaging approaches. The validation results show a correlation of 0.8, RMSE of 0.7 m and a Nash-Sutcliffe Efficiency (NSE) coefficient of 0.7. Table 2 lists the results of validation over 5 gauging stations along the Po River. High NSE values for Borgoforte, Sermide and Pontelagoscuro validate our methodology to densify altimetric water level time series. Over Piacenza and Cremona we obtain poor validation results, though, which might be due to water management activities at river's upstream. Also, despite the good NSE, peaks in daily water level data are often missed in our estimation still, which we will investigate in our future work.

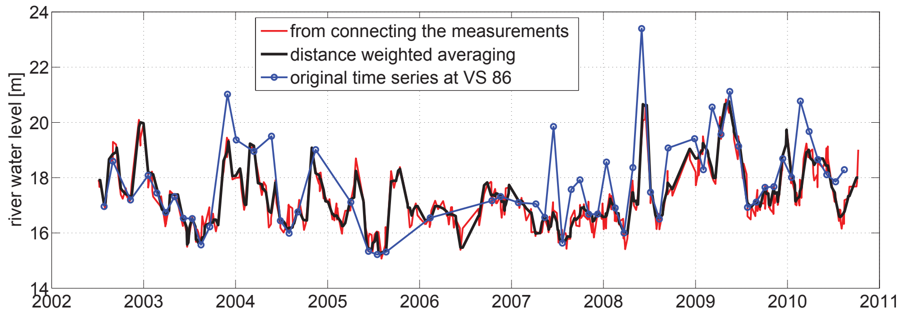

Figure 4: Obtained dense time series over the virtual station 86 together with its original time series from ENVISAT.

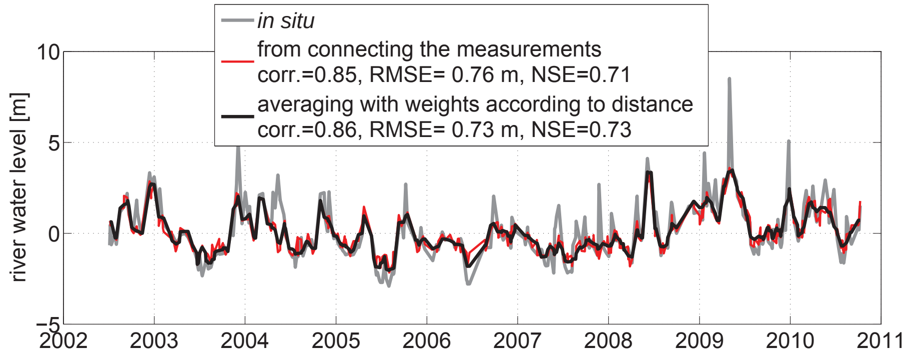

Figure 5: Validation of obtained altimetric dense time series from two averaging approaches against in situ *data.*

VS at	RMSE [m]	Correlation	NSE
Piacenza	0.63	0.71	**0.36**
Cremona	1.16	0.80	**0.20**
Borgoforte	0.73	0.86	**0.73**
Sermide	0.56	0.86	**0.75**
Pontelagoscuro	0.62	0.86	**0.74**

Table 2: Validation results at the location of 5 gauging stations along the Po River.

Storage Variation Estimated by River Discharge Using Least-Squares Prediction

Total water storage changes can be observed by GRACE . However, GRACE has already outlived its predicted lifetime by many years, thus increasing the risk of a possible gap in regular observations of the total water storage changes until GRACE Follow-On becomes operational in 2017. Hence, how to bridge this possible gap is one of the most important topics.

The variation in water storage is the result of interaction between hydrological fluxes e.g. river discharge. The river discharge has been monitored for long time. The relationship between river discharge and storage can be characterized as a Linear Time Invariant (LTI) System, which is revealed in Figure 6. Therefore, using statistical methods to model the relationship of storage and discharge might help to bridge such possible gap.

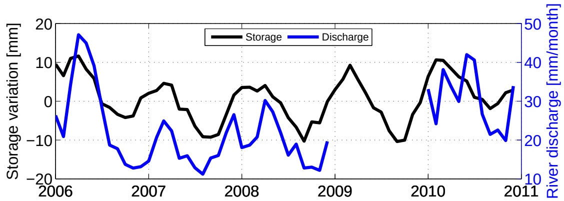

Figure 6: River discharge from GRDC and storage from GRACE of Danube basin

With observations of river discharge only in Danube basin, we explore the viability of least-squares prediction at catchment scale. The storage change of Danube basin is predicted by river discharge, and the results (as shown in Figure 7) are validated by the observations from GRACE. The results (as shown in Figure 7) are validated against in-situ discharge measurements. The Nash-Sutcliffe Efficiency (NSE) of our results can reach 0.73, and NSE with respect to monthly mean is above zero. That reveals a good consistency compared with the observations from GRACE. Therefore, our analysis shows that river discharge can be used to estimate storage change in order to bridge the possible gaps at catchment scale.

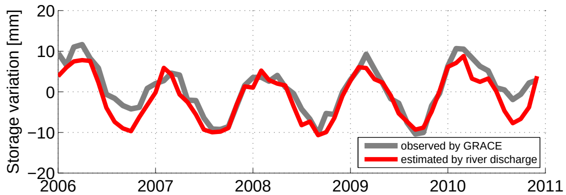

Figure 7: Storage variation estimation by river discharge in Danube basin

GRACE Signal Leakage due to Filtering

Due to high noise in higher degree of spherical harmonic terms from GRACE, filtering is a mandatory process. Filtering reduces noise but affects signal also. Since convolution on sphere is weighted integration over the globe, the behaviour of signal from globe would affect the behaviour of filtered signal evaluated at kernel. The effect of nearby signal while evaluating convolution is termed as leakage. The larger the area enveloped by filter kernel, the larger are the chances of noise reducing to a minimum, and the larger is leakage. Quantifying leakage requires knowledge of filter function *and* signal distribution. Since for GRACE signal is not known beforehand, it is complicated to quantify leakage. However we can use a simulated field and study leakage.

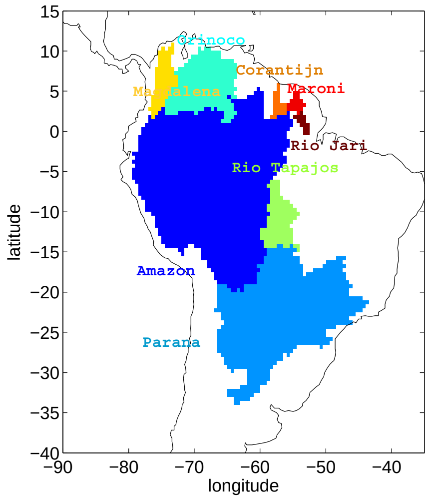

Figure 8: The south American catchments analyzed.

The same methodology can later be applied on GRACE. The first step in this direction would be to visualize leakage, which would help us to attain a raw feeling for the amount of leakage to be expected from a certain catchment. Let us assume a uniform homogeneous field of unit magnitude distribution over catchment 1 and zero field in a nearby catchment 2. Then we compute convolution for catchment 2 in which we want to visualize leakage. Figure 9 shows the leakage behaviour of 8 river catchments (Figure 8) in South America. We used a Gaussian 500 km filter kernel.

The diagonals are basin functions. The off diagonal maps shows inter-catchment leakage.The leakage signal is quite strong near borders and it decays as soon we move away. The visualization of inter-catchment leakage would be very different if we take real distribution of signal instead

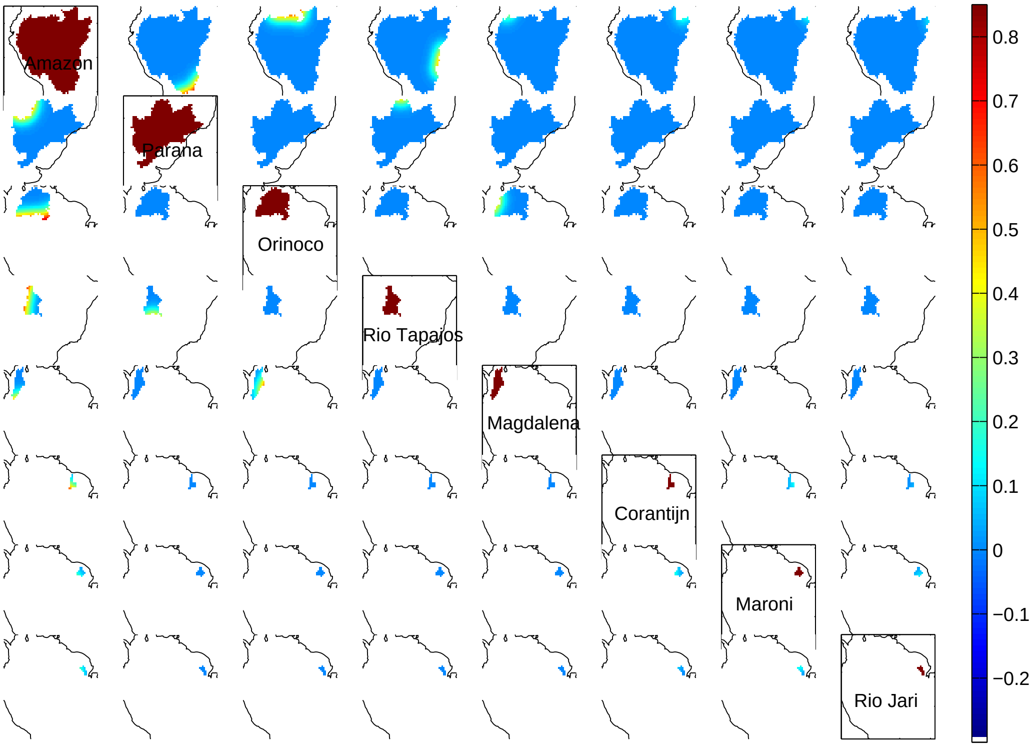

Figure 9: Visualization of inter-catchment leakage for 8 South American catchments; The diagonal maps in boxes represent the basin function. Each row shows how much the catchment (in red) receives leakage from other catchments while the column elements denote how much the catchment (in red) gives away to other catchments. The colour bar represents the signal strength.

of a homogeneous layer. But a first look suggests that major portion of small catchments suffer from leakage. Thus their catchment average would be affected more. While the big catchments would have less affect from leakage. The catchment shape is also a key factor, catchment sharing a longer border leak more into each other. Rio Tapajos receives huge amount of leakage because its shape follows Amazon basin border. Since leakage also depends on the field nearby, we can not judge the situation as of now. The computation of leakage with fields involved provides better insight. We calculated leakage fields following the above mentioned strategy by replacing unit field by WaterGap Global Hydrology Model (WGHM) terestrial water storage change as field. The leakage time-series are shown in Figure 10. The plots are arranged anologous to Figure 9. Leakage

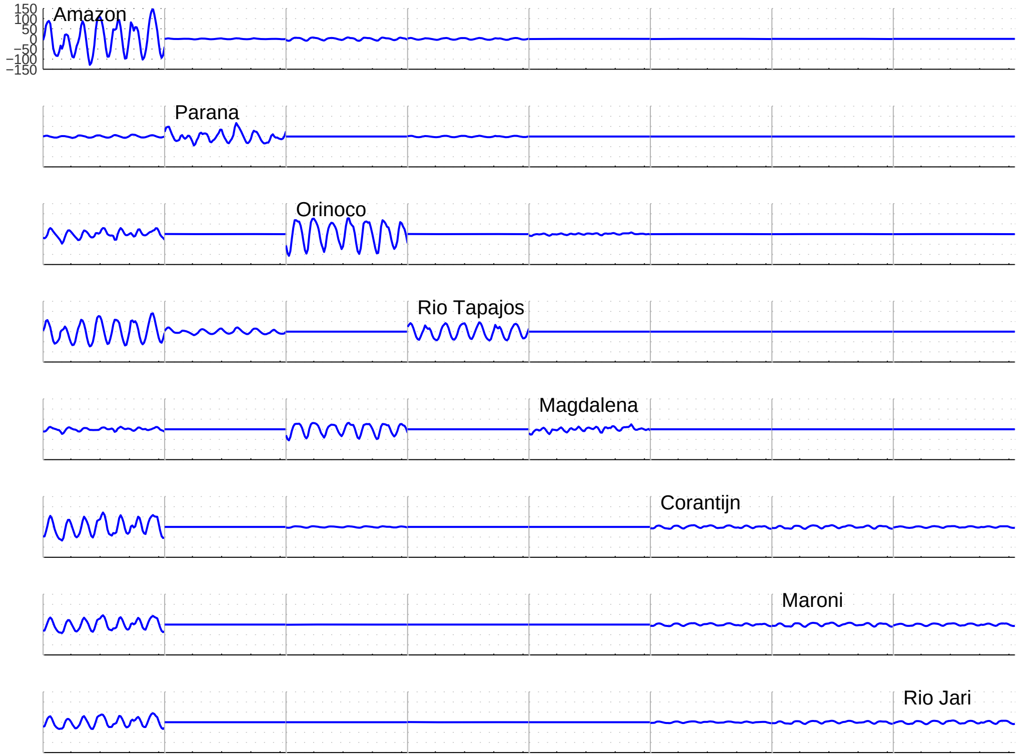

Figure 10: Leakage time-series for 8 South American catchments computed from WGHM *terestrial water storage change; The diagonal maps in boxes represent the filtered catchment time-series. Each plot in a row other than diagonal plot shows leakage time-series for catchment (diagonal), received from other catchments while the plots in columns denote how much the catchment (diagonal) gives away to other catchments.*

is more if catchment is near and small in size. It also depends on smoothing radius, larger the radius more is leakage. After analysing more into mathematics of convolution, we get to know that leakage affects amplitude and phase of the time-series. Thus, using GRACE after filtering might not be accurate representation of the catchment. We need a strategy to recover the signal of a catchment, and this is the future work in this direction.

Multispectral Image Transformations in Water Area Change Detection

Remote sensing techniques have been applied as a powerful tool to provide the temporal variation of Earth related phenomena. In optical images, water bodies appear very dark in infrared and near-infrared bands while they absorb nearly all sunlight in this part of wavelength. So applying a threshold on the image histogram is the common way to build the water mask. Despite its straightforward procedure, precise distinctions among water bodies may not be possible in some areas or seasons because of the complicated relationship between water and land in some area and also because of the effect of vegetation. As well as thresholding, other change detection methods ae widely used to monitor the extent of water bodies. Multispectral transformation analyses like principal components analysis (PCA) and canonical correlation analysis (CCA) are able to highlight the important information about the change in all spectral bands and also to reduce the dimension of data.

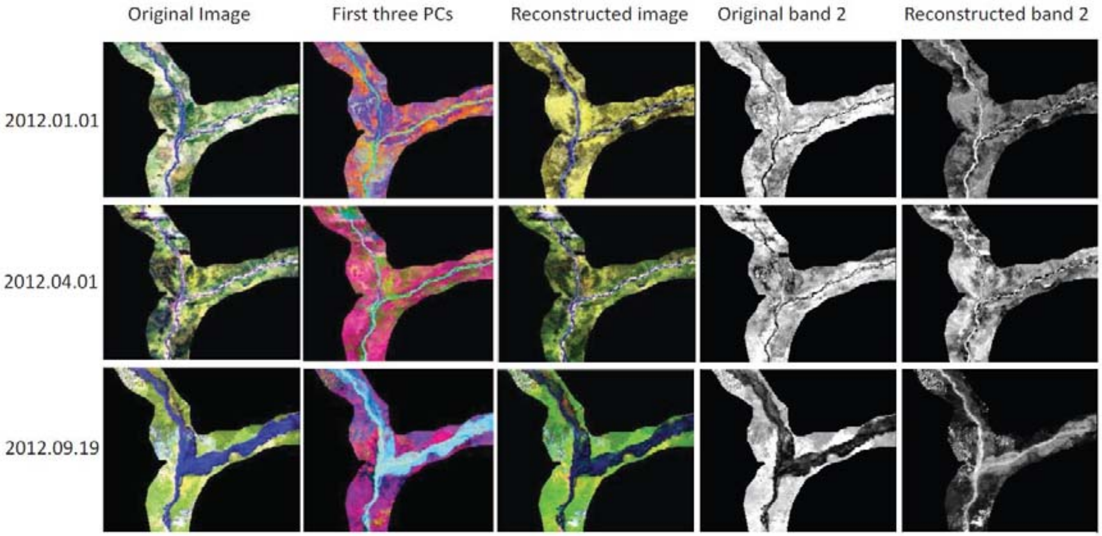

Figure 11: Reconstruction of the images to reduce the noise. (First column) original RGB images.(Second column) Representation of first three PCs.(Third column) Reconstructed images with first three PCs. (Fourth column) Original band 2. (Fourth column) Original band 2. (Fifth column) Reconstructed band 2.

To reduce the noise level of the images and also to enhance the quality of it, PCA transformation is applied to each multispectral image band separately. We then reconstruct the images from first PCs. Moreover, combining the primary PCs as image bands provides an opportunity to improve our understanding about the surrounding area and status of the change.

While each spectral band represents a certain characteristic of Earth, we can highlight the information about water content by using selected PCs based on their coefficients in the eigenvectors.

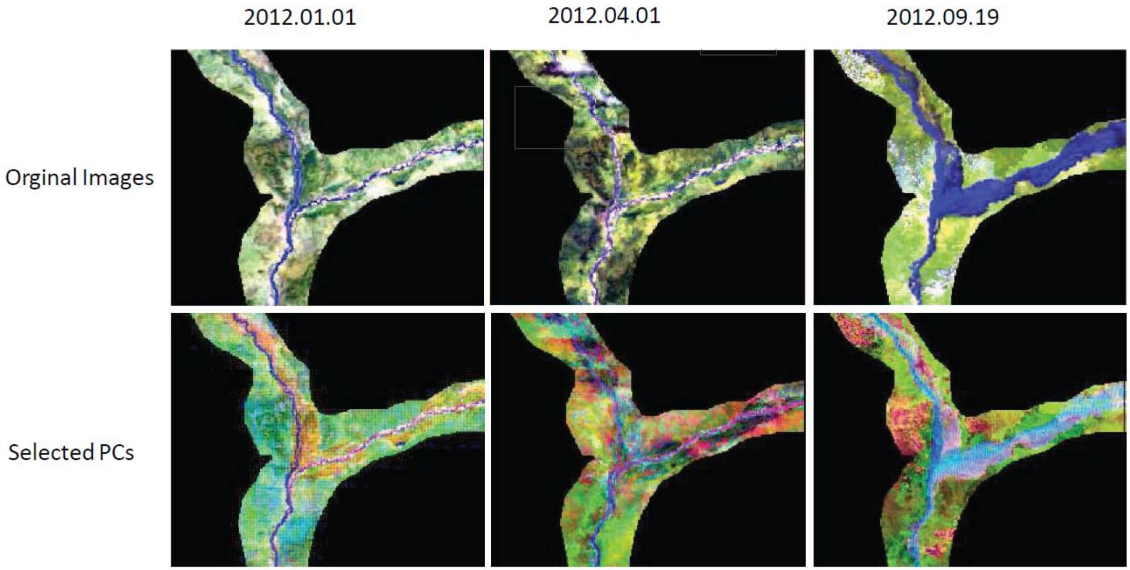

Figure 12: Comparison of original RGB images and images generated by three selected PCs. In each image, PCs in which the appropriate spectral bands have bigger coefficients are selected.

A common way to detect the change in the multitemporal images is to study the difference between them. The difference in value of same pixel in two images represents the change in physical characteristic if two images have the same radiometric basis. To detect the significant change and also to eliminate the trivial pixel values variation, we apply PCA on their image difference. Here we select first and third images of Figure 12 and apply PCA on their image difference and then select the first three PCs while they contain more than 90 % of the total variance.

A key issue is that the change mask should not contain unimportant or nuisance forms of change like an additive shift in mean level or a scaling between different multispectral bands. Unlike normal correlation analysis which is highly dependent on the basis in which the variables are described, CCA is invariant with respect to affine transformations of the different variables. The so-called MAD transformation converts two set of multivariate data (multispectral satellite images) into a number of difference between two linear combinations of original spectral bands using CCA in a way that maximum change is explained in the first MADs. In natural phenomena, the intensity of pixels in the image is strongly correlated with neighbouring pixels, while the noise shows only weak spatial correlations. So to find the area with maximum change and also with high spatial correlation a MAF transformation is applied to the MAD variates. It is expected that major change with high spatial correlation is highlighted in the first MAFs of MADs. This transformation can be considered as a spatial extension of PCA in which the new variates maximize autocorrelation between neighbouring pixels rather than variance.

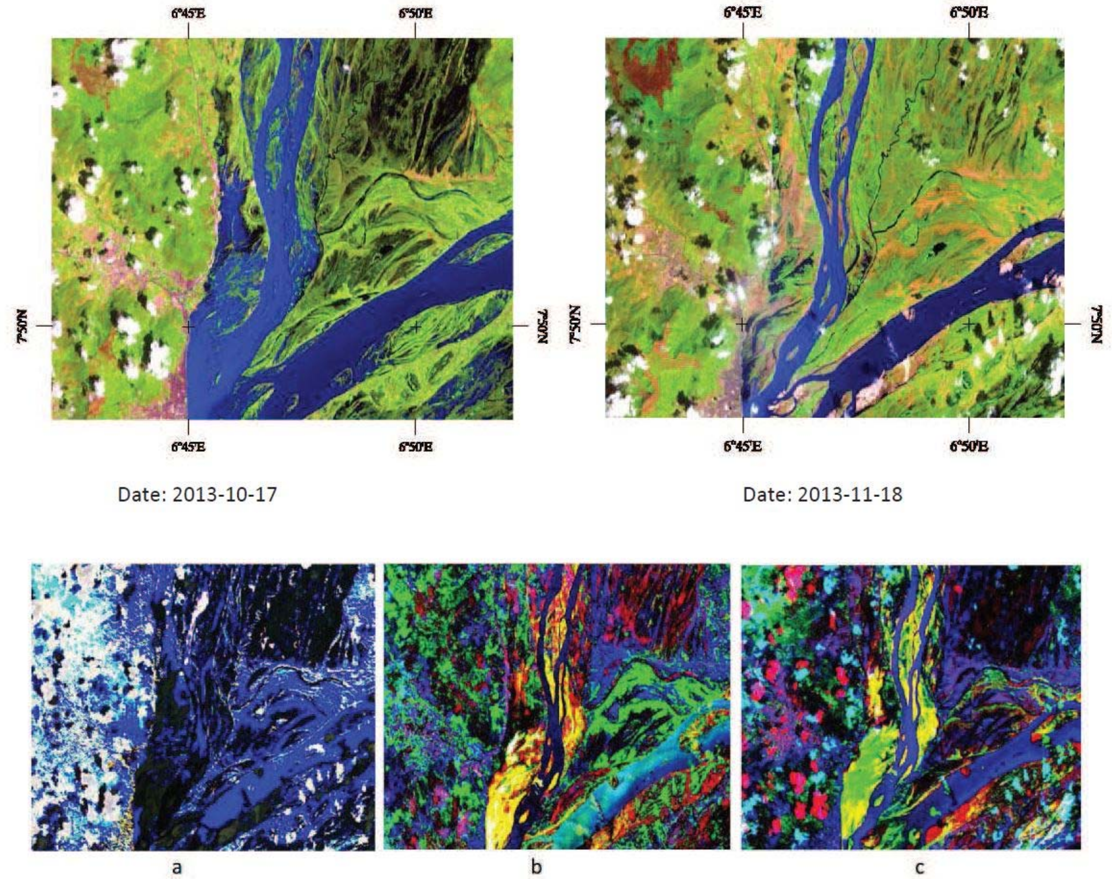

Figure 13: Up: Part of Niger river form Landsat 8 at two different time. Down: a) Ordinary difference of spectral bands 6, 5 and 4, b) Color composite of first three MADs, c) Color composite of first three MAFs.

CryoSat-2 Satellite Mission for Monitoring Water Level Variation of Inland Water Bodies

SAR Interferometry Radar Altimeter (SIRAL) on board the CryoSat-2 mission was designed originally to study variations in the thickness of the Earth's marine ice cover and continental ice sheets. Its primary objective was to study the ice fluctuation in the arctic region due to climate change.

Over the flat ice sheet, land and ocean SIRAL works in Low Resolution Mode (LRM) with limited pulses. For the sea ice areas, coastal zones and some testing areas it collects data in Synthetic Aperture Radar mode (SAR). The most advanced measurement mode is SAR Interferometry (SARIn), which is running mostly over mountain glaciers and the sloped ice sheets. In LRM, SIRAL sends pulses separate enough with an interval of 500 µs to have uncorrelated return signals. By averaging uncorrelated return echoes speckle noise is being reduced. In SAR mode the radar sends a burst of pulses every 11.8 ms. Within a given burst the pulse repetition frequency is about 50 µs, so we have correlated echoes (CryoSat-2 handbook, 2013).

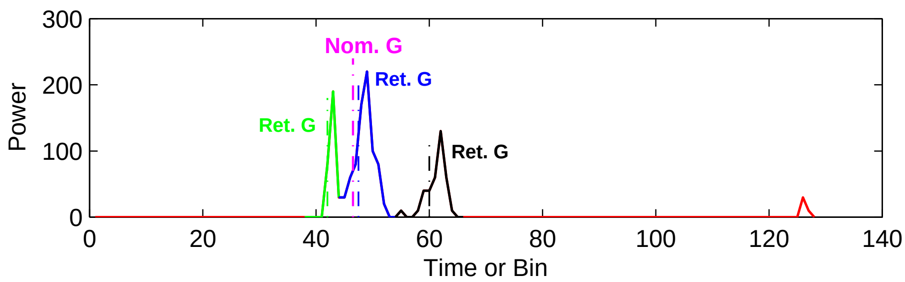

Figure 14: A measured multi-peak waveform from Envisat mission over Urmia lake.

In SARIn mode, both antennas are used for measurements, and so the slope of the illuminated surface can be computed. Based on the phase difference between received echoes on both antennas the origins of the echoes are identified (Wingham et al. 2006).

Full and sub-waveform retracking

Even though we have had progress in the radar system of current missions, on-board range measurements have no enough precision for many hydrological purposes. Therefore we need further process over the on-board measured ranges to provide more precise ranges. To this end, it is necessary to derive the true range from the measured waveforms. Because of complex nature of the surface inside the footprint of the radar, even for small footprint size in SAR mode, some of the reflected echoes back to the radar do not belong to the water surface. These unwanted echoes make spurious peaks and deteriorate the waveform. If the extracted ranges from these corrupted waveforms are used to determine water level, we can't have precise water level monitoring.

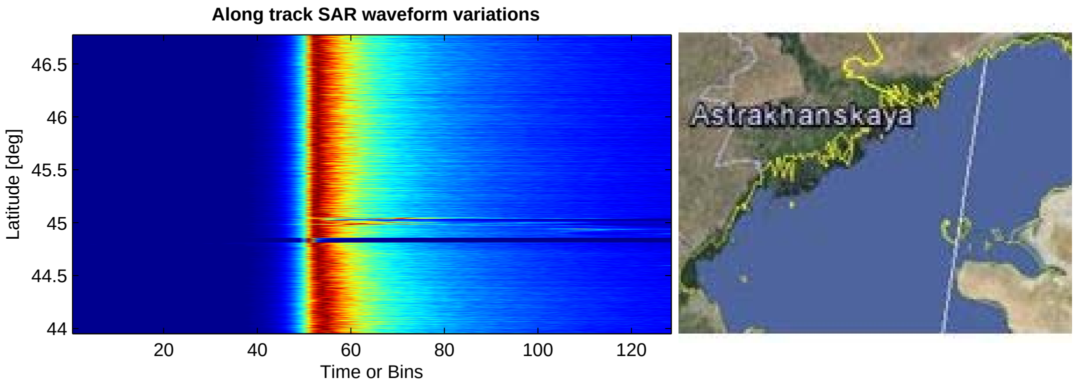

Figure 15: SAR waveform variation for the longest pass (Jan 2011) over northern part of Caspian Sea.

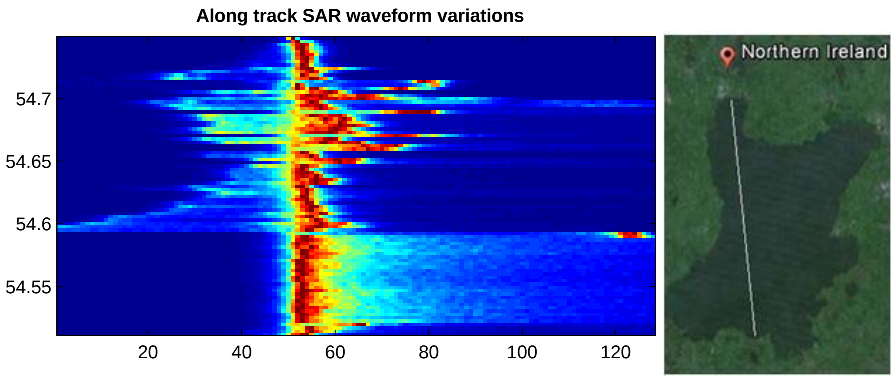

Figure 16: SAR waveform variation for the longest pass (Apr 2012) over Neagh lake (Ireland).

Extracting the true range from the corrupted waveform is a challenge in altimetry for inland water bodies. Retracking and individual SAR data processing techniques help us to fight against this challenge. Retracking is an effective solution to derive the true range measurement from the measured waveforms. The quality of water level estimation depends not only on the retracking but also on the type of retracking algorithms. Since there is no standard way to select a proper retracking for a given water body, we must test different physical retrackers, e.g. β-parameter, SAMOSA, Brown model, and empirical retrackers, e.g. OCOG, threshold, and examine their performance.

In the current research work for the first time in the operating time of CryoSat-2, we analyze data of all modes over different inland water bodies based on the full and sub-waveform with different empirical and physical retracking algorithms. In the full-waveform retracking we retrack a given waveform as one waveform and estimate the corrected range. In the sub-waveform retracking, on the other hand, a given waveform includes some small waveforms, the so called sub-waveform (Figure 14). All detected meaningful sub-waveforms are retracked separately.

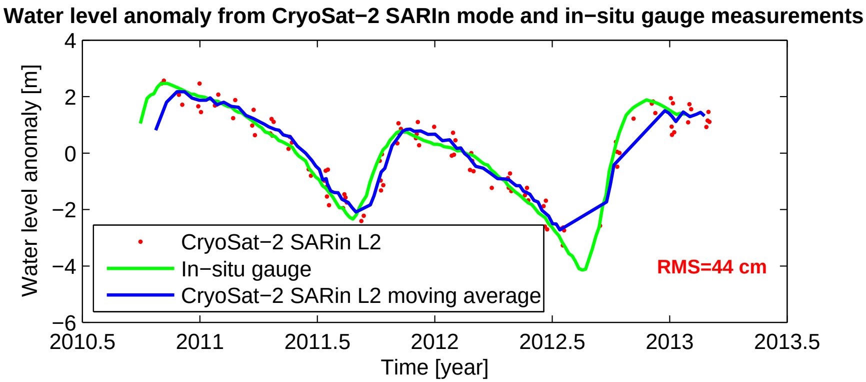

Figure 17: Water level anomaly from CryoSat-2 SARIn mode and in-situ gauge data for Nasser lake (Egypt).

Our analysis shows that for Qinghai lake, covered by LRM, full waveform retracked by 5β parameter retracker, is the best retracking scenario with an RMS of 17 cm. In the case of Nasser lake, observed with SARIn mode, retracking the first detected sub-waveform by 5β parameter (with 44 cm RMS) produces the most accurate water level measurements. Over the northern part of Caspian sea covered by SAR mode, SAMOSA3 retracker provides an RMS of 13 cm for full-waveform retracking.

SHBundle

The history of the SHBundle dates back to 1994 when a first collection of functions concerning spherical harmonic (SH) synthesis and analysis were implemented. Over the years the bundle was distributed to different researchers who in turn added their own functions and eventually spread their versions further.

This habit went well for a long time. However, in the year 2013, we found ourselves in the situation that several persons at our institute worked with different versions of the SHBundle, striving to implement missing functions, however, those were already present in another version. Hence, we decided to collect and unify these different versions into a single software bundle.

The unification process involved four steps. First and foremost, we identified functions with the same purpose, replacing them by the most versatile version. Then, we replaced all variables and code concerning angles by a radian version. After that, we identified time crucial bottlenecks in the code and replaced it by a faster implementation, trying not to loose its educational purpose. Finally, we added better elaborated help text and examples to the functions.

The features of the SHBundle cover at the moment

- SH synthesis and analysis,
- bi-polar SH synthesis,
- Legendre functions/polynomials and SH,
- visualization,
- SH coefficients storage format conversion,
- SH power-spectrum,
- complex SH co-efficients to real and vice-versa.

For the whole unification process we found it highly useful to have the help of git, a well-known source code management system which handles e. g. also the Linux kernel. For this purpose, we set up our own git-server. git made it possible that all contributing persons could easily keep track of the changes done by others. Additionally, we have the complete change records since the start of our unification process which also means that we gan go back to any previous state of the SHBundle.

While now in 2014 the main goal of the unification is reached, the code is still undergoing changes. Hence, for the moment, we decided to make the SHBundle available upon request by writing us an e-mail (bundle@gis.uni-stuttgart.de). The code itself is placed under the GNU General Public Licence version 3, which means that the software can be canged and redistributed. Nonetheless, we would like to encourage everyone who is using the SHBundle to provide us with feedback about problems, usability and missing functions.

All functions also underwent a purpose check whether they fit or do not fit into the SHBundle. It was decided for several of them to form more dedicated bundles like FilterBundle (SH filtering), RotationBundle (SH rotation), visBundle (visualisation) and the commonly used uberall.

Theses

Diploma/Master Theses

(http://www.uni-stuttgart.de/gi/education/MSC/master_theses.de.html)

Efinger, Benjamin: Gravimetrische Untersuchungen und Einflussmodellierung ‘Stuttgart 21’

Li, Haochen: Jekeli’s Approach for Regional GRACE Gravity Field Refinement

Wanthong, Prapas: Height Systems Calculations at Swabian Alb Test Area

Zhang, Jinwei: Analysis of seasonal loading-induced displacements from GPS and GRACE

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

Refereed Journal Publications

Chen Q., T. van Dam, N. Sneeuw, X. Collilieux, M. Weigelt and P. Rebischung: Singular spectrum analysis for modeling seasonal signals from GPS time series. Journal of Geodynamics 72, pp 25-35, DOI 10.1016/j.jog2013.05.005

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Lorenz C., H. Kunstmann, B. Devaraju, M. J. Tourian, N. Sneeuw and J. Riegger: Large-Scale Runoff from Landmasses: A Global Assessment of the Closure of the Hydrological and Atmospheric Water Balances. Journal of Hydrometeorology 15, pp 2111-2139, DOI 10.1175/JHM-D-13-0157.1

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Other Refereed Contributions

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Poster Presentations

Gruber T., M. Baldesarra, P. Brieden, I. Daras, K. Danzmann, B. Doll, D. Feili, F. Flechnter, J. Flury, G. Heinzel, S. Iran Pour, J. Kusche, M. Langemann, A. Löcher, J. Müller, V. Müller, M. Murböck, M. Naeimi, R. Pail, J. C. Raimondo, J. Reiche, T. Reubelt, B. Sheard, N. Sneeuw and X. Wang: Next Generation Satellite Gravimetry Mission Study (NGGM-D). EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Gruber T., M. Baldesarra, P. Brieden, I. Daras, K. Danzmann, B. Doll, D. Feili, F. Flechnter, J. Flury, G. Heinzel, S. Iran Pour, J. Kusche, M. Langemann, A. Löcher, J. Müller, V. Müller, M. Murböck, M. Naeimi, R. Pail, J. C. Raimondo, J. Reiche, T. Reubelt, B. Sheard, N. Sneeuw and X. Wang: Next Generation Satellite Gravimetry Mission Study (NGGM-D). IGFS General Assembly, Shanghai, China (30.6.-6.7.)

Iran Pour S., T. Reubelt and N. Sneeuw: Relative importance of coloured noise vs. model errors in reduced scale gravity field recovery of future satellite missions. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

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Reubelt T., N. Sneeuw, S. Iran Pour, R. Pail, T. Gruber, M Murböck, P. Visser, J. de Texeira de Encarnação, T. van Dam, M Weigelt, S. Cesare and S. Cornara: The ESA project SC4MGV 'Assessment of Satellite Constellations for Monitoring the Variations in Earths Gravity Field overview, objectives and first results'. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Roohi S. and N. Sneeuw: CryoSat-2 SARIn mode success to determine lake level variations. Geodätische Woche Berlin, Germany (7.-9.10.)

Roohi S. and N. Sneeuw: On the performance of CryoSat-2 SAR and LR mode over inland water bodies. New frontiers of altimetry, Ocean Surface Topography Science Team Meeting (OSTST), Constance, Germany (27.-31.10.)

Wang L., T. van Dam, M. Weigelt, M. J. Tourian, Q. Chen and N. Sneeuw: Continental water storage inferred from 3-D GPS coordinates in Danube Basin. AGU Fall Meeting 2014, San Francisco, USA (15.-19.12.)

Wu G., M. J. Tourian and N. Sneeuw: Monitoring Lake Level Variations in Yangtze River Basin Derived from Multi-Mission Satellite Altimetry. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Ye Z., N. Sneeuw, R. Tenzer and L. Liu: Depth inversion of a deep homogeneous layer using gravity and vertical gravity gradient disturbance. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Zhang J., M. J. Tourian and N. Sneeuw: River discharge estimation of Yangtze River by least-squares prediction. Geodätische Woche Berlin, Germany (7.-9.10.)

Zhang J., M. J. Tourian and N. Sneeuw: Storage and discharge estimation of Danube basin by least-squares prediction. Geodätische Woche Berlin, Germany (7.-9.10.)

Zhang Y., R. Widmer-Schnidrig and N. Sneeuw: Coherency analysis between superconducting gravimeters at BFO and Strasbourg. Jahrestagung der Deutschen Geophysikalischen Gesellschaft (DGG), Karlsruhe, Germany (10.-13.3.)

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Antoni M., Roth M. and W. Keller: Construction of directional wavelets on the sphere, Geodätische Woche Berlin (7.–9.10.)

Chen Q., B. Devaraju and N. Sneeuw: Hydrological loading signal observed by GPS and GRACE in South America. Geodätische Woche Berlin, Germany (7.-9.10.)

Daras I., R. Pail, P. Visser, M. Weigelt, S. Iran Pour, M. Murböck, S. Tonetti, T. Gruber, J. Encarnação, S. Cesare, C. Siemes, J. van den IJssel, S. Cornara, T. van Dam, N. Sneeuw and R. Haagmans: Treatment of temporal aliasing on future gravity satellite missions – an insight into ESA-SC4MGV project. GRACE Science Team Meeting Potsdam, Germany (29.9.-1.10.)

Elmi O., M. J. Tourian and N. Sneeuw: River discharge estimation using channel width measurements from satellite imagery (MODIS). Geodätische Woche Berlin, Germany (7.-9.10.) Gruber T. and DLR NGGM-D PROJECT TEAM Next Generation Satellite Gravimetry Mission Study (NGGM-D). GRACE Science Team Meeting, Potsdam, Germany (29.9.-1.10.)

Iran Pour S., J. C. Raimondo, M. Murböck, X. Wang, T. Reubelt, I. Daras, T. Gruber, B. DOLL, R. Pail, F. Flechnter and N. Sneeuw: Auswahl Bahnkonfiguration. DLR NGGM-D project Abschlussseminar, Bonn, Germany (10.7.)

Iran Pour S., J. C. Raimondo, M. Murböck, X. Wang, T. Reubelt, I. Daras, T. Gruber, R. Pail and N. Sneeuw: Towards the selection of optimal gravity satellite missions: Orbit configuration and Technological conditions. Geodätische Woche Berlin, Germany (7.-9.10.)

Iran Pour S., M. Weigelt, M. Murböck, S. Tonetti, P. Visser, I. Daras, J. Encarnação, S. Cesare, C. Siemes, J. van den IJssel, S. Cornara, T. Gruber, T. van Dam, R. Pail, N. Sneeuw and R. Haagmans: Search strategy for optimal double pair scenarios for future gravity satellite missions – experience from the ESA SC4MGV project. 5th International GOCE User Workshop, Paris, France (25.-28.11.)

Murböck M. and DLR NGGM-D PROJECT TEAM: Next Generation Satellite Gravimetry Mission Study (NGGM-D). 5^{th} International GOCE User Workshop, Paris, France (25.-28.11.)

Roohi S., N. Sneeuw, KH Tseng and CK Shum: Full and sub-waveform retracking to assess the ability of pulse limited altimeter in monitoring water level variations of inland water body. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Sneeuw N.: Trends and seasonalities in the gravity field, direct and indirect, from space geodetic methods. The first international workshop on the detailed structure of the Earth gravity field, its temporal variation effects and the national vertical datum modernization. 1st International Workshop, Wuhan, China (20.-22.4.)

Sneeuw N., J. Cai and M. J. Tourian: Current and Future Geodetic Satellite Missions for Global Change Monitoring GSM4GCM. Dragon 3 Mid-Term Results Symposium, Chengdu, China (26.-29.5.)

Sneeuw N., M- J. Tourian, O. Elmi, S. Roohi and Q. Chen: Multi-mission monitoring of the desiccation of Lake Urmia in Iran. Ocean Surface Topography Science Team Meeting (OSTST), Constance (27.-31.10.)

Sneeuw N., M. J. Tourian, O. Elmi, S. Roohi, Q. Chen and B. Devaraju: A spaceborne multi-sensor approach to monitor the desiccation of Lake Urmia in Iran. Geodätische Woche Berlin, Germany (7.-9.10.)

Sneeuw N., M. J. Tourian, O. Elmi, S. Roohi, Q. Chen and B. Devaraju: Komplementarität geodätischer Raumverfahren – ein hydrogeodätisches Beispiel. DGK Jahressitzung, München (12.-14.11.)

Tourian M. J., C. Lorenz, B. Devaraju, J. Riegger, H. Kunstmann and N. Sneeuw: Discharge Estimation Using Hydro-Geodetic Approaches. AGU Fall Meeting 2014, San Francisco, USA (15.-19.12.)

Tourian M. J., T. Qin, A. Tarpanelli, L. Brocca, T. Moramarco and N. Sneeuw: Improving the temporal and spatial resolution of water level time series over Po River (Italy) obtained by multi-mission satellite altimetry. New frontiers of altimetry, Ocean Surface Topography Science Team Meeting (OSTST), Constance, Germany (27.-31.10.)

Vishwakarma B. D. and N. Sneeuw: Aspects of inter-catchment signal leakage due to filtering of GRACE observed total water storages. Geodätische Woche Berlin, Germany (7.-9.10.)

Weigelt M., O. Baur, H. Steffen, A. Jäggi, T. Mayer-Gürr, T. van Dam, M. J. Tourian, K. Sosnica, N. Zehentner and N. Sneeuw: How well can the combination of hlSST and SLR replace GRACE? GRACE Science Team Meeting, Potsdam, Germany (29.9.-1.10.)

Weigelt M., S. Iran Pour, M. Murböck, S. Tonetti, P. Visser, I. Daras, J. Encarnação,, S. Cesare, C. Siemes, J. van den IJesel, S. Cornara, T. Gruber, T. van Dam, Rail, N. Sneeuw and R. Haagmans: A methodology to choose the orbit for a double pair scenario future gravity satellite mission experiences from the ESA SC4MGV project. GRACE Science Team Meeting, Potsdam, Germany (29.9.-1.10.)

Weigelt M., T. van Dam, O. Baur, H. Steffen, M. J. Tourian, A. Jäggi, L. Prange, U. Meyer, H. Bock, T. Mayer-Gürr, N. Zehentner and N. Sneeuw: Pushing the limits of gravity field recovery from high-low satellite-to-satellite tracking – a combination of 10 years of data of the satellite pseudo-constellation CHAMP, GRACE and GOCE. EGU General Assembly, Vienna, Austria (27.4.-2.5.)

Ye Z., N. Sneeuw and L. Liu: 3D constrained inversion of airborne gravity gradient data using the ART method. Geodätische Woche Berlin, Germany (7.-9.10.)

Zhourun Y., N. Sneeuw and L. Liu: Moho depth inversion from gravity and gravity gradient data. 5^{th} International GOCE User Workshop, Paris, France (25.-28.11.)

Books

Flechtner F., N. Sneeuw and W. D. Schuh (Eds.): Observation of the System Earth from Space – CHAMP, GRACE, GOCE and Future Missions. Geotechnologien Science Report No. 20, Springer Verlag, Berlin Heidelberg. DOI 10.1007/978-3-642-32135-1

Grafarend E. W., R. J. You and R. Syffus: Map Projections – Cartographic Information Systems. 2nd edition. Vol. 1, pp 413, Vol. 2, pp 520, Springer, Berlin, Heidelberg, New York

Gruber T. and NGGM-D Team: e^2.motion: Earth System Mass Transport Mission (Square) – Concept for a Next Generation Gravity Field Mission . Final Report of Project Satellite Gravimetry of the Next Generation (NGGM-D). Deutsche Geodätische Kommission der Bayerischen Akademie der Wissenschaften, Reihe B Angewandte Geodäsie, No. 318, München, ISBN 978-3-7696-8597-8

Guest Lectures and Lectures on special occasions

Jäggi, A. (Astronomisches Institut, Universität Bern, Switzerland): Bahnbestimmung im Zeitalter der Space Geodesy (10.1.)

Lectures at other universities

Grafarend E.:
The Geodetic Cosmos, Technical University Budapest, Department of Geodetic Sciences, Budapest, Hungary (3.10.)

Keller W.:
Wavelets for Geodynamics, University of Environmental Sciences Wroclaw (22.4 – 26.4)

Sneeuw N.:
Hydrogeodesy, Geodetic quantification of the continental water cycle, ESPACE Seminar, TU München (27.1.)
Satellite Gravimetry and its Applications in Earth Science, Chinese Academy of Surveying and Mapping, Beijing, China (15.4.)
Spaceborne gravimetry: Present and future missions and applications, University of Isfahan, Isfahan, Iran (1.10.)
A spaceborne multi-sensor approach to monitor the desiccation of Lake Urmia in Iran, University of Tehran, Tehran (29.9.) + Sharif University, Tehran, Iran (30.9.)
Spaceborne gravity field mapping – theoretical considerations, Institute for Theoretical Physics, University of Bern (3.12.)
Inland Altimetry II, SPP-Summerschool, Mayschoss, Germany (15. – 19.9.), together with M. J. Tourian

Research Stays

Grafarend E.:
Finnish Geodetic Research Institute, Masala/Helsinki, Finland (12.8. – 31.8.)
Seismological Institute, Academy of Sciences, Budapest, Hungary (1. – 8.10.)

Keller W.:
National University of Tainan, Taiwan (2.7. – 8.8)

Sneeuw N.:
Department of Surveying and Geomatics Engineering, College of Engineering, University of Tehran, Iran (29.9. – 3.10.)

Lecture Notes

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

Grafarend E. W. and F. Krumm:
Kartenprojektionen (Map Projections), 236 pages

Keller W.:
Foundations of Satellite Geodesy, 51 pages
Foundations of Satellite Geodesy (Viewgraphs), 281 pages
Observation Techniques in Satellite Geodesy, 211 pages

Krumm F.:
Map Projections and Geodetic Coordinate Systems, 236 pages
Mathematical Geodesy (Landesvermessung), 170 pages
Reference Systems (Referenzsysteme), 174 pages

Sneeuw N.:
Geodesy and Geoinformatics, Part Geodesy, 31 pages
History of Geodesy, 38 pages
Physical Geodesy, 137 pages

Sneeuw N., Krumm F. and Roth M.:
Adjustment Theory, 155 pages

Participation in Conferences, Meetings and Workshops

Keller W.
The 3rd International Gravity Field Service (IGFS) General Assembly, Shanghai, China (30.6-6.7)

Schlesinger R.
Erfahrungsaustausch der Anwender des Relativgravimeters Scintrex CG-5, Universität Hamburg, Institut für Geophysik (04.-06.03.)

Sneeuw N.
DVW Fachtagung, Biberach, Germany (7.5.)
Dragon-3 Mid-Term-Result 2014 Symposium, Chengdu, China (26.-29.5.)
Geodetic Week, Berlin, Germany (6.-9.10.)
SARAL/AltiKa Workshop, Konstanz, Germany (27.10.)
Ocean Surface Topography Science Team (OSTST), Konstanz, Germany (28.-31.10.)
GOCE User Workshop, Paris, France (25.-28.11.)

University Service

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

Keller W.
Associate Dean (Academic) Geodäsie & Geoinformatik and GeoEngine, Stuttgart

Roth M.:

Member/chairman of the PR-committee of the study course Geodesy & Geoinformatics
Member of the appointments committee “Photogrammetry, Remote Sensing and Geoinformatics”

Sneeuw N.

Search Committee Photogrammetrie, Fernerkundung und Geoinformation
Search Committee Differentialgeometrie
Search Committee Navigation und geodätische Schätzverfahren
Search Committee Satellitentechnik
Stand-by Member Senate Committee for Structural Development and Research, Stuttgart

Professional Service (National)

Grafarend E. Emeritus Member German Geodetic Commission (DGK)

Sneeuw N.

Full Member Deutsche Geodätische Kommission (DGK)
Chair DGK section ”Erdmessung”
Member Scientific Board of DGK
Member Scientific Advisory Committee of DGFI
Chair AK7 (Working Group 7), ”Experimentelle, Angewandte und Theoretische Geodäsie”, within DVW (Gesellschaft für Geodäsie, GeoInformation und LandManagement)

Professional Service (International)

Grafarend E.

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

Sneeuw N.

President IAG InterCommission Committee on Theory (ICCT)
Member Editorial Board of Studia Geophysica et Geodaetica
Member of IAG GGOS Working Group Satellite Missions
Fellow International Association of Geodesy (IAG)
Member Assessment Panel ”Space Research”, NWO, Netherlands

Courses – Lecture/Lab/Seminar

Advanced Mathematics (Keller, Antoni)	3/2/0/0
Aktuelle Geodätische Satellitenmissionen (Sneeuw)	2/2/0/0
Amtliches Vermessungswesen und Liegenschaftskataster (Steudle)	2/0/0/0
Amtliche Geoinformation (Heß)	2/0/0/0
Ausgewählte Kapitel der Parameterschätzung (Krumm, Roth)	2/2/0/0
Ausgleichungsrechnung I, II (Krumm, Roth)	3/1/0/0
Dynamische Erdmodelle (Tourian)	0/2/0/0
Dynamische Satellitengeodäsie (Sneeuw, Tourian)	1/1/0/0
Einführung Geodäsie und Geoinformatik (Sneeuw)	2/2/0/0
Foundations of Satellite Geodesy (Keller)	2/1/0/0
Integriertes Praktikum/Integrated Field Work (Keller, Sneeuw)	10 days
Koordinaten- und Zeitsysteme in der Geodäsie (Sneeuw)	2/2/0/0
Landesvermessung (Krumm, Roth)	2/2/0/0
Map Projections and Geodetic Coordinate Systems (Krumm, Roth)	2/1/0/0
Physikalische Geodäsie (Engels, Tourian)	2/2/0/0
Referenzsysteme (Krumm, Roth)	2/2/0/0
Satellitengeodäsie (Sneeuw, Tourian)	2/1/0/0
Satellitengeodäsie (Keller, Tourian)	1/1/0/0
Satellite Geodesy Observation Techniques (Keller, Tourian)	2/1/0/0
Statistical Inference (Krumm, Roth)	2/1/0/0
Wertermittlung I, II (Bolenz)	4/0/0/0

Institute of Navigation

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Deputy: Dr.-Ing. Aloysius Wehr
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Dipl.-Ing. Michael Gäb	Navigation Systems
Dipl.-Geogr. Thomas Gauger	GIS Modelling and Mapping
Dipl.-Ing. Marc Goetzke	GIS Modelling and Mapping
Dipl.-Ing. René Pasternak	Remote Sensing
Dipl.-Ing. Bernhardt Schäfer	Navigation Systems
M. Sc. Hendy Suhandri	Navigation Systems
Dipl.-Ing. (FH) Martin Thomas	Laser Systems
Dr.-Ing. Aloysius Wehr	Laser Systems
Dr. Ing. Franziska Wild-Pfeiffer	Navigation 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 Braunv - RST Raumfahrt Systemtechnik AG, St.Gallen
Dr. Werner Enderle - Europäisches Satelliten Kontrollzentrum (ESOC), Darmstadt

Research Projects

Design and Production of Wireless Inertial Measurement Units from EMS Components for Sport Monitoring and Indoor Navigation

Stand alone and miniature inertial measurement units and data loggers are required in sport monitoring for training purposes. The requirements in size and sensor characteristics mostly overlap with those for pedestrian indoor navigation. Prototypes have been designed by TGU LOPSTRE navigation to meet the requirements to monitor movements in ice figure skating. The new battery powered prototypes offer synchronised data transfer via Bluetooth without distracting cables. The units fit in a small custom made 3D-printed case with the dimensions 18x30x38 mm, see Figure 1.

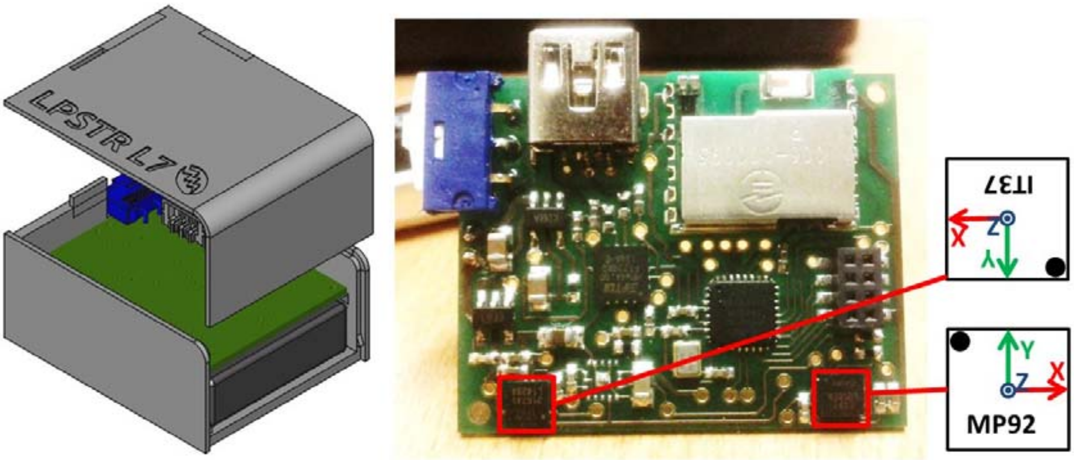

Figure 1: CAD design case (left) and prototype PCB (right).

Analysis and Correction of Data Sets of Nitrogen Deposition in Baden-Württemberg Contributing to a Country Specific Nitrogen Balance

On behalf and on the account of Baden-Württemberg the project „Application of modelled nitrogen deposition 2007/2009 for ecosystems in Baden-Württemberg" is carried out. The results of the research BMU/UBA project PINETI (Pollutant Input and EcosysTem Impact; BMU/UBA FE-No 3712 63 240-1), are compiled and analysed within this project.

Since the latest PINETI results of anthropogenic nitrogen dry deposition, modelled using the chemical transport model LOTOS-EUROS, are severely underestimating measurements of total nitrogen input into forest ecosystems in Baden-Württemberg, it was decided to correct those PINETI deposition data fields in order to be in line with empirical „ground truth" data available at more than 20 forest plots.

The modelled data of air pollutants in Germany derived on behalf of BMU/UBA modelling and mapping projects are of are supporting EU and national regulations on air pollution control and emission abatement (EU NEC directive, BImSchG, TA-Luft, and directives on nature protection and biodiversity), which have to be implemented on the sub-national level, i.e. the German Federal States. Moreover, the approving administrative authorities and consultants within the planning process do need reliable nitrogen deposition flux data for the obligatory proceeding relating to permission of projected animal husbandry, road construction, industrial settlements, and power plants, respectively.

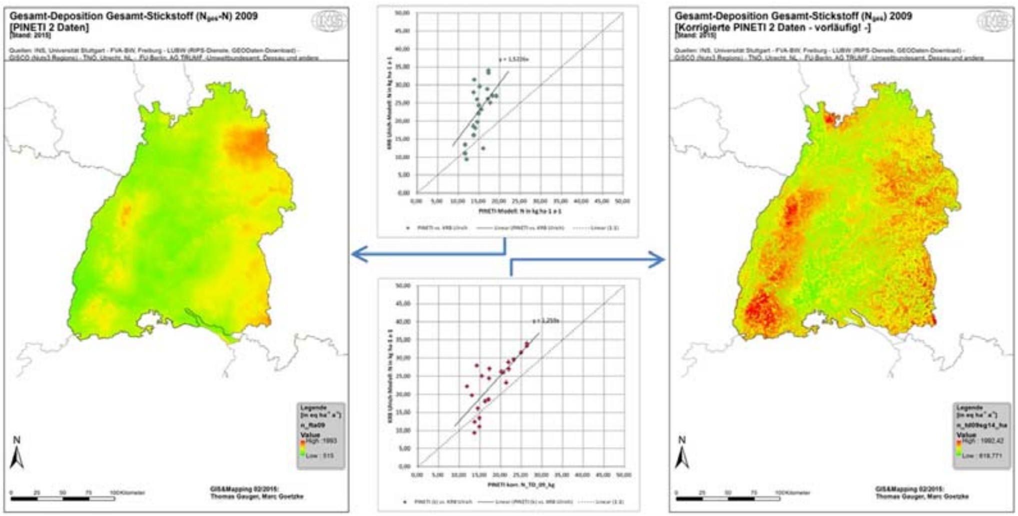

Figure 2: Total deposition of reactive nitrogen in Baden-Württemberg 2009.

Within the project national nitrogen deposition maps are corrected and high resolution maps of ecosystem specific nitrogen deposition fluxes are generated for Baden-Württemberg (see Figure 2, right). The resulting data of this project are delivered as data base for further calculation of a comprehensive nitrogen balance for Baden-Württemberg. The data will also be made accessible via internet at LUBW (StickstoffBW online) and used for different administrative applications aiming at emission control and emission reduction.

Publications and Presentations

Gäb, M. and Wehr, A.: Aiding of Software GNSS Receiver by Low-Cost MEMS-IMU for Land Vehicle Navigation. ENC-GNSS 2014, Rotterdam, Niederlande.

Gäb, M. and Wehr, A.: Determination of Optimal Loop Parameters for Software GNSS Receiver Based on Signal- to- Noise Ratio Observations for Land Vehicle Navigation. ENC-GNSS, 2014, Rotterdam, Niederlande.

Diploma Thesis

Schmidt, M.: Bewertung und Weiterentwicklung einer Fahrzustandserkennung für die Fahrzeuglokalisierung beim hochautomatisierten Fahren (Wild-Pfeiffer).

Bachelor Thesis

Kappel, F.: Vergleich von MEMS-Inertialsensoren anhand ihrer Parameter (Wild-Pfeiffer).

Study Thesis

Yang, Guanchen: Investigation of Human Gait Walking on Curved Lines Using Stride Lengths (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

Guest Lectures

Tao, J. (DLR, Institut für Methodik der Fernerkundung - Technische Universität München): Combination of LIDAR and SAR data with simulation techniques for image interpretation and change detection, 22.01.2014.

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, Gäb)	2/2/0/0
Inertial Navigation (Kleusberg, Schäfer)	2/2/0/0
Remote Sensing I (Wild-Pfeiffer, Pasternak)	2/2/0/0
Remote Sensing I (BSc) (Wild-Pfeiffer, Pasternak)	2/1/0/0
Remote Sensing II (Wild-Pfeiffer, Pasternak)	1/1/0/0
Satellite Programs in Remote Sensing, Communication and Navigation I (Liebig)	2/0/0/0
Satellite Programs in Remote Sensing, Communication and Navigation II (Liebig)	2/0/0/0
Radar Measurement Methods I (Braun)	2/0/0/0
Radar Measurement Methods II (Braun)	2/1/0/0
Dynamic System Estimation (Kleusberg, Suhandri)	2/1/0/0
Integrated Positioning and Navigation (Kleusberg, Suhandri)	2/1/0/0
Satellite Navigation (Kleusberg, Suhandri)	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 2014)

Institute for Photogrammetry

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Research Groups at the ifp:

Geoinformatics

Chair: Prof. Dr.-Ing. Dieter Fritsch	
Deputy: Dr.-Ing. Volker Walter	Geographic Information Systems
Dr.-Ing. Susanne Becker	Point Cloud Interpretation and Hybrid GIS

Photogrammetry and Computer Vision

Chair: Prof. Dr.-Ing. Dieter Fritsch	
Deputy: Dr.-Ing. Michael Cramer	Digital Airborne Sensors
M.Sc. Eng. Ali Mohammed Khosravani	Indoor Modeling and Positioning
Dipl.-Ing. Alessandro Cefalu	Photogrammetric Calibration and Object Recognition
M.A. Chance Michael Coughenour	Remote Sensing Applications to Archaeology
Dipl.-Ing.(FH) Markus Englich	Sensor Laboratory, Computing Facilities
M.Sc Eng. Wassim Moussa	Integration of Laser Scanning and Photogrammetry
Dipl.-Ing. Michael Peter	Indoor Positioning
Dipl.-Ing. Konrad Wenzel	Dense Image Matching in Close Range Applications

Photogrammetric Image Processing

Chair: apl. Prof. Dr.-Ing. Norbert Haala	
MSc. Stefan Cavegn	Image-based Mobile Mapping
Dipl.-Ing. Mathias Rothermel	Semi-Global Matching
Dipl.-Ing. Max Schneider	3D Indoor Data Collection
Dipl.-Ing. Patrick Tutzauer	Façade Reconstruction, Interpretation and Modelling

External Teaching Staff

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

Research Projects

Geoinformatics

3D indoor grammar for the reconstruction of 3D interiors from raw point clouds

A grammar-based approach has been developed for the robust automatic reconstruction of 3D interiors from raw point clouds. The core of the approach is a 3D indoor grammar which is an extension of our previously published grammar concept for the modeling of 2D floor plans. The grammar allows for the modeling of buildings whose horizontal, continuous floors are traversed by hallways providing access to the rooms as it is the case for most office buildings or public buildings like schools, hospitals or hotels. The grammar is designed in such way that it can be embedded in an iterative automatic learning process providing a seamless transition from LOD3 to LOD4 building models. Starting from an initial low-level grammar, automatically derived from the window representations of an available LOD3 building model, hypotheses about indoor geometries can be generated. The hypothesized indoor geometries are checked against observation data - here 3D point clouds - collected in the interior of the building. The verified and accepted geometries form the basis for an automatic update of the initial grammar. By this, the knowledge content of the initial grammar is enriched, leading to a grammar with increased quality. This higher-level grammar can then be applied to predict realistic geometries to building parts, where only sparse observation data are available. Thus, our approach allows for the robust generation of complete 3D indoor models whose quality can be improved continuously as soon as new observation data are fed into the grammar-based reconstruction process.

The iterative grammar-based reconstruction approach has been tested based on following data: 1) 3D point cloud from laser scanning (Leica HDS3000) collected in the 4th floor of our office building that comprises in total seven floors; 2) LOD3 model of the building. The approach begins with the instantiation of an initial low-level grammar which can then be applied to start the iterative reconstruction process. The initial low-level grammar consists of an initial L-system and an initial split grammar. Here, the initial L-system has been derived from the given point cloud by means of a heuristic algorithm. The initial split grammar has been derived by analyzing the window structures of the LOD3 building model. For the reconstruction of the building's interior, at first, the initial split grammar is applied to segment the body of the building into floor spaces. Then, the initial L-system is used to generate a complete hallway network which traverses all floors of the building. Based on this hallway network, the floors are segmented into hallway and non-hallway spaces. Afterwards, the initial split grammar is applied to segment the non-hallway spaces of the 4th floor into room configurations. The proposed split walls are tested against the point cloud, and the initial split grammar can be updated. The resulting higher-level grammar is then applied to generate reliable hypotheses about the room configurations for the remaining floors where except for the knowledge about the window positions no observation data is available. The result is exemplarily shown for the floors 2 to 6 in Figure 1.

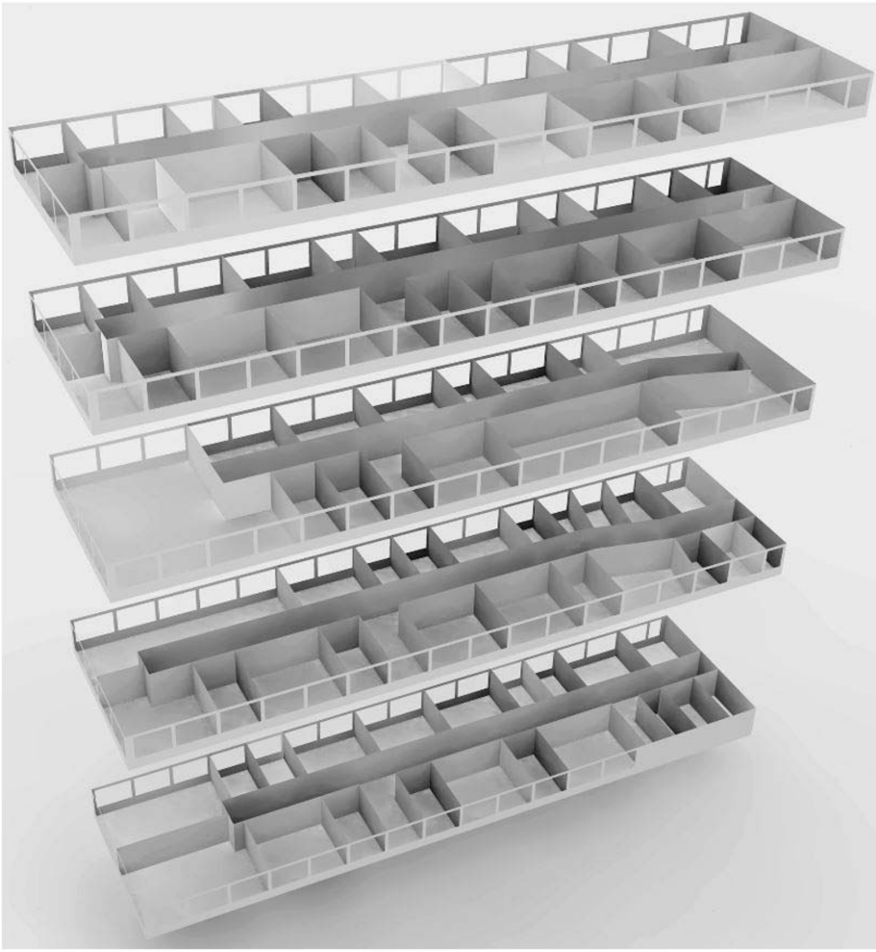


Figure 1: Grammar-based reconstruction of the floors 2 to 6.

Crowd-based data collection from aerial images

The aim of this project is the development of a web-based program for the crowd-based collection of spatial data from aerial images by non-experts. Compared to already existing crowdsourcing approaches, this project realizes paid crowdsourcing, which means that the crowdworkers are paid for their work. The developed program is published on the crowdsourcing platform Microworkers (https://microworkers.com), which has currently about 600.000 members. In principle, the developed program can also be operated autonomously. However, Microworkers provides a huge pool of registered crowdworkers, allows the specification of many project parameters (targeting countries, speed of project, payment, etc.) and handles the money transfer. Figure 2 shows the Graphical User Interface of the developed program.

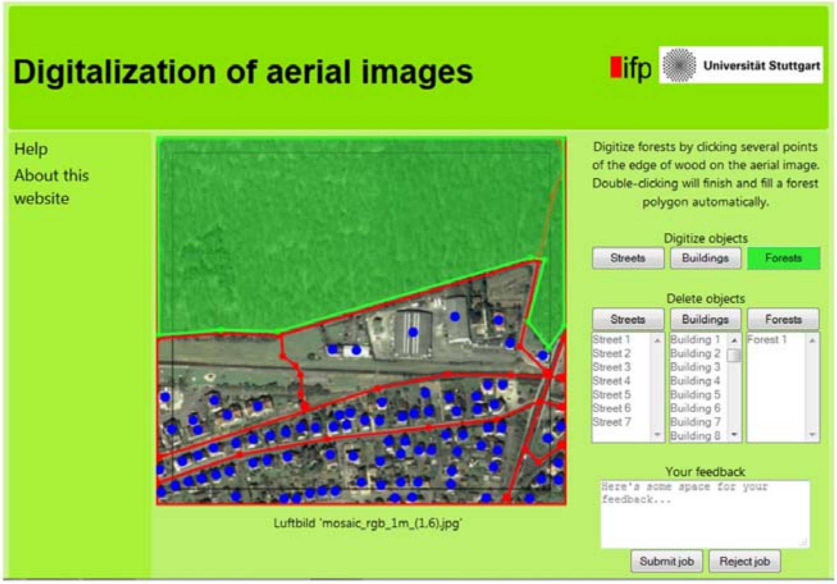


Figure 2: Graphical User Interface of the web-based program for crowd-based data collection.

Crowdsourcing has the potential of producing high quality datasets. However, first tests showed that the quality of the collected data varies significantly. Some crowdworkers collected the data with very high quality (see Figure 3 a) whereas other crowdworkers collected completely wrong data (see Figure 3 b). In the following research we will concentrate on three topics: (1) What are the parameters that influence the quality of the collected data? (2) How can we automatically select crowdworkers who collect data with high quality? (3) How can the collected data automatically be checked?

Figure 3: Two examples of crowdsourced spatial data collection

Photogrammetry and Computer Vision

Non-Incremental Structure-from-Motion

The majority of approaches to solve Structure from Motion apply an incremental triangulate-and-resect strategy in order to reconstruct camera motion and scene structure in a common reference frame. The sequential addition of images may cause a drifting behavior during the reconstruction, in some cases causing the process to fail. Over the last decade, more attention has come to non-incremental approaches, which exploit the network characteristics arising from the 2- or 3-view relations, given for a set of images through relative orientations. Most approaches employ rotation registration, followed by translation registration. The latter being carried out with or without simultaneous scene reconstruction. In all cases, the result serves as approximate solution for bundle adjustment.

We suggest an approach for obtaining the approximate solution which relies on the identity constraint (or loop constraint, Figure 4) and makes no use of 3D object points, thus keeping the number of unknowns small. We start with an estimation of the relative scales, followed by a simultaneous registration of rotation and translation. The latter is achieved by employing a path-finding algorithm based on Ant-Colony-Optimization (ACO). We also suggest a simple method for the detection of outlier orientations. Starting with a set of relative orientations between the images the outline of our suggested approach is:

- ▷ Remove outlier orientations by rotational cycle consistency
- ▷ Estimate the scale of the baselines
- ▷ Remove outlier orientations by translational cycle consistency
- ▷ Compute approximate absolute orientations using a robust, adaptively guided variant of ACO

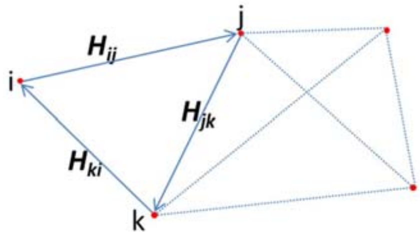


Figure 4: Sketch of a camera graph. Chaining the relative transformations H needs to yield identity.

The convergence behavior of our approach, in comparison with other variants, is depicted in Figure 5. A comparison of the resulting approximate orientations with (fully optimized) ground truth solutions is shown in Figure 6.

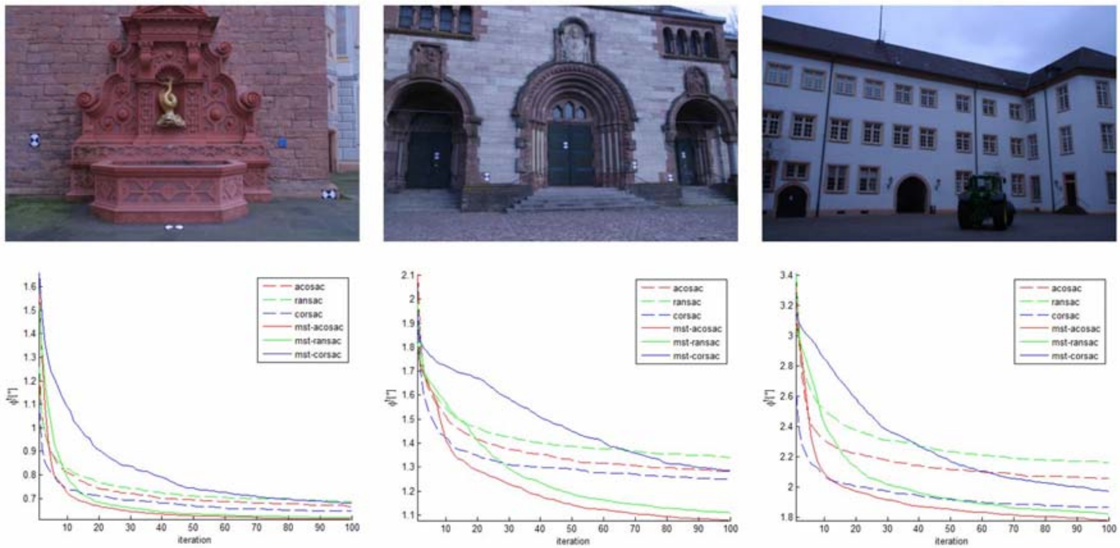


Figure 5: Mean convergence behavior (median error in over iterations, 100 runs over 100 iterations) of different tree sampling methods. The dashed lines show the best directly picked result. The solid lines show the best result for minimal spanning trees derived from dynamic weighting. After a few iterations our suggested method (solid red) finds superior solutions. Datasets from left to right: FountainP11, HerzJesuP25 and CastleP30, all being part of the benchmark dataset of (Strecha et al., 2008).

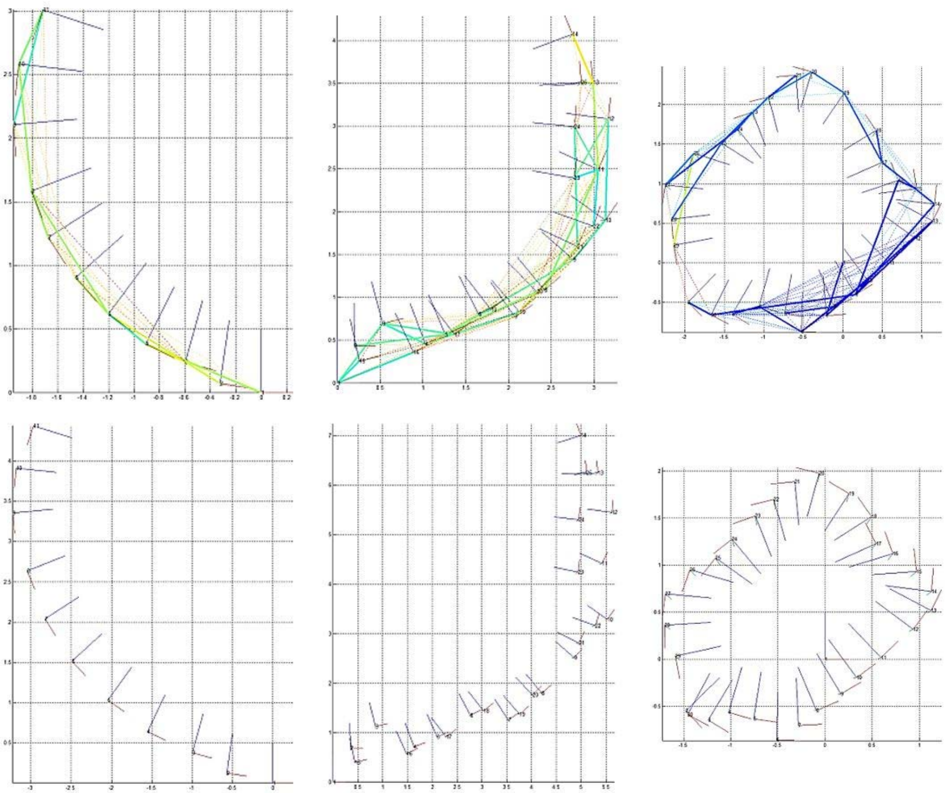


Figure 6: Top-view plots of the camera positions for the datasets of Figure 2 (same order). First image used as reference frame. Upper Row: Results derived after 20 iterations of our approach. The cameras are connected by edges corresponding to the established 2-view-connections. Thick lines represent the minimal spanning tree. Lower row: Reference solution computed using a commercial SfM software.

Applying Close Range Photogrammetry to 4D Archaeological Data

Thanks to recent advances in photogrammetry, computer vision, 3D object modeling, animation software, and CAD mapping, archaeological projects can enhance both the accuracy and detail of recording cultural heritage data, which facilitates interpretation and presentation, while reducing the cost and time required in comparison to previous methods. In the following the results of implementing this workflow at an archaeological site located in a tropical rainforest in Belize are presented.

Two excavations conducted during the 2013 field season were captured for photogrammetric processing following the completion of each lot or significant stage of excavation. Highly-detailed, quantifiable 3D models were then processed and imported into modeling software for further data augmentation. These scaled lot models were then used to create an animation which illustrates the excavation process through time by both highlighting important features, fading through each stratum, and illustrating measurements. Compared to conventional recording methods which require meticulous hand-measured and hand-drawn plan and wall profile drawings, this strategy was proven to increase both the momentum of investigation and precision of its documentation. Moreover, traditional recording methods cannot provide the precision, depth, and color-coded representation for post-excavation analysis, interpretation, and presentation which this workflow can deliver.

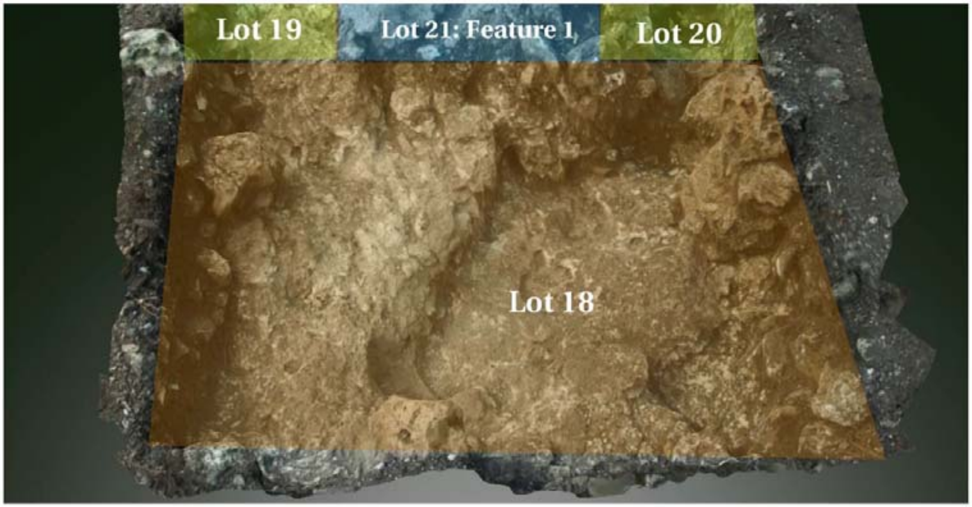


Figure 7: Photogrammetric model of excavation with demarked lots in 4D model.

Archaeological excavation is by its very nature destructive and can only be done once. Therefore, as researchers in digital cultural heritage, we are obligated to balance conservation with investigation when documenting, interpreting, and presenting our findings. Also, the power to reconstruct an excavation from the very beginning with such a great degree of precision promises to be invaluable for future archaeological projects. Moreover, photogrammetric documentation at this site is ideally suited to the broad scope of world cultural heritage preservation. Not only does it provide archaeologists with the ability to ideally record as much data as possible during the destructive process of excavation, but long-term application of this workflow decreases the time and, consequently, the cost of fieldwork.

This form of archaeological documentation can be expanded on multiple ways. First, the photogrammetric documentation of an excavation should start before the first trowel strikes the ground. Surface features on and within the proximity of the unit should be well documented because excavation results may be prudent in later interpretations. In densely-forested environments, for example, small structures or modified landscape features only become apparent after clearing the area of investigation. Furthermore, photogrammetric collection before excavation presents another opportunity to preserve the original cultural heritage data as well as document minute topographic changes that may be useful in hydrological considerations. These 3D models can then be used as the principal data to situate all posterior models of each stratum as shown in Figure 8.

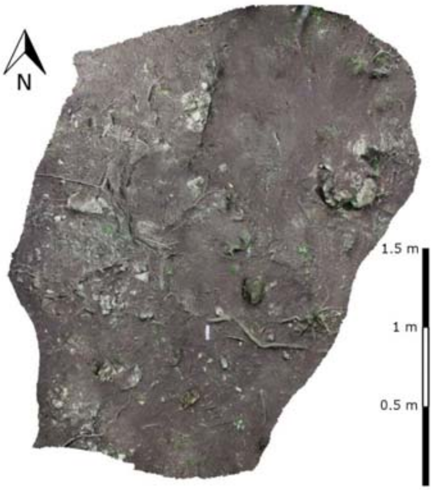


Figure 8: Top view of 3D surface of theorized hydrological feature for future investigation.

Image based 3D surface reconstruction

Dense image matching methods enable efficient 3D data collection. Digital cameras are available at high resolution, high geometric and radiometric quality and high image repetition rate. They can be used to acquire imagery for photogrammetric purposes in short time. Accuracy and resolution can be chosen freely with the selection of the camera and the image stations.

Photogrammetric image processing methods can be used to derive 3D information automatically. For example, Structure from Motion reconstruction methods can be used to derive orientations and sparse surface information. In order to retrieve complete surfaces with high density, dense image matching methods can be applied subsequently.

At the Institute for Photogrammetry, a software solution for dense image matching with the name SURE has been developed. It was released online in early 2013 and is since then in constant maintenance and improvement. It is provided to a large research community worldwide.

Furthermore, a spin-off has been founded with the name nFrames - providing and maintaining the software in a commercial environment. Multiple licenses are in use in particular in the airborne image processing market.

In 2014, several enhancements have been applied to the software as a result of research, which was presented at various conferences. Such features are for example a large scale out-of-core point cloud filtering enabling the dense reconstruction of large datasets of oblique airborne images (Figure 9). Furthermore, true orthophotos can be derived automatically while closing gaps from the digital surface model (Figure 10). Also, algorithms for the generation of meshed triangle surfaces have been presented and introduced to the software SURE (Figure 11).

The start-up company as well as the software SURE can be found at *nframes.com*.

Figure 9: Point cloud from oblique imagery.

Figure 10: Automatic true orthophoto.

Figure 11: Meshed triangle surface of a lion.

Automatic Modeling of Building Interiors

Indoor reconstruction or 3D modeling of indoor scenes aims at representing the 3D shape of building interiors in terms of surfaces and volumes, using photographs, 3D point clouds or hypotheses. The automation of the reconstruction process is still a challenge, due to the complexity of the data collection in indoor scenes, as well as geometrical modeling of arbitrary room shapes, especially if the data is noisy or incomplete. Available reconstruction approaches rely on either some level of user interaction, or making assumptions regarding the scene, in order to deal with the challenges.

The presented work aims at increasing the automation level of the reconstruction task, while making fewer assumptions regarding the room shapes, even from the data collected by low-cost sensor systems subject to a high level of noise or occlusions. This is fulfilled by transforming the modeling task from 3D to 2D space, which enables the topological correction of the reconstructed model using morphological image processing techniques, constraining in 2D space, topology and graph analysis algorithms. In more detail, the modeling process consists of the following steps:

- ▷ Data pre-processing: This step aim at the automatic removal of furniture and clutter, reducing the noise of the range measurements, leveling the point cloud and projecting the points onto the ground plane. The output of this step is an orthographic projected image.
- ▷ Estimating the line segments corresponding to walls in 3D: This step estimates straight line segments in the resulted orthographic projected image using morphological image processing techniques and the Hough transform. The resulted Hough lines corresponding to the same walls are found based on a new clustering approach, and then are averaged within the clusters.
- ▷ Topological corrections: Due to errors in the point cloud alignment, remaining noise as well as occlusions in the projected image of walls, the resulted line segments in the previous step do not necessarily fulfill a topologically correct geometry and do not meet each other at the end points. Therefore, following topological corrections are proposed: 1) refinement of the orientation of resulted line segments by enforcing perpendicularity or parallelism to the line segments whose orientations make a difference of 0 or 90 degrees within a tolerance; 2) extension and trimming of the line segments supported by the graph theory, in order to find correct line intersections.
- ▷ 2D to 3D conversion of reconstructed models, based on the point height histogram (see Figure 12).

Finally, this work shows how the resulted 3D models with a higher level of details can be used to refine available coarse floor plans. The refinement approach firstly registers the detailed model of individual rooms with the coarse model, based on the user’s track collected by a foot mounted MEMS IMU. The models are then merged together, and finally possible gaps within the detailed models are automatically reconstructed using a new learning-based approach employing the information inferred from the coarse model (Figure 13). This further enables the detection of changes in the coarse model (Figure 14).

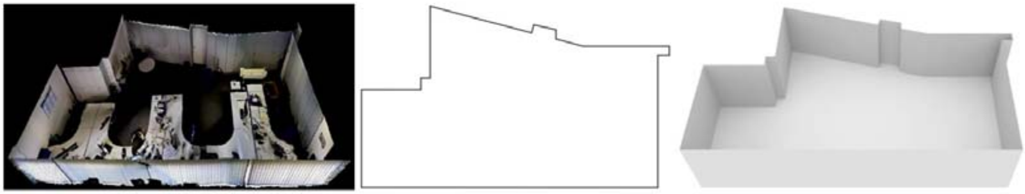


Figure 12: Left to right: Collected and registered point cloud; Resulted 2D model; Resulted 3D model.

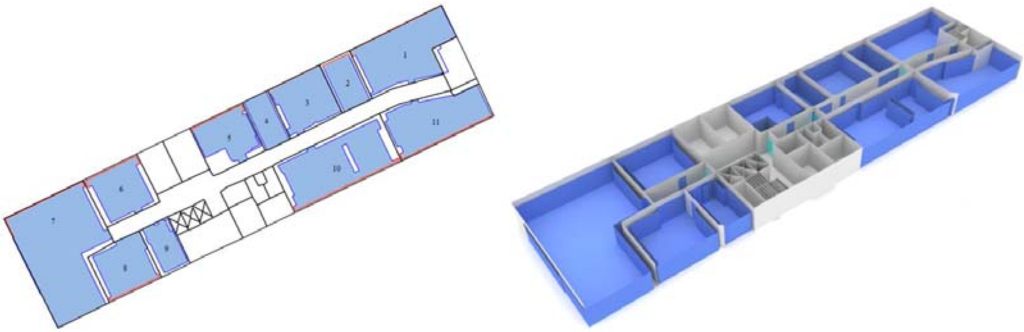


Figure 13: Refined coarse model.

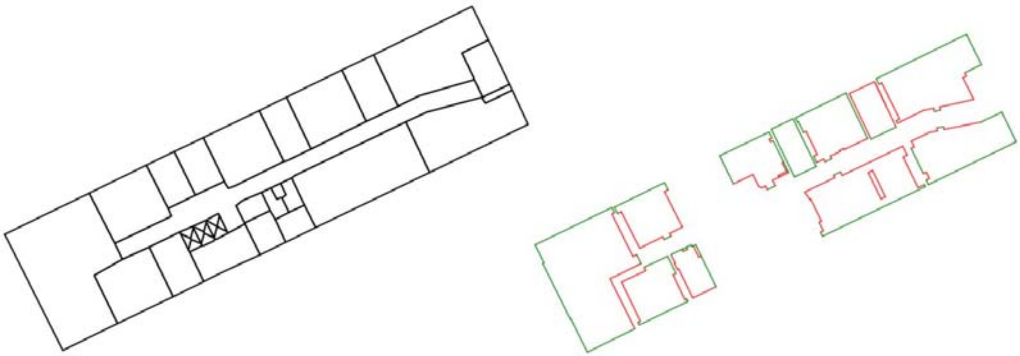


Figure 14: Left: coarse model; Right: Detected changes to the coarse model marked by red color.

Integration of Laser Scanning and Photogrammetry in one Bundle

At the Institute for Photogrammetry an automatic methodology is explored capable of registering non-overlapping laser scans connected with a bundle block adjustment for the pose estimation of synthetic images generated from the 3D laser data and camera images by means of a Structure-from-Motion (SfM) reconstruction. The generated images are derived from reflectance or RGB values obtained from the laser scanner's embedded camera, in a central projection representation. Adding camera images to the registration of the synthetic images can improve the block geometry by providing sufficient overlapping geometry in between and they can match with the surrounding scans as well. Employing both input images in one SfM process provides accurate image orientations and sparse point clouds, initially in an arbitrary model space. This enables an implicit determination of the 3D-to-3D correspondences between the sparse point clouds and the laser data via 2D-to-3D correspondences stored in the generated images. Using these 3D correspondences, the Helmert transformation is introduced and its parameters are computed. This results in registering the non-overlapping laser scans, since the relative orientations between the generated images are determined at the SfM step and transformed to the absolute coordinate system directly. The proposed approach was tested on real case studies and experimental results are shown to demonstrate the effectiveness of the presented approach.

Within this fully automatic approach, a target-free registration of non-overlapping laser scans is presented. The method uses images generated from laser point clouds and collected from a standard digital camera. Image orientations and sparse point clouds with high accuracy were computed using a SfM reconstruction method. This leads to the determination of accurate 3D-to-3D correspondences that enable the calculation of the seven-parameter transformation, which can be applied on the relative image orientations determined by the SfM process. This results in automatic alignment of the scans with an option to reduce the final registration error by any error minimization algorithm. One advantage of this approach is that it retrieves directly the scale information to the SfM output. Another advantage is that the deformations caused by camera interior parameters, if calibration is not available for input camera images, can be reduced using the bundle adjustment similar to self-calibration. This opens the door to utilize low-cost sensors such as mobile phones (see figure 4) for the image collection and tablet computers with its integrated cameras for online services. In practice, this can help to continue the scanning in the second workday where targets cannot be hold in the field. In future works, images captured by the laser scanner's integrated camera could be combined also in the SfM process since some modern TLS systems; e.g. the Leica ScanStations C10 and P20 provide information about the latter images including calibration and orientations.

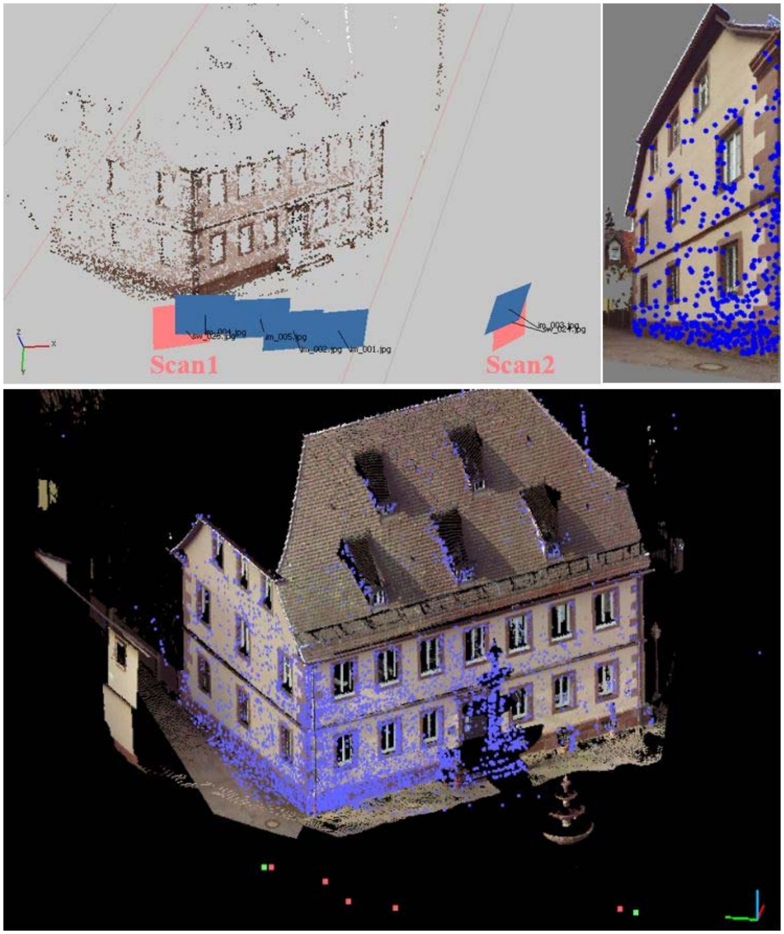


Figure 15: (First row) SfM output: sparse point clouds (coloured), 5 camera positions (blue image planes) and 2 scan stations (pink image planes) of the Building 1 dataset at the Hirsau Abbey, aligned in one local coordinate system (left). 3D correspondences (478 keypoints) between the sparse point clouds and the laser data (of Scan1) which are used for the calculation of the seven-parameters, depicted on the corresponding RGB image (right). (Second row) The latter sparse point clouds (blue), 5 camera positions (red dots) and 2 scan stations (green dots) aligned in one coordinate system with laser point clouds (coloured) from both scan stations.

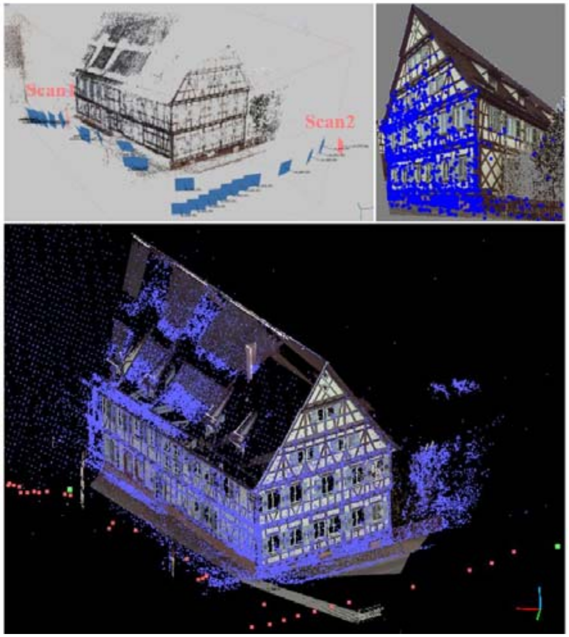


Figure 16: First row) SfM output: sparse point clouds (coloured), 30 camera positions (blue image planes) and 2 scan stations (pink image planes) of the Building 2 dataset at the Hirsau Abbey, aligned in one local coordinate system (left). 3D correspondences (2104 keypoints) between the sparse point clouds and the laser data (of Scan1) which are used for the calculation of the seven-parameters, depicted on the corresponding RGB image (right). (Second row) The latter sparse point clouds (blue), 30 camera positions (red dots) and 2 scan stations (green dots) aligned in one coordinate system with laser point clouds (coloured) from both scan stations.

Scan ID	ΔX (m)	ΔY (m)	ΔZ (m)	Δω (°)	Δφ (°)	Δκ (°)	ΔD (m)
1	0.007	0.050	-0.037	-0.026	-0.052	-0.040	0.016
2	-0.014	0.004	-0.013	-0.009	0.050	0.010	
RMS	0.011	0.035	0.028	0.019	0.051	0.029	0.016

Table 1: Absolute registration accuracy of the Building 2 dataset at the Hirsau Abbey: residuals of registration parameters and consecutive pair distances, using target registration results as a reference and the corresponding root mean square of the residuals.

The European Union 4D CH Project - Four-dimensional Cultural Heritage World

The 4D-CH-World project aims to analyze, design, research, develop and validate an innovative system integrating the latest advances in computer vision and learning, as well as 3D modeling and virtual reality for the rapid and cost-effective 4D maps reconstruction in the wild for personal use, and support the aim of our European Commons and the digital libraries EUROPEANA and UNESCO Memory of the World (MoW) to build a sense of a shared European cultural history and identity.

The main goal of the 4D-CH-World is to enable historians, architects, archaeologists, urban planners, or any other affiliated scientists to reconstruct from available data on repositories, study, understand, preserve or document urban environments, as well as organizing collections of thousands of images (spatially and temporally) in generating novel views of historical scenes by interacting with the time-varying model itself. The evolving steps depiction helps understanding the cultural trends, performing behavioral analysis, exploiting the impact of the available raw resources in building development, further analyzing the urban economy factors, and simulating a future urban growth in order to understand the future demands, and satisfy in time the people's concrete needs. Education systems will have the opportunity to exploit this innovative system to motivate students and help them better understand many things in an amusing way. Finally, pupils, university students, tourists, communes, future mechanics and economists, will observe urban environment changes through time, not just read it, and therefore understand it, so as, future plans of action, regarding urban renewal or sustainable development would be less likely to fail.

The huge amount of data collected through photographs over the past decades provide a base for the three-dimensional digitalisation of existing monuments and sites using all kind of imagery available at online archives as well as in-situ data collections. These sources allow for achieving time dependent morphological 3D models to enable historians, architects, archaeologists, urban planners, or any other affiliated scientists to study, compare and share their conclusions with a broader public. Additionally, the resulting material can be used for various multi-media formats such as immersive virtual reality or augmented reality applications supporting cultural heritage service providers and educational programs.

One of the main testbeds chosen for this study is the historic Market Square in Calw, a city located 40 km southwest of Stuttgart, Germany. The on-going data collection using terrestrial laser scanning, close-range photographs and aerial imagery and its resulting 3D modeling is serving not only the interests of the researchers of the 4D-CH-World project, but also the public, as this city has thousands of visitors every year.

As an example for a photorealistic 3D reconstruction photos of the famous "Nikolausbruecke" (Santa Claus Bridge) have been downloaded „from the wild" and used in a manual reconstruction process, in cooperation between the Institute for Photogrammetry and 7reasons GmbH, Vienna (see Figure 17).

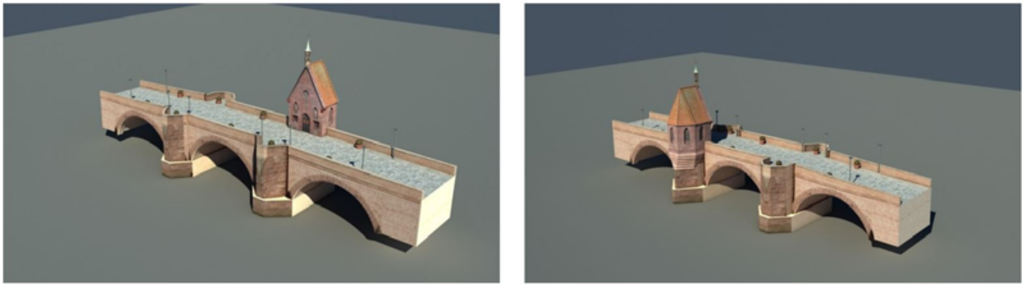


Figure 17: 3D reconstruction of the famous “Nikolausbruecke“, Calw.

Getting back to the roots - Building the bridge from state-of-the-art photogrammetry to Albrecht Meydenbauer

It was in 1858 when Albrecht Meydenbauer had to survey the Wetzlar cathedral. Because of an accident, which nearly took place, he thought to use the just introduced photography for the survey of monuments. His trials led in 1867 to an article, where the word „Photogrammetrie“ was published first.156 years after invention, in June 2014, ifp organized a two-day trip offered for the students of the German BSc program „Geodäsie & Geoinformatik“ and the international students from the MSc program „Geomatics Engineering“ to visit this historical city of Wetzlar. Altogether 40 people attended this tour, including Prof. Fritsch and Dr. Cramer from ifp. But it was not only looking back - demonstrations of the latest technology developments in mobile mapping as well as an impressive insight view in lens design and camera production of very high quality consumer cameras were also part of this trip. And finally it was the FIFA football championships in Brazil that made the third pillar of our trip - at least for the evening program.

Mobile Mapping - the IGI approach

The IGI Company is a long term partner of the Institute for Photogrammetry and since more than 20 years joint projects have been accomplished. They started in the field of (photogrammetric) mission planning and guidance of survey aircraft, GNSS/inertial data integration and direct georeferencing of airborne camera systems, the company nowadays offers the full portfolio of mapping sensors from large format camera systems including multiple view oblique cameras, laser-scanning and GNSS/inertial integrated system. These systems can be very flexibly used in different mobile platforms: from standard photoflight airplanes, to more unconventional carriers like light-weight gyrocopters. The systems are also modified for terrestrial mobile street mapping - *StreetMapper* - and can also be used for 3D mapping of railways, the *RailMapper*. Latest, a new software the so-called *IGImatch* - a software for the image based dense point cloud generation - was presented, which also originated from an ifp development. Many of these systems have been investigated and approved by ifp already.

During the students' visit all these technologies were impressively demonstrated - not only by theory but also in a „hands-on" way. As an example the *RailMapper* system should be mentioned in more detail. Figure 18 shows the 2-way-vehicle shortly after it was railed on the tracks. The *RailMapper* offers a 360 deg field of view with different sensor options. *RailMapper* equipment can be operated on speeds above 100 km/h and is a complete system solution with an established workflow. The system can be equipped with different types of laser scanners which differ in precision and range. A typical solution comprises of 2 to 3 scanners to get the best possible results. In addition different kind of RGB and video cameras for integration are available. The on-board navigation system includes a GNSS receiver, a fiber optic gyro-based Inertial Measurement Unit and the latest Direct Inertial Aiding Plus software (DIA+) to assist in areas of poor GNSS signal reception. Laser scanners have rotating heads of frequency up to 200Hz and an IMU can measure movements with 512KHz.

Figure 18: The IGI RailMapper *system as during demonstration. The system is installed on a high-rail vehicle - here shortly after railing on the tracks. The measuring sensors are installed in the trunk of the car and lifted up for the survey. The students are waiting to join the test drives.*

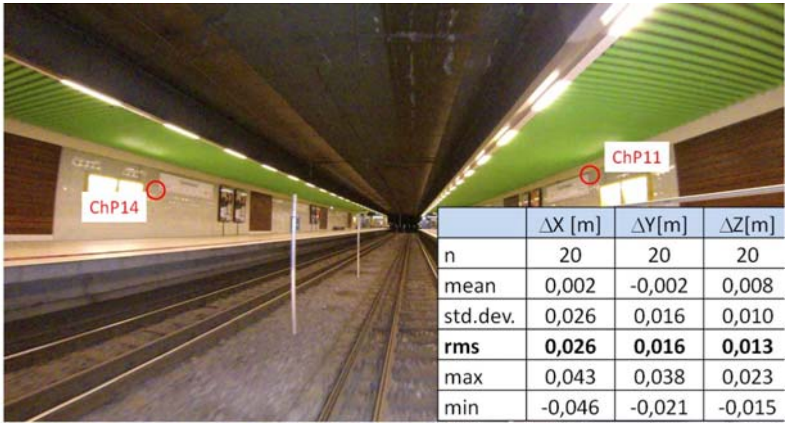
This system also has been extensively used and evaluated within a joint project between IGI, the „Stuttgarter Straßenbahn AG (SSB)" and ifp. In 2014 a second test campaign was done to continue and apply experiences from the first test the year before. The system installation is shown in Figure 19. During this test laser data was recorded with IGI's *StreetMapper*, comprised of two compact, phase-based Z+F PROFILER laser scanners. With a scan rate of more than 1 million points per second and a scan speed of 200 profiles per second short distances between the profiles could be achieved.

Again the 3.6km long SSB tunnel between the two city rail stops Stöckach and Marienplatz was used as test bed and surveyed several times, using different speeds varying between 20 - 50 km/h. Driving underground is especially demanding as there are no GNSS signals available. Position and velocity information from GNSS typically is used to support the integrated trajectory solution to get precise data for sensor orientation. This is the demanding step to solve the georeferencing task. In order to get highest accuracy in georeferencing, the GNSS/inertial and laser data processing was supported by some signalized control points. This approach is well established in classical photogrammetry (indirect georeferencing). With the help of these control point support, the overall accuracy (RMS) for 3D points is within 2mm (relative) and 20-25mm (absolute). This absolute performance was evaluated from about 20 independent check points, as shown in Figure 20. Finally the tunnel infrastructure and the rail geometries were extracted from 3D point clouds.

Figure 19: The RailMapper *system installed on the SSB vehicle before the measurement campaign (May 16, 2014). The boresight parameters have already been pre-surveyed and the system is now ready to start.*

Back to the roots of Photogrammetry - Wetzlar & Meydenbauer

Wetzlar is one of the important cities in the history of photogrammetry. This is not only because of the well-known optical industry, which is located in and around Wetzlar (like Leitz, now Leica Camera) it is mainly because of the invention of the „Photogrammetrie“ by Albrecht Meydenbauer. In 1867 Meydenbauer received an order by the Prussian government to do the survey of the Wet-



	ΔX [m]	ΔY[m]	ΔZ[m]
n	20	20	20
mean	0,002	-0,002	0,008
std.dev.	0,026	0,016	0,010
rms	**0,026**	**0,016**	**0,013**
max	0,043	0,038	0,023
min	-0,046	-0,021	-0,015

Figure 20: Independent accuracy check from check point analysis. Some of the used check points in the city rail stop Charlottenplatz are shown with one of the exemplarily results (test drive 4).

zlar cathedral. While he was doing so, he almost fell down the scaffold. Luckily nothing happened, but this event was the triggering moment to develop photogrammetry as new method to „remotely" measure objects without touching them. Prof. Albrecht Grimm, senior chef and founder of IGI, is one of Meydenbauer's biographers and he did a very tantalizing and inspiring speech about the history of photogrammetry. Moreover, historic lenses used in these first photogrammetric cameras were shown by Prof. Grimm: One lens from 1867 with 90deg opening angle, the BUSCH *Pantoscop*, and another one from 1900 with 130deg, the GOERZ *Hypergon*, were shown to the students. It was amazing to see the big difference with the new up-to-date lenses. Figure 21 shows one of these lenses and Prof. Grimm during his lecture. The day after, the whole group visited the Wetzlar cathedral to take this photo (see Figure 22) in front of the „Meydenbauer-church-tower".

Leica Camera Wetzlar

The second day of the excursion was completed by an impressive visit of the brand new Leica Camera facilities in Wetzlar. It was Oskar Barnack, another pioneer of early photography, who was the head of the former Leitz development and who introduced the full-format analog film (24mm x 36mm) - thus named as grandfather of 35mm photography. He also constructed the first Leica camera, the so-called „Ur-Leica" in 1914 - exactly 100 years before we visited this place. From 1925 the first Leica I, a modified version of the „Ur-Leica" went into serial production. All this impressive history of Leica is now presented in the new Leica facilities, which were completely new built at the border of the city of Wetzlar. Like a „transparent factory" (see Figure 23) the high quality camera production is contrasting to the remarkable history of this company, which impressed the students very much. With this it was really possible to see and understand the

Figure 21: Prof. Albrecht Grimm lecturing on the early days of Photogrammetry. He also brought historic lenses, used in the (terrestrial) cameras developed by Albrecht Meydenbauer.

Figure 22: The students group in front of the Cathedral of Wetzlar, a very historic place. The inset shows Meydenbauer's historic photograph, where he exactly marked the place on the tower where he almost fall. This was the reason why he invented photogrammetry.

progress in 100 years of photography. All this was underlined by Mr. Peter Karbe, the head of the optical development department at Leica Camera AG. Within his talk he gave a little insight view into the important things and quality aspects for the design of high quality lenses and cameras. There is nothing to add - just impressive and a must-see!

Figure 23: Camera final assembly in the new Leica Camera „transparent factory“ in Wetzlar.

Altogether the two days in Siegen and Wetzlar were very impressive not only for the students but also for the accompanying persons. As it was such great success, IGI company has recently decided that they would like to host such a group of highly interested students every year! Thus they already agreed to financially support this ifp excursion by sponsoring all the expenses for travel and accommodation. With that the 2014 excursion may become the starting point of another very good, long term tradition!

Photogrammetric Image Processing

Benchmarking High Density Image Matching for Oblique Airborne Imagery

Benchmarks have proven to be extremely useful in order to document the rapid progress of software tools for image based 3D point cloud generation, which are currently developed by a number of research institutes and photogrammetric software vendors. Well known examples which measure the performance of state-of-the-art matching algorithms are the Middlebury Stereo Vision Page or the benchmark on multi-view stereo reconstruction. Similarly, the joint EuroSDR/ISPRS initiative Benchmark on High Density Image Matching for DSM Computation investigates the potential of photogrammetric 3D data capture. Basic scope is the evaluation of 3D point clouds and DSM produced from aerial images with different software systems. The benchmark is based on three sub-blocks from aerial image flights. Two image blocks consist of date from standard photogrammetric camera systems captured at different landuse and block geometry. These data sets were already used in a preliminary first version of the benchmark started in the year 2013.

The third test scenario consists of an oblique aerial image block captured in a built-up area. These investigations are motivated by the increasing number of oblique systems as triggered by the rapidly growing market for this type of data. Furthermore, the preliminary version of the benchmark showed, that a number of software systems already can generate DSM from nadir flights at vertical accuracies close to the sub-pixel level. However, oblique data sets feature occlusions, depth jumps and varying image scale, which put additional challenges to the matching algorithms.

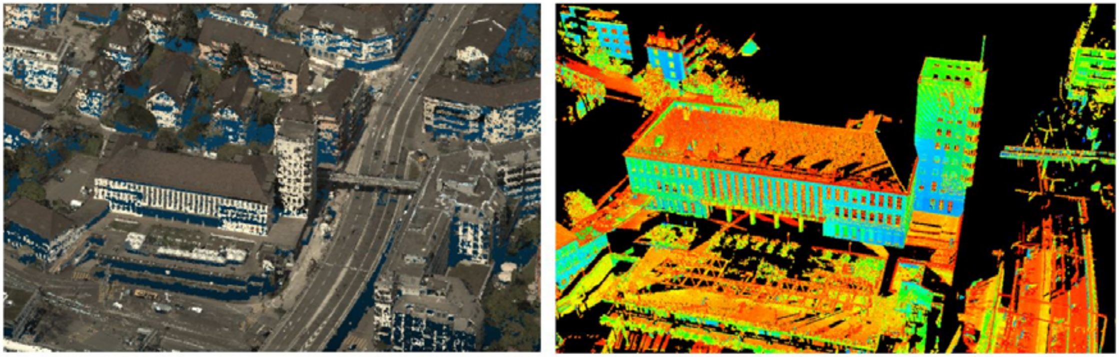


Figure 24: Exemplary point clouds of the test as generated from oblique imagery (left) and terrestrial laser scanning (right).

The test data set consists of Leica RCD30 Oblique Penta imagery for an area in the west of Zürich. An exemplary point cloud generated from this imagery is depicted in Figure 24 (left). As it is visible, oblique images can be used very well to capture 3D point clouds at building facades. For this type of objects, point clouds from terrestrial laser scanning provide suitable reference data at superior accuracy. Such a point cloud is depicted in Figure 24 (right).

Additionally, 3D building models were made available in LOD2 by the city of Zürich. As depicted in Figure 25 and 26 these data will be used within the evaluation procedure.

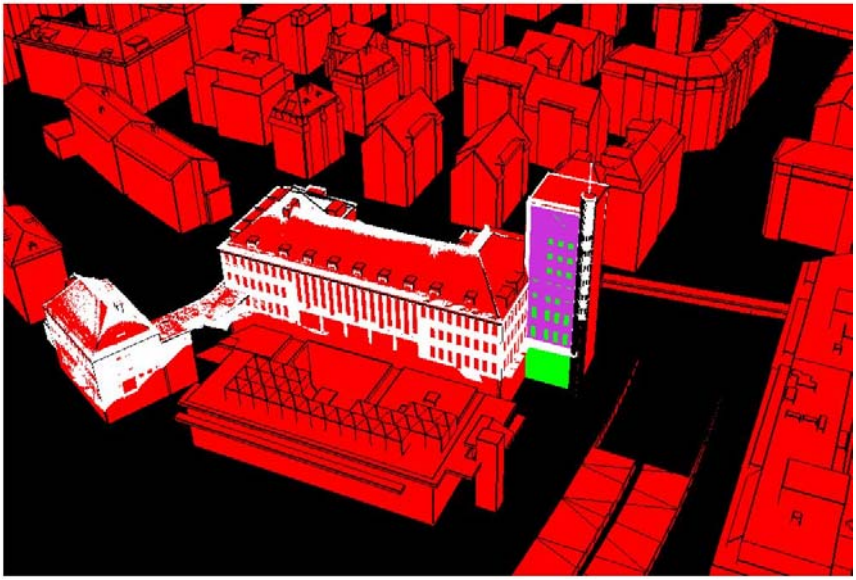


Figure 25: LOD2 building model with point clouds from image matching and terrestrial laser scanning as selected for further investigations.

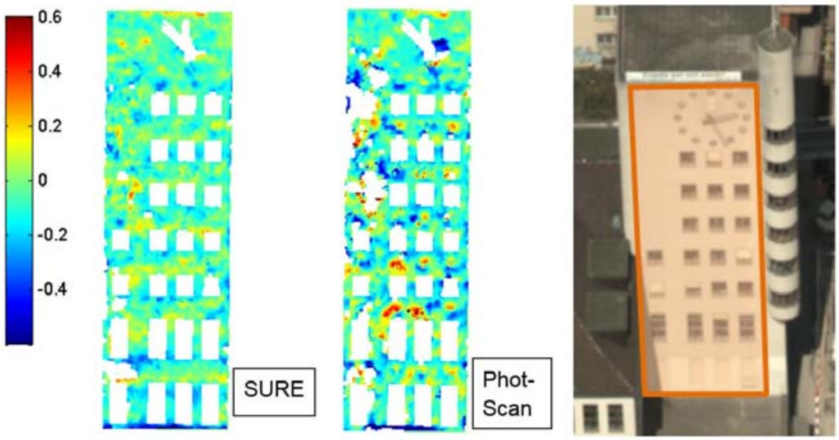


Figure 26: Point cloud deviation at building facades for software systems SURE und PhotoScan.

Dense image matching exploiting stereo imagery captured by mobile mapping vehicles

Street-level mobile mapping has emerged to an efficient mapping technology. Frequently these systems use LiDAR sensors to provide area-covering 3D point clouds. Meanwhile, advanced algorithms for dense stereo-image matching alternatively allow 3D data capture by camera-based systems. Since data processing is restricted to imagery, there is no need for co-registration to other sensors, which is beneficial for accuracy enhancement by integrated georeferencing. Furthermore, the direct link between captured imagery and 3D information at the same resolution supports both further automatic analysis and interactive data capture.

In order to evaluate such Mobile Mapping imagery by our stereo-matching-software SURE, the rectification process as one important processing step had to be adapted. Standard rectification approaches fail for epipoles located in the stereo image pairs. This situation is unlikely for airborne imagery, where nadir looking imagery is captured by forward moving platforms, but typical for the use of forward or backward looking cameras of Mobile Mapping Systems. To overcome this problem, the polar rectification technique was additionally implemented in the SURE framework. By these means, stereo matching is no longer restricted to image pairs as provided from the multi-camera system at common timeframes, but can be extended easily to an in-sequence matching for identical cameras. This considerably extends potential configurations for multiple image pairs, which increases reliability, completeness and accuracy of both depth maps and point clouds as result of the matching process.

Figure 27: IVGI Mobile Mapping System.

This process is demonstrated for imagery captured by the Mobile Mapping System of the Institute of Geomatics Engineering (IVGI), University of Applied Sciences and Arts Northwestern Switzerland (FHNW) and the company iNovitas, which is depicted in Figure 27. As it is visible, the system features industrial stereo cameras and a Ladybug5 panorama camera. The forward looking cameras have a resolution of 4008 x 2672 pixels at a pixel size of 9μm and a focal length of 2 mm.

Figure 28: Stereo image pair and rectified image captured by left and right forward looking camera.

Figure 28 depicts a result of the rectification process for a standard stereo image pair, which was captured from the left and right forward looking cameras with a stereo base of 0.905 m.

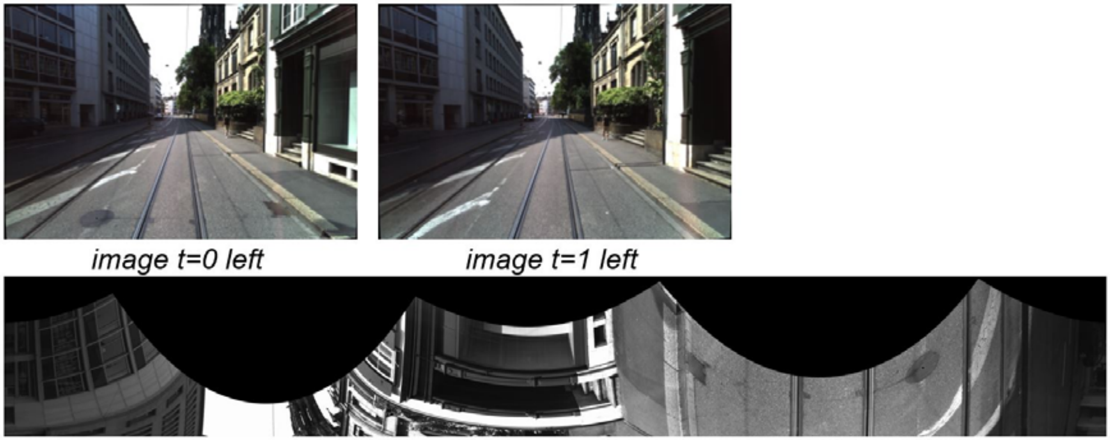


Figure 29: Stereo image pair and rectified image captured by left camera at point of time t=0/t=1.

An example for the in-sequence rectification, which is e.g. required for stereo image pairs captured from the left camera at the point of time t=0 and t=1 is given in Figure 29. In this example, the left camera was moved in look-direction by approximately 2m.

Figure 30 finally shows some 3D point clouds generated from the Mobile Mapping Imagery. All required processing steps were realized within SURE.

Figure 30: Point cloud generated by SURE from Mobile Mapping Imagery.

Building Reconstruction and Modelling in Urban Areas

With the evolving market of data collection applications, two techniques particularly suitable for façade reconstruction have emerged: Mobile Mapping systems and aerial imagery from oblique camera systems. Mobile Mapping platforms mounted onto vehicles capture the environment of urban areas efficiently. These platforms can carry camera systems, LiDAR sensors or combinations of several data collection devices. Within the scope of our investigations, camera-based systems are of interest. Continuously collected stereo images are processed by means of image matching approaches and lead to a point cloud for the whole urban area covered by the vehicle (Figure 31).

In case of aerial imagery, oblique camera systems gather increasing popularity. Most systems combine nadir camera heads with oblique ones, hence giving the opportunity to almost completely capture buildings, including their façades. However, both terrestrial and airborne data collection also have their drawbacks and problems. Compared to dense image matching for the standard nadir case, oblique imagery has to cope with additional challenges like the big difference in scale for foreground and background objects, disadvantageous viewing angles, as well as many obscured areas. Mobile Mapping platforms can only move along streets. Thus, it is not always possible to capture all relevant building sides. Furthermore, other vehicles, pedestrians or vegetation lead to obstructed views on buildings. In addition, high buildings can vertically not be captured at sufficient resolution. This results in building point clouds with partially limited accuracy and completeness.

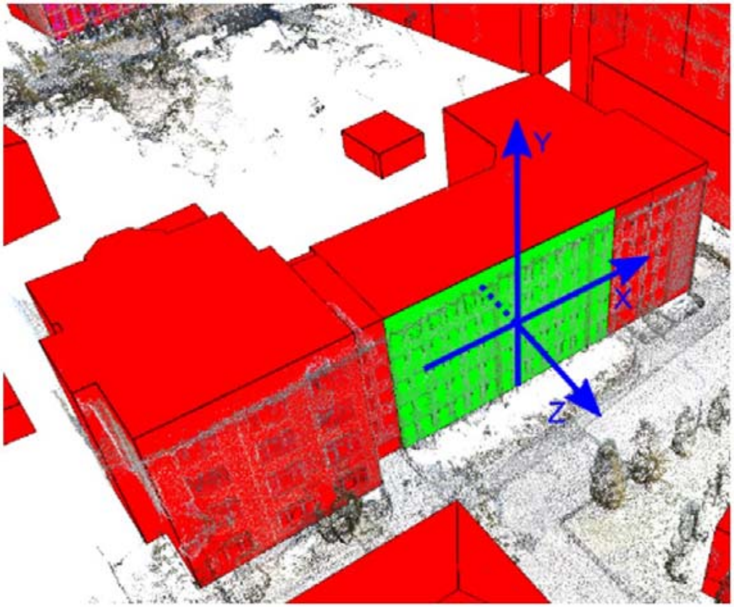


Figure 31: Selected façade (green) with local coordinate system depicted in blue.

Point clouds from dense image matching provide both geometry and color information, which can be exploited by our radiometric segmentation approach for geometric reconstruction support. Yet, this does not overcome the problem of missing or obstructed building areas. Here, the advantage of a grammar based reconstruction and modelling approach becomes apparent. For façade parts with sufficient point coverage, the reconstruction process is performed and subsequently rules defining a grammar are derived. By means of this grammar it is possible to synthetically model building parts that were not or insufficiently covered. The developed approach extends the work of (Becker, 2011), so that it is capable of generating building models compliant with CityGML. Furthermore the data input is not restricted to a single façade point cloud and building anymore. To deal with large point clouds, processing of data stored in the LAS format is possible.

Point clouds from dense image matching with imagery both from Mobile Mapping systems and oblique airborne cameras are used within the investigations. Façades of interest can be selected by user interaction. Based on this selection points belonging to the façade are automatically extracted. Figure 32 shows a selected façade and its local coordinate system. The interpretation of façade structures is based on a geometric reconstruction. For this purpose a pre-segmentation of the point cloud into façade points and non-façade points is necessary. Approaches for point clouds with limited geometric accuracy where a geometric segmentation might fail have been investigated. A radiometric segmentation approach serves as new contribution. Via local point features, based on a clustering in hue space, the point cloud is segmented into façade-points and non-façade points. This way, the initial geometric reconstruction step can be bypassed and point clouds with limited accuracy can still serve as input for the façade reconstruction and modelling approach. Figure 33 shows exemplary results for the outcome of the radiometric segmentation. Figure 34 shows the advantage of working with georeferenced data. After modelling, the generated building or block of buildings can be directly viewed in a global coordinate system and furthermore converted into kmz format e.g., hence giving the possibility to display the results in Google Earth.

Figure 32: GUI showing CityGML LOD2 overlaid with Mobile Mapping point cloud.

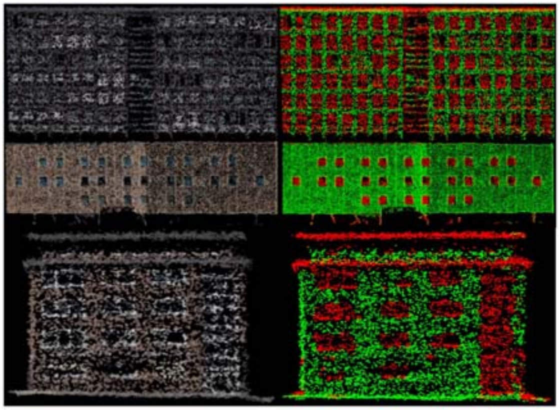


Figure 33: Left column: Point cloud from Mobile Mapping data. Right column: Segmentation into façade plane (green points) and primitives (red).

Figure 34: Export of modelled building blocks into Google Earth.

roomplan - a company for 3D indoor models and floor plans

roomplan is a software startup which is supported by the ifp and the University of Stuttgart. Starting in September 2014 roomplan develops a software hardware combination to redefine the process of measuring indoor environments using a low cost 3D camera. The technology is based on a structure from motion algorithm combined with SLAM and processes RGB and 3D images captured with the Kinect v2 sensor.

roomplan's core customer group will be architects and real estate agents who need a quick and easy way to generate the floorplan and possibly a 3D model of an existing building. The data is captured by the Kinect in combination with a laptop. While recording the data the operator can already see the reconstructed model and ensure that it is complete. After finishing the data recording the model is refined during post processing steps. Finally the floorplan is calculated automatically as the core product for the customer.

roomplan's founders are Dipl.-Ing. Max Schneider, who is responsible for software development and Lion Rink for business administration. The team is complemented by the students B.Sc. Dominik Laupheimer and B.Sc. Falk Kappel who belong to the software development team. Apl. Prof. Dr.-Ing. Norbert Haala is the mentor of the team.

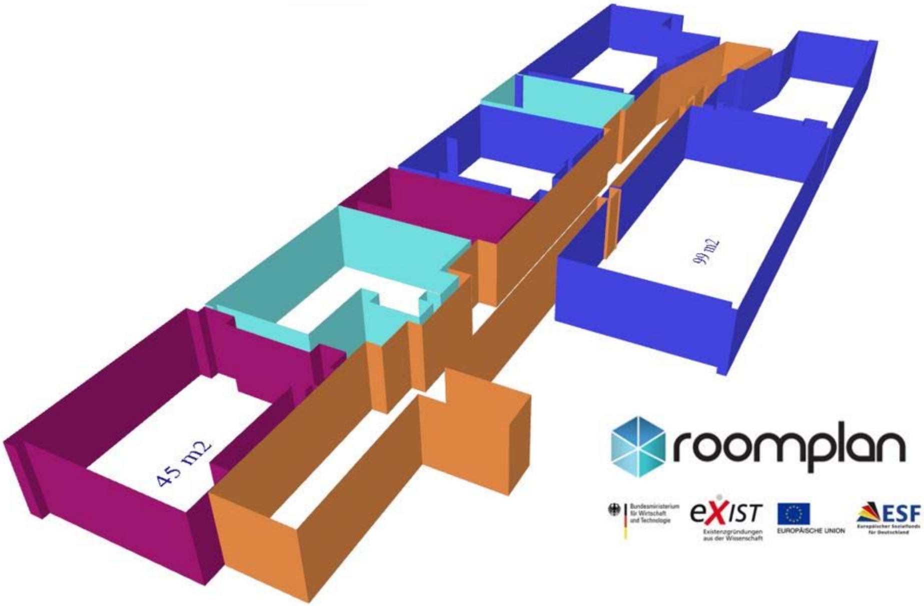


Figure 35: Example of a floorplan created by roomplan software.

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Li, Y.: High Definition Modelling of Calw, Badstrasse, and its Google Earth Integration. Supervisor: Fritsch, D.

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Yang, G.: Vergleich von 3D-Digitalisiersystemen für Bestandsanalysen. Supervisors: Fritsch, D., Schmidgall, G. (Daimler).

Yang, J.: Kontur- und oberflächenbasierte 3D Objekterkennung für Serviceroboter. Supervisors: Fischer, J. (Fraunhofer IPA), Haala, N.

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Study Theses / Bachelor Theses

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Geoinformatics II (Walter)	1/1/0/0
Image Processing (Haala)	2/1/0/0
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Introduction into Geodesy and Geoinformatics (Cramer, Fritsch, Sneeuw, Keller, Kleusberg)	4/2/0/0
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Signal Processing (Fritsch)	2/1/0/0
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Pattern Recognition and Image Understanding (Haala)	1/1/0/0
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Topology and Optimisation (Becker)	2/1/0/0
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