

## Annual Report 2017

Institute of Engineering Geodesy (IIGS)



### 1. Members of Staff

Head of Institute:	Prof. Dr.-Ing. habil. Volker Schwieger	
Secretary:	Elke Rawe Ute Schinzel	
Emeritus:	Prof. Dr.-Ing. Dr.sc.techn.h.c. Dr.h.c. Klaus Linkwitz (died on 11 June 2017)	
Scientific Staff:	M. Sc. Alexandra Avram	GNSS
	M.Sc. Marko Gasparac	GNSS and Digital Map
	M.Sc. Aiham Hassan	Monitoring
	Dipl.-Ing. Patric Hindenberger	Location Referencing
	Dipl.-Ing. Stephanie Kauker (until 14.03.2017)	Monitoring
	M.Sc. Gabriel Kerekes (since 01.04.2017)	Terrestrial Laser Scanning
	Dipl.-Ing. Otto Lerke	Machine Guidance
	Dr.-Ing. Martin Metzner	Engineering Geodesy
	M. Sc. Dung Trung Pham	Kinematic Positioning
	Dipl.-Ing. Annette Scheider	Kinematic Positioning
	M.Sc. Annette Schmitt	Multi-Sensor-Systems
	M.Sc. Martin Wachsmuth (since 01.06.2017)	Digital Map
	M.Sc. Jinyue Wang	Map Matching
	Dr.-Ing. Li Zhang	Monitoring
Technical Staff:	Andreas Kanzler Martin Knihs Lars Plate	
External Teaching Staff:	Dipl.-Ing. Jürgen Eisenmann	Geschäftsbereichsleiter Landratsamt Ostalbkreis, Geoinformation und Landentwicklung
	Dipl.-Ing. Christian Helfert	Fachdienstleiter Flurneuordnung im Landkreis Biberach
	Dipl.-Math. Ulrich Völter	Geschäftsführer der Fa. Intermetric
	Dr.-Ing. Thomas Wiltschko	Daimler AG, Mercedes-Benz Cars; Research and Development

## **2. Obituary for Prof. Klaus Linkwitz**

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

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

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

Klaus Linkwitz was substantially involved with his institute in the planning for the Olympic roofs in 1972 in Munich; he developed new methods for its mathematical form finding and analysis: the so-called force-density method. He succeeded in further developing these methods within the special research area 64 „Weitgespannte Flächentragwerke“ into a practicable process. Cooperation partners in this special research area were apart from Frei Otto the colleagues Fritz Leonhardt, Jürgen Joedicke, John H. Argyris, Jörg Schlaich, Gallus Rehm and others. In the special research area 230 „Natürliche Konstruktionen“ following the special research area 64, the cooperation with other disciplines was even more diversified. Klaus Linkwitz achieved great merits for the geodesy in Stuttgart by initiating between 1984 and 1995 the special research area 228 „Hochgenaue Navigation – Integration geodätischer und navigatorischer Methoden“. As speaker, Klaus Linkwitz lead this special research area to great success thanks to his integrating personality; apart from the geodesy colleagues Ackermann, Grafarend and Hartl with the colleagues Gilles, Mehring, Sorg and Tiziani, there also participated representatives of the Faculties of Physics, Mechanical Engineering and Process Engineering. By his activities within the special research areas, Klaus Linkwitz succeeded in giving the Geodesy importance in an interdisciplinary national and international way.

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

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

## **3. General View**

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

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

Since 2011, he is a full member of the German Geodetic Commission (Deutsche Geodätische Kommission – DGK). Furthermore, Prof. Schwieger is a member of the section „Engineering Geodesy“ within the DGK. He is head of the DVW working group 3 “Measurement Techniques and Systems” and chairman of the FIG Commission 5 “Positioning and Measurements” in the period from 2015 to 2018.

The institute’s main tasks in education focus on geodetic and industrial measurement techniques, kinematic positioning and multi-sensor systems, statistics and error theory, engineering geodesy and monitoring, GIS-based data acquisition, and transport telematics. Here, the institute is responsible for the above-mentioned fields within the curricula of “Geodesy and Geoinformatics” (Master and Bachelor courses of study) as well as for “GEOENGINE” (Master for Geomatics Engineering in English). In addition, the IIGS provides several courses in German for the curricula of “Aerospace Engineering” (Bachelor and Master), “Civil Engineering” (Bachelor and Master), “Transport Engineering” (Bachelor and Master) and “Technique and Economy of Real Estate” (Bachelor). Furthermore, lectures are given in English to students within the Master course “Infrastructure Planning”. Finally, eLearning modules are applied in different curricula.

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

## **4. Research and Development**

### **4.1. Automated Multi-sensor Early Warning System on the Three Gorges Dam - DAAD PPP China**

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

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



Figure1: Ground-based SAR and GNSS measurement at Three Gorges Dam

There were discussions on the requirement analysis of the monitoring system and on the ground-based SAR for monitoring purpose during the visit of Prof. Yaming Xu, who was at the IIGS in June for one month, and Dr. Cheng Xing, who was here from June to September. From October to December, there were discussions with Prof. Jinjun Xu and Dr. Guanlan Liu on the analysis of the measurement. All participants have written a joint paper: "Towards integration of GNSS and GB-SAR measurements: Exemplary monitoring of a rock fall at the Yangtze River in China"; its abstract was accepted for FIG congress 2018 in Istanbul. The next measurement will be in March 2018.

#### **4.2. DAAD Thematic Network Summer School on Geodetic Techniques for Global Change Monitoring**

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

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



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

#### 4.3. Development of Models to Predict the Movement Behaviour of a Surveying Vessel

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

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

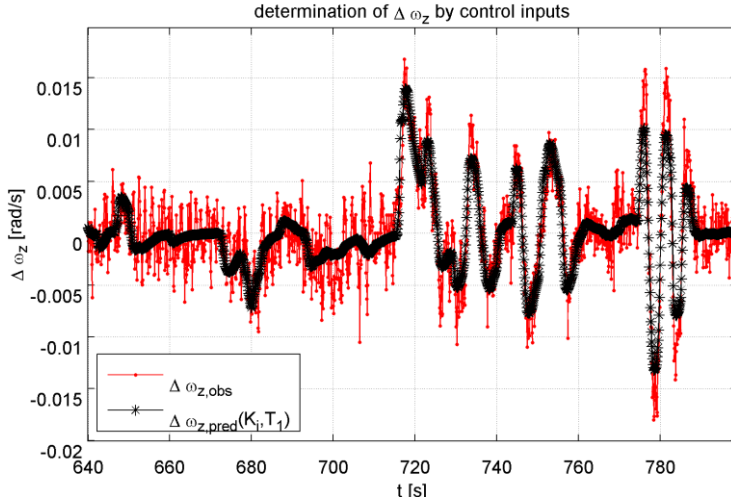


Figure 3: Determination of the change of turning rate ( $\Delta\omega_z$ ) caused by  $F_{contr}$

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

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

#### 4.4. Steering Method for Automatically Guided Tracked Vehicles

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

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

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

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

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

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

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



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

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

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

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

#### 4.5. Optimization of the Positioning of Adaptive Supports

At the University of Stuttgart, the first adaptive double curved plane load bearing structure was developed. This structure is called Stuttgart Smartshell. It has got a base area of about 100 m<sup>2</sup> and a thickness of 4 cm, made of multilayer wood. Resting on three adaptive supports and one static support, the Stuttgart SmartShell offers the investigation of possibilities to reduce stress and structural vibration, while the weight of the structure is reduced drastically. Figure 4 shows the Stuttgart SmartShell.



Figure 4: Stuttgart SmartShell (© Bosch Rexroth)

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

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

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

#### 4.6. GNSS Multipath Error Modelling and Simulation

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

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

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

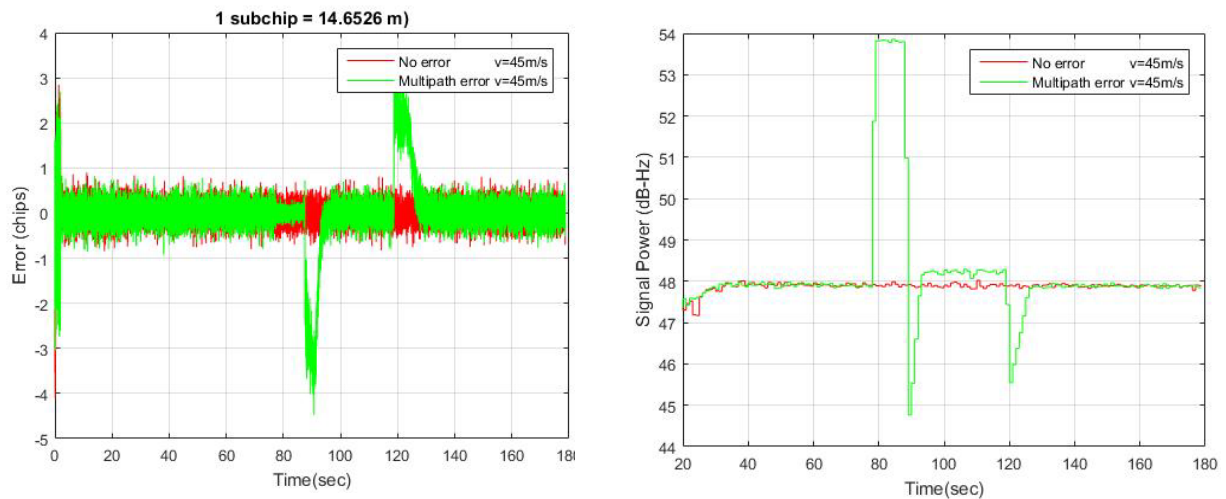


Figure 5: Delay Lock Loop (left) and signal strength of a GPS satellite (right)

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

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



#### 4.7. Ghosthunter - Telematics System against Ghost Drivers using GNSS

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

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

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

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

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

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

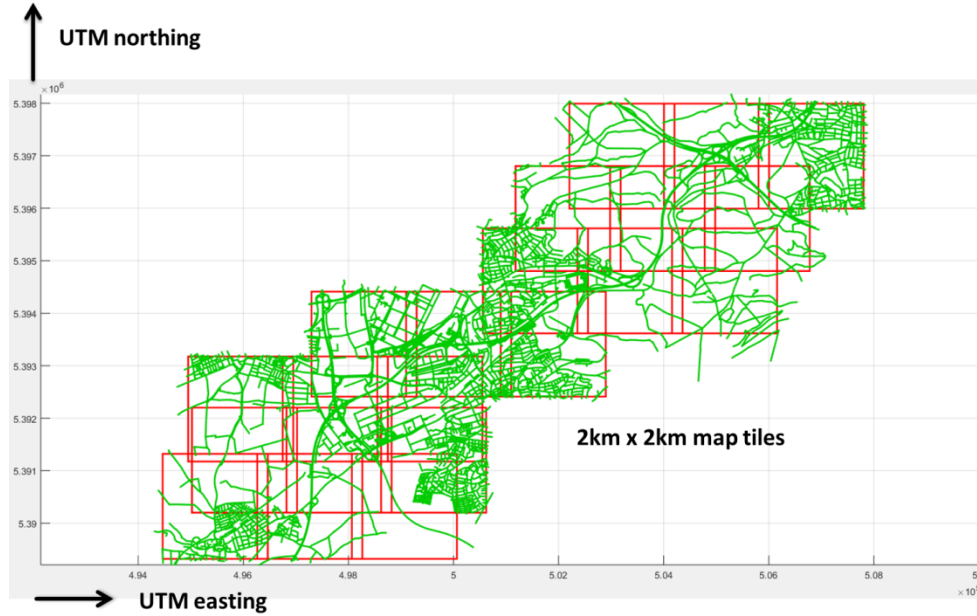


Figure 6: Division of large digital road map files into 2 km x 2 km map tiles

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

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

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

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



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

The implementation is done in an explorative and incremental development cycle with early prototypes adding functionality step by step. Demonstrations with a truck on and off road will

show the results. Testing and pilots on public roads and public areas will prove a higher level of security.

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

#### 4.9. Map-based Multi-GNSS Vehicle Positioning with Lane Identification Capability

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

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

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

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

#### 4.10. Probability and Fuzzy Logic based dynamic Location Referencing Methods

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



Figure 7: Process of Location Referencing

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

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

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

#### 4.11. Level Nonlinearity and Determination of Nonlinear Filtering Algorithms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

#### 4.12. Undergoing Research for Total Stations

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



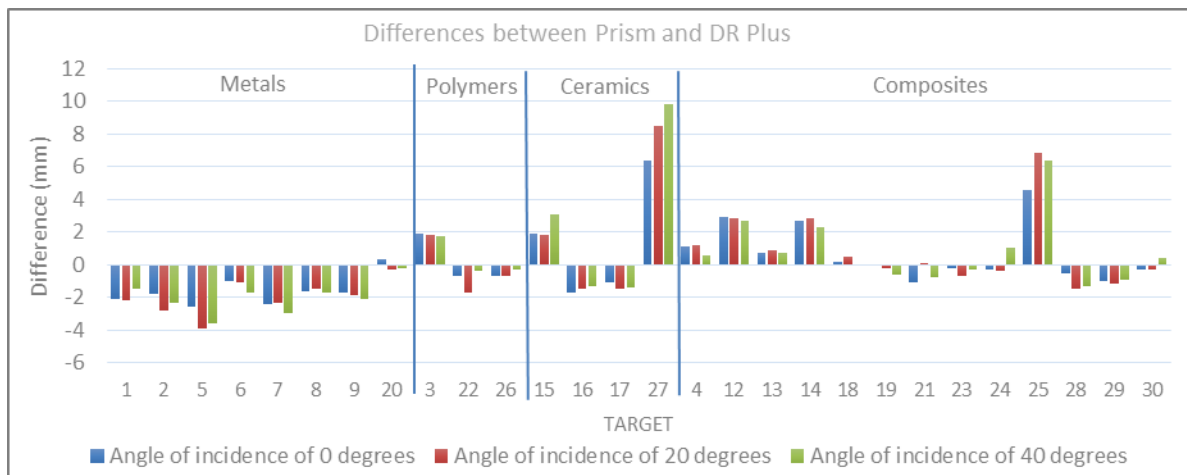


Figure 8: Differences at 30 m field range

## 5. Publications

### Refereed Publications

Kauker, S., Schwieger, V.: A synthetic covariance matrix for monitoring by terrestrial laser scanning. *Journal of Applied Geodesy*, Vol. 11, Issue 2, pp. 77-88, deGruyter, Berlin, 2017.

Kauker, S.; Harmening, C.; Neuner, H.; Schwieger, V.: Modellierung und Auswirkung von Korrelationen bei der Schätzung von Deformationsparametern beim terrestrischen Laserscanning. In: Lienhart, W. (Hrsg.): Beiträge zum 18. Internationalen Ingenieurvermessungskurs in Graz 2017, pp. 321-336, Wichmann, Berlin.

Rinke, N., v. Gösselen, I., Kochkine, V., Schweitzer, J., Berkhahn, V., Berner, F., Kutterer, H., Neumann, I., Schwieger, V.: Simulating quality assurance and efficiency analysis between construction management and engineering geodesy. In: *Automation in Construction*, Vol. 76, pp. 24-35, Elsevier B.V., Amsterdam.

Wang J., Metzner M., Schwieger V. (2017a). Accuracy and Quality Assessment of Various Digital Road Maps for Wrong-Way Driving Detection on the German Autobahn. In: *Proceeding of FIG Working Week, 29.05.-02.06.2017, Helsinki, Finland.*

Zhang, L., Schwieger, V.: Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System. In: *Proceeding of FIG Working Week, 29.05.-02.06.2017, Helsinki, Finland.*

### Non-Refereed Publications

Beckmann, H., Frankl, K., Schütz, A., Philips-Blum, A. Wang, J., Metzner, M., Schwieger, V., Pany, P., Eissfeller, B.. Performance Comparison of Different GNSS-based Multi-sensor Systems for Detecting Wrong-way Driving on Highways, 30th International Technical Meeting of the Satellite Division of The Institute of Navigation ION GNSS+ 2017, 25-29.09.2017, Oregon Convention Center, USA.

Beckmann H., Frankl K., Pany T., Eissfeller B., Wang J., Metzner M., Schwieger V., Stapelfeld M., Grzebellus, M.: GNSS-based detection of wrong-way drivers with an automatic warning of other traffic, DGON Convent 2017,04./05.05.2017, Berlin.

Haala, N., Schwieger, V.: UAV - Anforderungen und Möglichkeiten. 156. DVW-Seminar Unmanned Aerial Vehicles 2017 (UAV 2017), Stuttgart.

Karpik, A., Musikhin, I. and Schwieger, V.: Research and Practical Trends in Geospatial Sciences: The Five to Seven Year Vision. Beiträge zu 19. Geodätische Woche Obergurgl 2017, Obergurgl - Ötztal - Tirol, 12.-18.02.2017, Wichmann Verlag im VDE-Verlag, Berlin.

Lerke, O., Schwieger, V.: Steering Method for Automatically Guided Tracked Vehicles. In: Proceeding of FIG Working Week, 29.05.-02.06.2017, Helsinki, Finland.

Maxim, A., Lerke, O., Prado, M., Dörstelmann, M., Menges, A., Schwieger, V.: UAV Guidance with Robotic Total Station for Architectural Fabrication Processes; 156. DVW-Seminar Unmanned Aerial Vehicles 2017 (UAV 2017), Stuttgart.

Schmitt, A., Schwieger, V.: Estimation of wooden coefficient of expansion due to temperature and moisture with geodetic sensors. In: Kopáčik, Kyrnovič, Henriques (Hrsg.): INGEO 2017, 7th International Conference on Engineering Geodesy, Proceedings, 18.-20.10.2017, Lisbon, Portugal.

## 6. Presentations

Schwieger V.: GEOENGINE – The University of Stuttgart International Master Program with more than 10 Years of Experience, GeoSiberia 2017, 19.-21.04.2017, Novosibirsk, Russia.

Schwieger V.: Cost-Effective GNSS – FIG activities and IIGS Research, Workshop on Cost Effective Positioning and Geo Data, 20.04.2017, Novosibirsk, Russia.

Schwieger V.: Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System, Workshop on Cost Effective Positioning and Geo Data, 20.04.2017, Novosibirsk, Russia.

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

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

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

Wang J., Metzner M., Schwieger V. (2017b). Weighting-function based map-matching algorithm for a reliable wrong-way driving detection. In: Proceeding of 12th ITS European Congress, 19.-22.06.2017, Strasbourg, France.

## 7. Activities at the University and in National and International Organisations

Volker Schwieger

- Dean of the Faculty of Aerospace Engineering and Geodesy, University of Stuttgart
- Chair of FIG Commission 5 "Positioning and Measurement"
- Head of Working Group III „Measurement Methods and Systems“ of Deutscher Verein für Vermessungswesen (DVW)
- Chief Editor of Peer Review Processes for FIG Working Weeks and Congresses
- 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

- Vice chair of Administration of FIG Commission 5 "Positioning and Measurement"

- Member of Working Group III „Measurement Methods and Systems“ of Deutscher Verein für Vermessungswesen (DVV)

## 8. Doctorates

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

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

## 9. Diploma Theses and Master Theses

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

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

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

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

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

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

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

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

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

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

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

## 10. Bachelor Theses

Ehmke, Svenja: Überprüfung der Messgenauigkeit verschiedener Laserscanner (Hassan)

Guan, Ruomeng: Evaluierung der Qualität der Ublox LEA-M8T GNSS-Empfänger (Zhang)

Huber, Christina: Gegenüberstellung und Vergleich verschiedener Ansätze zur Phototexturierung von Laserscans (Schmitt)

Pfizenmeier, Tobis: Untersuchung verschiedener Filterarten zur Extraktion von Geländepunkten aus full-Waveform-basierten Laserscannerpunktswolken zur Erstellung eines DGMS (Hassan)

Stähle, Felix: Bewertung und Analyse des Flurneuerordnungsverfahrens Neuenstein-Neufels zur Verbesserung der Agrarstruktur wie auch der allgemeinen Landeskultur (Metzner)

Xiao, Weixin: Investigation on the Quality of u-blox RTK application board package (Zhang)

## 11. Education

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

### Bachelor Geodesy and Geoinformatics (German):

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

### Master Geodesy and Geoinformatics (German):

Causes of Construction Deformation (Metzner, Wang)	1/1/0/0
Deformation Analysis (Zhang)	1/1/0/0
Industrial Metrology (Schwieger, Kerekes, Kanzler)	1/1/0/0
Land Development (Eisenmann)	1/0/0/0
Monitoring Measurements (Schwieger, Wang)	1/1/0/0
Monitoring Project (Lerke)	0/0/2/0
Terrestrial Multisensor Systems (Zhang, Lerke, Kerekes)	1/1/0/0
Thematic Cartography (Zhang, Wachsmuth)	1/1/0/0
Transport Telematics (Metzner, Scheider)	2/2/0/0

### Master GeoEngine (English):

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

*Bachelor and Master Aerospace Engineering (German):*

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

*Master Aerospace Engineering (German):*

Industrial Metrology (Schwieger, Kerekes, Kanzler) 1/1/0/0

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

*Bachelor Civil Engineering (German):*

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

*Master Civil Engineering (German):*

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

Transport Telematics (Metzner, Scheider) 1/1/0/0

*Bachelor Technique and Economy of Real Estate (German):*

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

*Bachelor Transport Engineering (German):*

Statistics (Metzner, Kanzler) 0.5/0.5/0/0

Seminar Introduction in Transport Engineering (Hassan) 0/0/0/1

*Master Infrastructure Planning (English):*

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