Annual Report 2019

Institute of Engineering Geodesy (IIGS)

1. Members of Staff

Head of Institute:	Prof. Dr.-Ing. habil. Dr. h.c. Volker Schwieger	
Secretary:	Elke Rawe Ute Schinzel (until 31.07.2019)	
Scientific Staff:	M.Sc. Laura Balangé	Quality Modeling
	M.Sc. Urs Basalla	Terrestrial Laser Scanning
	M.Sc. Aiham Hassan	Monitoring
	M.Sc. Gabriel Kerekes	Terrestrial Laser Scanning
	Dr.-Ing. Otto Lerke	Machine Guidance
	M.Sc. Philipp Luz	Digital Map
	Dr.-Ing. Martin Metzner	Engineering Geodesy
	M.Sc. Annette Schmitt (until 31.03.2019)	Multi-Sensor-Systems
	M.Sc. Martin Wachsmuth	Kinematic Positioning
	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
PhD-Students:	M.Sc. Julia Aichinger	Terrestrial Laser Scanning
	M.Sc. Alexandra Avram	GNSS
	M.Sc. Marko Gasparac	GNSS and Digital Map
	Dipl.-Ing. Patric Hindenberger	Location Referencing
	M.Sc. Yu Li	Digital Map
	M.Sc. Dung Trung Pham	Kinematic Positioning
	Dipl.-Ing. Annette Scheider	Multi-Sensor-Systems
	M.Sc. Tobias Schröder	Automation of Production Process
	M.Sc. Yihui Yang	Multi-Sensor-Systems
	M.Sc. Christian Bader	Kinematic Laser Scanning

2. General View

The Institute of Engineering Geodesy (IIGS) is directed by Prof. Dr.-Ing. habil. Dr. h.c. 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, the IIGS is involved in the Center for Transportation Research of the University of Stuttgart (FOVUS). Thus, the IIGS actively continues the close collaboration with all institutes in the field of transportation, especially with those belonging to Faculty 2.

Since 2011, Prof. Schwieger is a full member of the German Geodetic Commission (Deutsche Geodätische Kommission – DGK). Furthermore, he is a member of the section „Engineering Geodesy“ within the DGK.

On October 31, 2019, Prof. Schwieger was awarded an honorary doctorate (Doctor Honoris Causa, Dr. h.c.) in a ceremony at the Technical University of Civil Engineering Bucharest, Romania. The award was made by the Rector Prof. Dr. Radu Sorin Vacareanu and the President of the Senate Prof. Dr. Iohan Neuner. The honorary doctorate was awarded to Prof. Schwieger as a sign of the high recognition of his remarkable contributions to the development and promotion of engineering geodesy, both in teaching and research, but also in appreciation of his important role at international level. Moreover, of course it is for his undoubted merits in developing and consolidating the cooperation and friendship with the Technical University of Civil Engineering Bucharest, during a quarter of a century. Last but not least, in deep gratitude for his way of positively highlighting Romania's culture, history and monuments on numerous occasions at international level.

The institut'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, IIGS is responsible for the above-mentioned fields within the curricula of "Geodesy and Geoinformatics" (Master and Bachelor in German) and 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.

In 2018 the Cluster "Integrative Computational Design and Construction for Architecture" (IntCDC), for which the University of Stuttgart has submitted an application for funding as part of the excellence strategy to strengthen top-level research in Germany, has been awarded funding for the next seven years. The cluster IntCDC aims to harness the full potential of digital technologies in order to rethink design and construction, and enable groundbreaking innovations for the building sector through a systematic, holistic and integrative computational approach. As a member of the cluster (IntCDC), the IIGS's research in the field of new construction methods is intensified in cooperation with architects, civil engineers, computer scientists, production engineers, and other scientists from various research institutions from inside and outside the University of Stuttgart.

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 modeling. The daily work is characterized by intensive co-operation with other engineering disciplines, especially with traffic engineering, civil engineering, architecture, and aerospace engineering.

At this year's GAERO-Fest Laura Balangé received the award from the association "Freunde des Studiengangsgang Geodäsie und Geoinformatik an der Universität Stuttgart e.V. (F2GeoS)" for the best master thesis 2018. The prize was presented by Matthias Wengert (member of the board). On 22th July 2019, Ms. Balangé also received the prize for the best Master's thesis 2018 within the Faculty 6 from the Association of Friends of the University of Stuttgart. The Title of the thesis is "Implementation of the Sea Level Equation" and her MSc thesis at the Geodetic Institute was supervised by PD Dr.-Ing. habil. Johannes Engels. Furthermore her work was awarded on the DVW CAMPUS GEOINNOVATION at the Intergeo 2019.

3. Research and Development

3.1. Precise Seamless 6-DoF Positioning for Georeferenced Assembly Control

Gefördert durch DFG Deutsche Forschungsgemeinschaft

IntCDC CLUSTER OF EXCELLENCE

The presented contribution is nested within the research project 16 "Robotic Assembler" which is part of the overarching research network II "Longspan Buildings" belonging to the cluster of excellence "Integrative Computational Design and Construction for Architecture (IntCDC)" funded by the Deutsche Forschungsgemeinschaft (DFG).

The goal of the project is the 6-DoF pose determination, consisting of positions and attitudes for the guidance process of the robotic assembly platform. Therefore the setup of a network of robotic total stations (RTS) (Figure 1) is planned. Beside the 6-DoF pose determination the research area considers the optimization of the geometric network configuration under aspects of accuracy and reliability as well as the ability to propose suggestions regarding the on-site arrangement of RTS for performance improvements of seamless positioning. Further research aspects are the steering of different RTSs within the network and the fusion of their data using data fusion algorithms like extended Kalman filter, unscented Kalman filter or particle Filter.

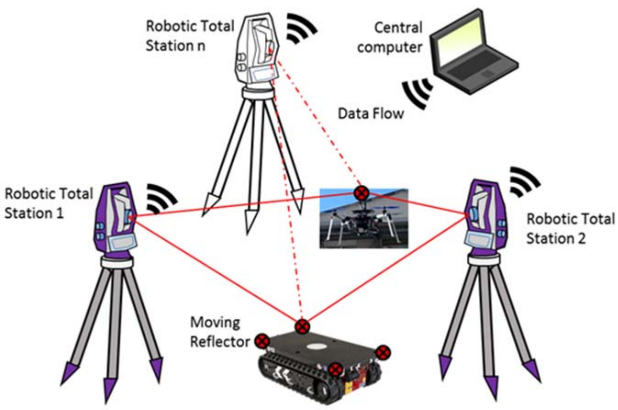

Figure 1: Principle sketch of RTS network

Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2120/1 – 390831618.

3.2. Holistic Quality Model for IntCDC Building Systems

During the framework of the Cluster of Excellence for Integrative Computational Design and Construction for Architecture, a Holistic Quality Model is to be developed. This model includes social, environmental and technical components. Thus, this project is a cooperation between the Institute for Social Sciences (SOWI), the Institute for Acoustic and Building Physics (IABP) and the Institute for Engineering Geodesy (IIGS). Each of the partners provides an column of the overall quality model. These columns are shown with exemplary quality characteristics in Figure 2.

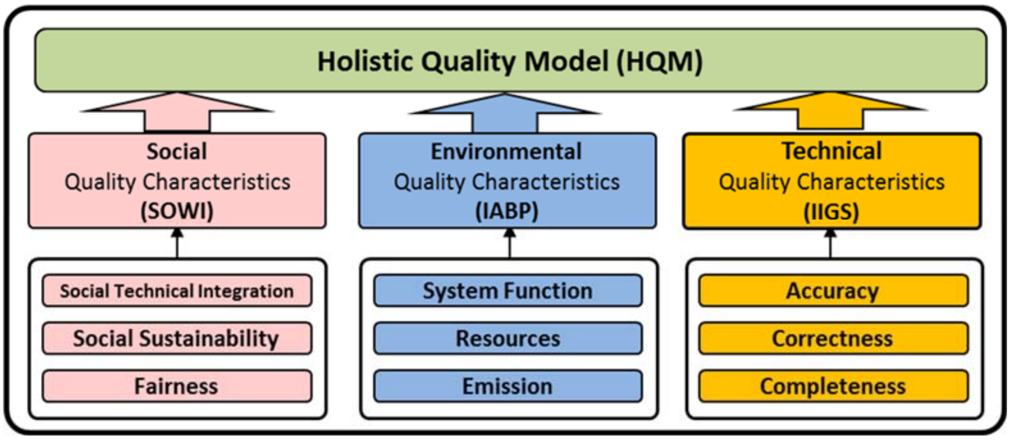

Figure 2: Holistic Quality Model

In a first step, the general understanding of the terms of quality was identified between the three partners. After that, a survey starts to learn about the general requirements for the quality model from the different disciplines included in the cluster. The results of the survey, i.e. the characteristics which are considered as important, such as accuracy, completeness and timeliness, have now been extended with further characteristics from the norms and standards of all disciplines involved in IntCDC, for example architecture, civil engineering or mechanical engineering. Thus, the model was extended by the features load bearing capacity, fire protection and water permeability.
With these extended quality characteristics, the structure of characteristics, condensed parameters and primary parameters were introduced (Figure 3). The condensed parameters consist of several primary parameters. In addition, the values of the condensed parameters are based on the values of the primary parameters. A primary parameter is a parameter that can be measured.

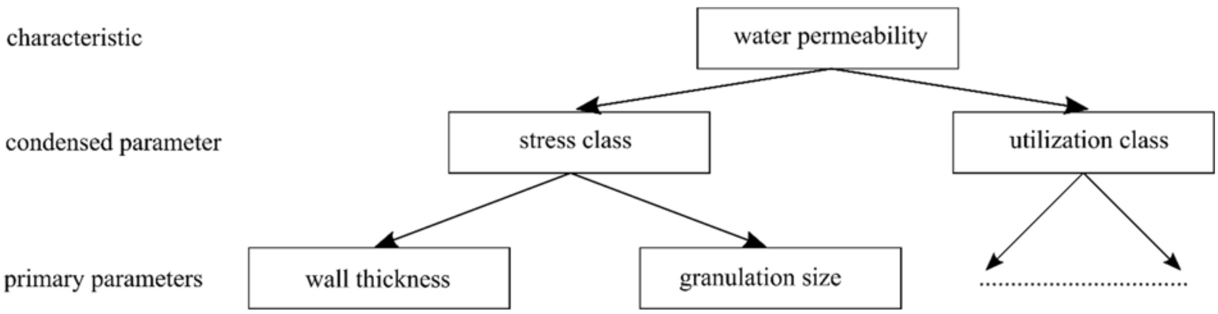

Figure 3 Structure of characteristics, condensed parameters and primary parameters

Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2120/1 – 390831618.

3.3. Quality Assurance for Wooden Pavilions

The Institute for Computational Design and Construction (ICD) has planned a wooden pavilion for the Bundesgartenschau 2019 in Heilbronn. This pavilion consists of so-called cassettes made of glued spruce wood. It is planned for this pavilion to manufacture the cassettes with low tolerances, i.e. the cassettes are milled true to shape. It should be investigated how precisely the milling process of the cassettes is carried out. Laser tracker measurements were made along the edges that come into contact with other elements. These measured edges were compared with the CAD model of the corresponding cassette. The average deviation of the measurements from the theoretical CAD model is 0.35 mm, which is sufficient for the robotic production of the cassettes.

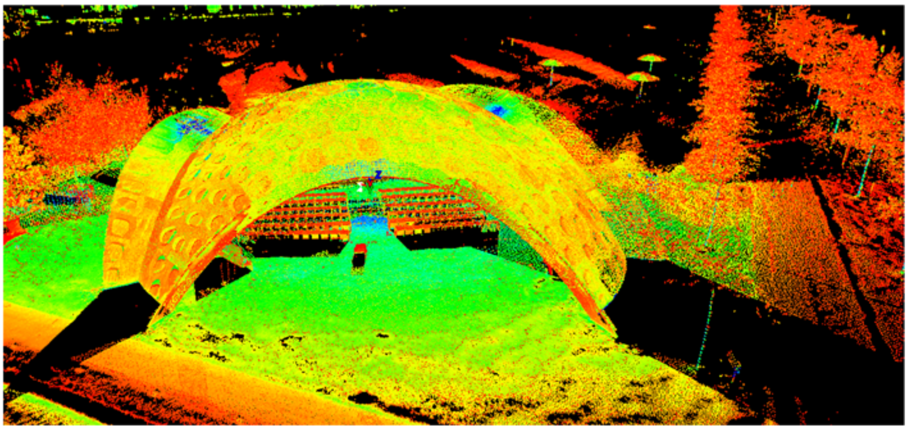

Figure 4: Two epoch comparison of recordings from April and August. Differences are in the range of a few millimetres

Furthermore, the pavilion was scanned during construction and during its lifetime at the Bundesgartenschau at recurring intervals. Any changes should be detected here. No significant deformation of the structure was detected in the multi-epoch comparisons (Figure 4).

The ICD has planned a wooden tower also for the Remstal Gartenschau 2019 (Figure 5). Half of the wooden elements were built in Switzerland. These wooden elements were built with curved wooden bilayers. The approximately 30 curved panels of wooden bilayers were scanned at the "Blumer-Lehmann" workshop in Gossau (CH) to determine the radii along them. In a next step, the wooden bilayers were glued together to form two fifteen-meter-long elements. These were also scanned in the factory. From these larger elements the finished components were milled out and scanned again. These scans are used for quality control and data storage. The tower was built near Urbach. The tower is scanned every 3 months to document the changes over its minimum 5 years lifetime. Furthermore, the humidity and temperature of the wood is measured in different parts of the tower.

Figure 5: Network measurement when measuring the fixed point network

The aim here is to determine a possible correlation between moisture/temperature and the deformation of the wood. In order to georeference the individual epochs, a fixed point network was set up on site.

3.4. NURBS Modeling for Terrestrial Laser Scan Point Clouds in the Context of Deformation Analysis

For deformation analysis of complex surfaces, NURBS surfaces (non-uniform rational B-spline surfaces) are determined from real laser scan point clouds. The NURBS surfaces of the different epochs are to be brought to coincidence by means of parameter-dependent superposition. In the presented approach the control points required for the NURBS surfaces result directly from laser scan points and are not determined by means of estimation methods. For a shape-correct control grid formation an intensive examination of necessary conditions at the edges of the point clouds as well as a selection of control polygons from the point cloud are necessary. Since in this work tensor product surfaces are used for NURBS determination whose control grid is based on a rectangular grid structure, a uniform control grid structure must first be created before NURBS surfaces can be calculated. In order to achieve this goal, two knot insertion algorithms will be investigated to determine new knots and control points. However, a change of shape of the curve or surface has to be avoided. While Boehm's algorithm inserts one knot at a time, the Oslo Algorithm allows for the simultaneous insertion of several knots. Nevertheless, the repeated insertion of knots with low computational effort with Boehm's algorithm must be set in relation to the one-time computational step with high computational effort with the Oslo algorithm.

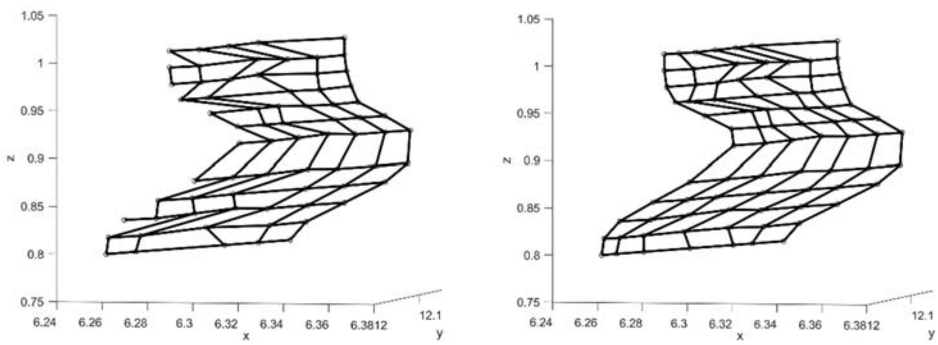

Figure 6: Control point grid consisting of control point polygons of different numbers (left). Control point grid consisting of control point polygons with the same number of points (right).

Figure 6 shows on the left side an exemplary control grid whose control polygons consist of different numbers of knot points. The right graph presents the result of the Boehm algorithm, whose knots insertion formed the basis for the formation of a tensor product NURBS surface. Figure 7 shows a third-degree NURBS surface. A stochastic investigation of the assumed non-shape changes is to be added to the previous analyses.

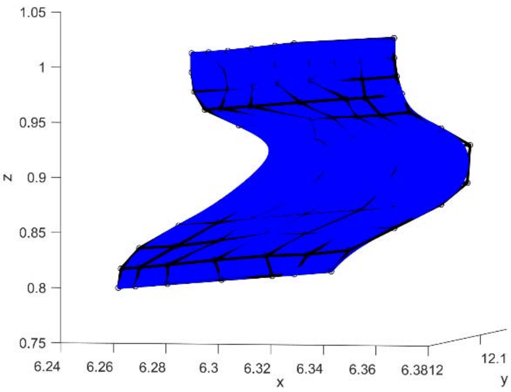

Figure 7: NURBS-surface of degree three

3.5. Integrated Space-time Modeling Based on Correlated Measurements for the Determination of Survey Configurations and the Description of Deformation Processes (IMKAD II)

Gefördert durch DFG Deutsche Forschungsgemeinschaft

This project aims at bringing new contributions in analyzing deformation processes with high spatial resolution Terrestrial Laser Scanning (TLS). The IMKAD II project, foresees measurement campaigns for objects of different dimensions. This is necessary for studying the existing variances, covariances and correlations of TLS point clouds. The Elementary Error Model (EEM) is used to determine a synthetic variance-covariance matrix (VCM). In August 2019 the first measurement campaign at the Kops lake in Austria took place. The Kops water dam is a concrete storage dam built between 1962 and 1969, and administrated by the Vorarlberger Illwerke AG. It is considered a hybrid type made out of a gravity dam and an arch dam with artificial counterfort or abutment The crown spans over 400 m, its height is 122 m from foundation to crest and it has a crest width of 6 m. Only measurements of the downstream (airside) arch dam are considered, since this can be interesting to model by means of B-Spline surfaces in the future. Results of the Leica HDS 7000 scans are further analysed after applying the EEM with solely instrumental error sources. Two intrumental error models are examined in parallel. In order to have an idea about the existing spatial correlations, different sections are seleted on the dam airside (Figure 8) and correlations from one point to all other points in that section are calculated.

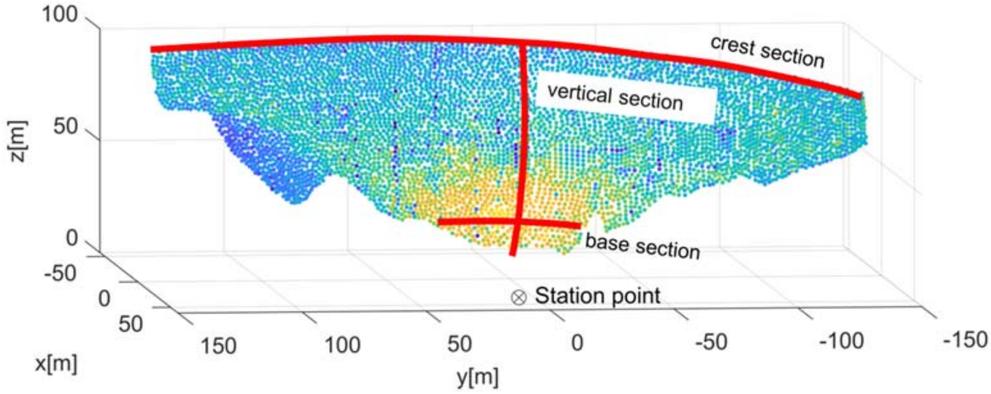

Figure 8: Sections used for spatial correlation analysis

Results of the existing correlations for the crest section can be seen in Figure 9 for both studied instrumental error models. Additionally, the standard deviation along the same axis (Y) is represented. These are all intermediate steps needed for a fully populated VCM, indispensible in the deformation analysis. A second measurement campaign will be completed in 2020.

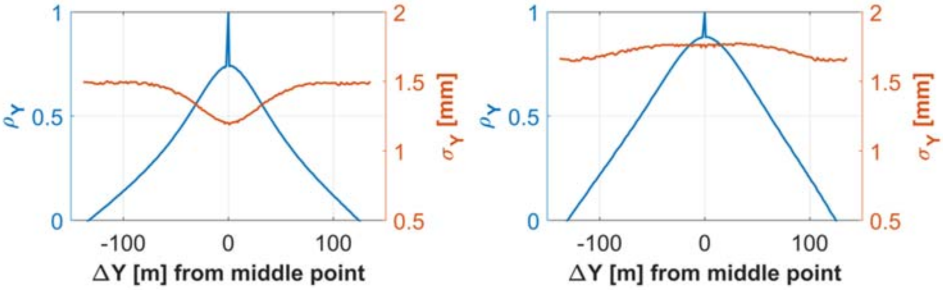

Figure 9: Spatial correlations and standard deviations along the crest section (model 1 on the left, model 2 on the right)

3.6. Automated Control for Car Door Adjustments Based on Neural Networks

The following research is the result of a partnership between IIGS and the Tec-Fabric at the Mercedes-Benz AG plant in Sindelfingen. The aim of this project is to realize an automated system providing the worker with a reference for car door adjustments. In the production process of a modern car the doors are built-in in a highly automated procedure, where multiple sensors and robots jointly calculate the optimum position of the door in relation to the side wall of the car. The precision of the alignment is verified by a final measurement. Two cases are considered: 1) the results are within the given tolerance, 2) the result is outside the tolerance. In the second case, the door is manually adjusted by human workers in a so called post-processing station. The workers rely on their experience and on the measurement results. The process therefore is based on trial and error, which is not very cost-effective. The challenge of the project was to make this heuristic adjustment process more determined and technically supported. Doors are dimensionally stable. Consequently, the door hinge screws define the three-dimensional orientation without any additional deformation components. As a consequence, the measured gap and flush values of the final measurement depend on the condition of the door hinge screws. Correlation between an input (i.e. gap-profile and values of gap and flush) and output (screw and direction of turn) are solid indicators for the usability of neural networks. To investigate the impact of each screw as well as their turning direction, two cases are implemented (Figure 10). In the first case the model is only trained on the detection of the affected screw, the second case also considers the turning direction clockwise (+) or counter-clockwise (-). In the first case the three true classes (S1, S2, S3) represent the three screws of the door hinges. The second case includes six true classes; one for each screw and its turning direction.

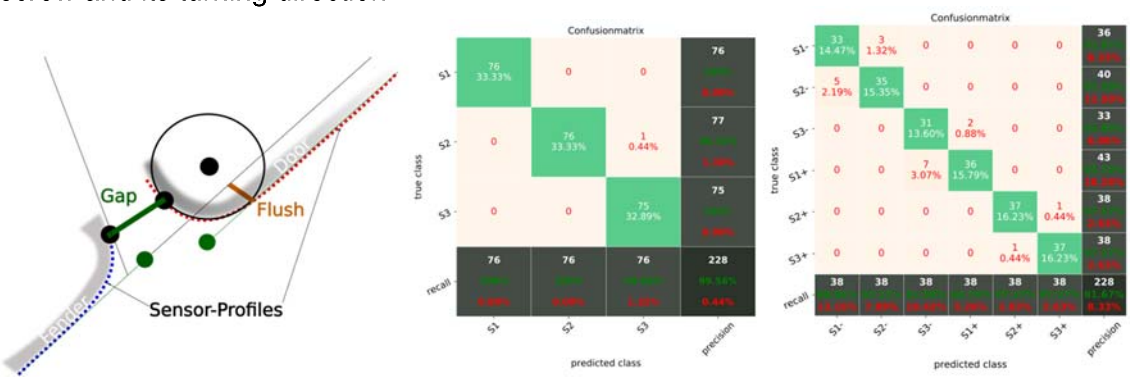

Figure 10: Input values with gap, flush and sensor-profiles (left), the resulting confusion matrix for the first (center) and the second case (right).

The first case has a 99.56 % precision, which is nearly perfect, considering that the training data with 234 measurements is rather small. The second case with its precision of 91.67 % is not as good as the first case, but still promising. The outcome encourages further investigations. Nowadays, the neural network is helping workers to adjust the doors in a field test. The results of the field test will give an impression about the applicability and will be discussed in later publications.

3.7. Non-Linearity of System and Observation Models

The non-linearity of a model is one of the most important characteristics in the estimation algorithms of kinematic positioning applications. Almost all estimation algorithms deal with in the non-linear environment of both system and observation models. The non-linearity of a system model and an observation model measured by the multivariate association is compared here. The quantity of non-linearity of these models can provide the information to use suitable estimation algorithms.

The non-linearity of a model is an amount that is determined by the non-linear relationship between the input and output variables. Multivariate association (MVA) is employed as a measure of the linear relationship between two sets of variables. Hence, 1-MVA is used to measure the non-linearity of the model. If 1-MVA is close to 0, the model is nearly linear. Inversely, if 1-MVA is close to 1, the model is non-linear. The procedure for determination of non-linearity of a model is depicted in Figure 11. Measures of non-linearities of system and observation models are evaluated for the case of kinematic positioning application.

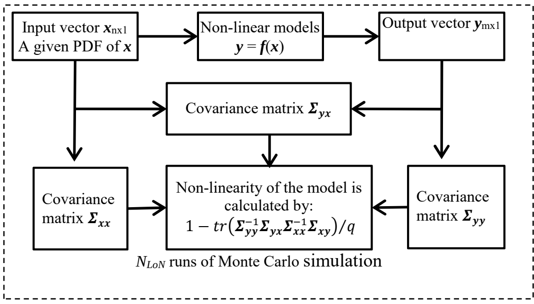

Figure 11 Determination of the non-linearity using 1-MVA

Supposing that a moving object is tracked by two radars located at reference points. This object moves from the west to the east in the x-y plane with a constant velocity v and is observed during the period of 100 epochs with a data rate Δt of 1 s. Two radars can provide information about the bearing angle. Their measurement accuracies are σ_{α}. The standard deviations of process noise, including acceleration a_{ξ} and rotational rate φ_{ξ}, for modeling the moving object are small with a_{ξ} = 0.04 m/s^2 and φ_{ξ} = 0.04 rad/s^2.

The straight line model and the bearing angle model are applied for the system model and the observation model, respectively in this study. These models are non-linear models with respect to the state vector. In these evaluations, the non-linearity of these models is determined with variation of their influencing factors. The data rate Δt, velocity v, and orientation change $\Delta\varphi$ are considered as its influencing factors for the system model and the measurement uncertainty and the geometry are corresponding factors for the observation model. Note that the distance between radars and the moving object characterizes the geometry.

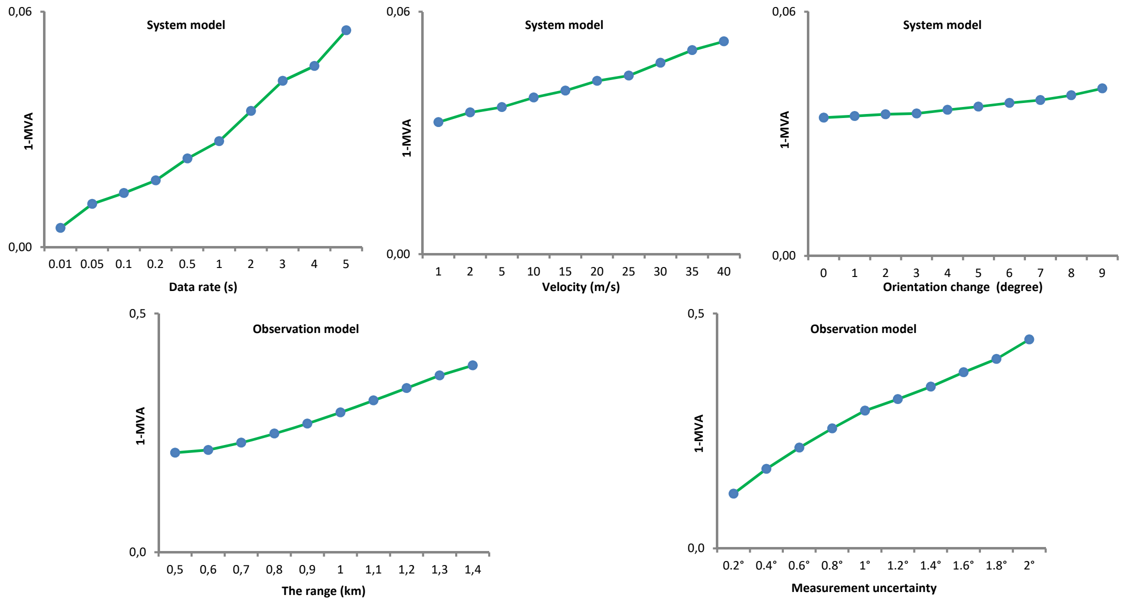

Fig. 12. Non-linearity of the system and observation models due to varying of influencing factors

Figure 12 shows that the non-linearity of the system model is relatively small (< 0.06% or 6%), and it also changes with its influencing factors. The small quantity for the system model is due to the assumption of the standard deviation of process noise. In this case, the mathematical function of the system model is to describe the behavior of a moving object that moves in a straight trajectory with constant velocity. In contrast, the non-linearity of the observation model is relatively high (nearly 0.5% or 50%) compared to that of the system model. Both observation geometry and measurement uncertainty considerably influence the non-linearity of this model. The change in the non-linearity of this model according to the two above influencing factors are 0.2 and 0.4 (20% and 40%), respectively. The high quantity in the non-linearity of the observation model is due to the mathematical functions of its model and influencing factors. In this case, the distance and bearing angle are non-linear models concerning the state vector and the measurement uncertainty is high. As a result, the non-linearity of the observation model is considerably higher than that of the system model according to the high uncertainty from low-cost sensors. The non-linearity of these models is a useful characteristic for applying suitable algorithms or hybrid algorithms in estimation.

3.8. Ghosthunter II - Telematics System against Ghost Drivers using GNSS

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

The Ghosthunter II project is carried out in cooperation with the Institute of Space Technology and Space Applications at the University of the Federal Armed Forces Munich and the company NavCert.

One of the most important topics of the project is investigating whether the time required to detect a wrong-way driver on motorway ramps can be reduced by using lane-precise maps. A wrong-way driver should be detected even if the lanes are not yet separated. However, this is only possible with lane-precise maps and a map matching algorithm adapted to this kind of maps. A map matching algorithm is utilized to allocate the measured vehicle position on the most probable road link or with the lane-precise map matching the most probable lane link. In this work, an algorithm is developed that performs map matching based exclusively on GNSS positions and a digital lane-precise map (shown in Figure 13). This is provided by 3D Mapping Solutions GmbH. The algorithm is based on three factors: heading, distance and connectivity. In contrast to other algorithms the connectivity is calculated in real time from the map data.

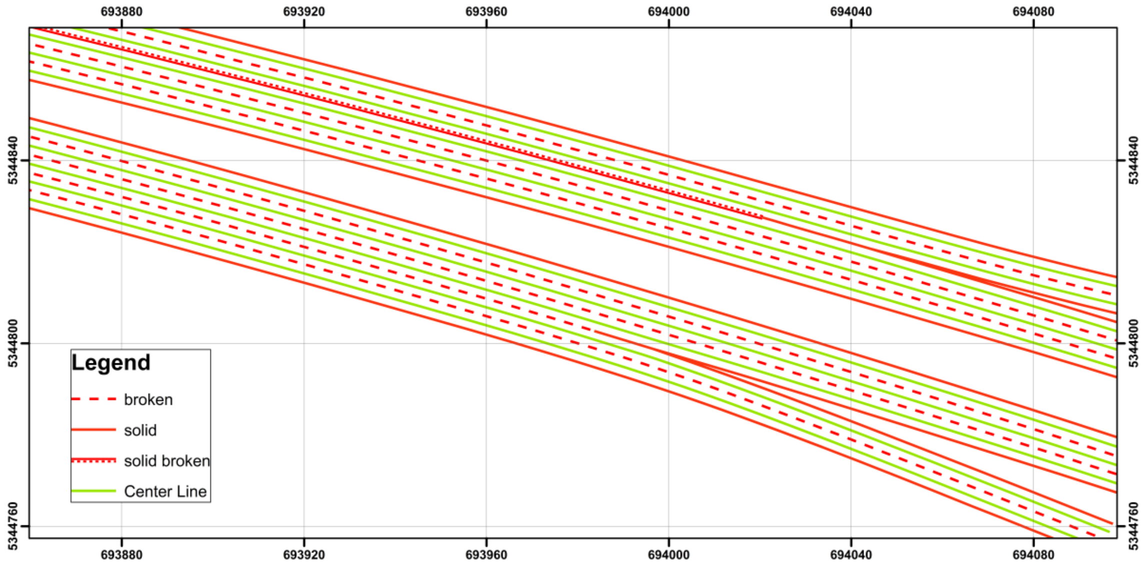

Figure 13: Detail of the lane-precise map

The basis for this new map matching algorithm is the algorithm developed by the IIGS during the Ghosthunter I project. As mentioned above, the connectivity is no longer included in the lane-precise map. Thus, a new approach has to be found to take these into account. The connectivity is therefore calculated in real time from the existing lane markings.
Each crossing of a lane marker results in a penalty or reward. The connectivity of the segment results from the sum of these. The algorithm not only checks whether the lane change is possible, but also how well the driven distance matches the map distance required for the drive from the last segment to the test segment. The overall accuracy is then made up of these two sub-connectivity elements and then be used like directly calculated connectivity in the map matching algorithm.
With these modifications the algorithm identifies the correct lane with 100% for high accuracies ($\sigma = 0.05$ m) and with 94% for medium accuracies ($\sigma = 1.50$ m).

The research project Ghosthunter II, is granted by the German Federal Ministry of Economic Affairs and Energy (BMWi) and the German Aerospace Center (DLR) under grant number 50 NA 1802.

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

The European Project TransSec (Autonomous emergency manoeuvring and movement monitoring for road transport security) is funded by the European Commission within the program Horizon H2020 for three years. This project was started in February 2018 and its goal is to design and implement a built-in intelligent safety system to prevent trucks and transport of goods to be misused for illegal purposes such as terror attacks. IIGS is one of the five partners involved in TransSec project.

One task of IIGS is to get the precise positioning of the trucks by integrating the data from GNSS and other additional sensors such as IMU. IIGS focuses on a Kalman-filter with strapdown algorithm in the positioning module.
The other task of the IIGS is to design and implement a map-aiding approach that considers on-road and particularly off-road scenarios for truck positions in order to detect potential risks. These two tasks will be described in the following text.

TransSec– Positioning Module
For the research project TransSec, the IIGS created a positioning module together with OHB Digital Solutions GmbH (formerly TeleConsult Austria), one of the project partners. Since the GNSS availability is decreased and even complete outages occur in urban city canyons and other obstructed areas like tunnels, we designed an integrated multi-sensor positioning system. The sensor data fusion uses GNSS and inertial measurement unit (IMU) inputs and is done using an error state Kalman filter. The filter estimates the position, velocity and attitude of the vehicle as well as the biases for the accelerometers and gyroscopes. The overall algorithm is divided into two parts. In the first part the IMU measurements and results of the previous filter update are used to predict the vehicles current state. This part is often called strapdown algorithm. Within the strapdown algorithm firstly the measurements of the gyroscopes are used to predict the new attitude of the vehicle. With the new attitude the measurements of the accelerometers, measured in the vehicles body frame, get transformed in the earth frame. With the accelerations in the earth frame it is possible to predict the vehicles velocity, which is also represented in the earth frame. Finally, the predicted new velocity is used to predict the vehicles new position. This strapdown algorithm is running with the frequency of the IMU measurements. Whenever a GNSS position is available, the second part of the overall algorithm which is the actual Kalman filter update, is done and a new state vector is estimated.
In Figure 14 the result of the current algorithm is shown. The situation shows a turning to the right at an intersection. The red crosses show the GNSS positions and the black dots are the predictions of the vehicle position using IMU measurements. Since the IMU measurement frequency was high with 100 Hz, the dots are so close to each other that they appear as lines at this scale. The small jumps (see figure 14) at the new GNSS position are due to the high accuracy of RTK GNSS compared to IMU measurements. This leads to a higher weighting in the Kalman filter compared to the GNSS measurements and results in these small jumps.

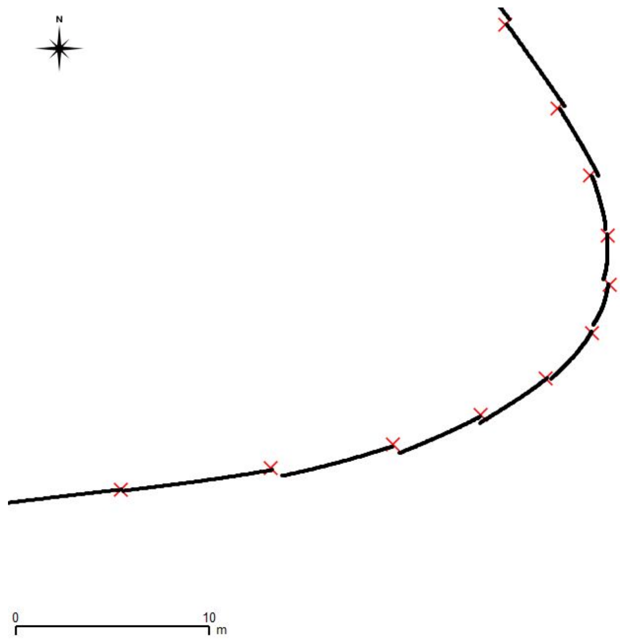

Figure 14: A turn to the right

TransSec – Map-Aiding
Within this project, the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart designed and implemented a map-aiding approach that considers on-road and particularly off-road scenarios for truck positions in order to detect potential risks. As a result, map-aiding provides the most probable road link, multiple candidate road links, the estimated off-road distance and additional information like total weight score/probability and perpendicular distance for each link to the TransSec risk estimation module. According to the test results, the

map-aiding performs quite well even at complex road conditions such as road intersections, junctions, overpass and underpass.
The map-aiding approach can be regarded as a modified and improved algorithm based on map-matching. The most probable road link and other candidate road links in the defined buffer zone derived from map-matching are used as base information in the map-aiding. The functionalities lane identification and on/off-road estimation are based on the information of number of lanes extracted from the digital road map data and the assumption that the lane generally keeps an approximately constant width of 3.5 meters. If the truck is on-road, the algorithm estimates on which lane the truck is probably travelling. If the perpendicular distance from the truck position to the most probable road link exceeds the range of the road width, the truck position is identified as off-road and the off-road distance is estimated by subtracting half of the road width from the perpendicular distance.

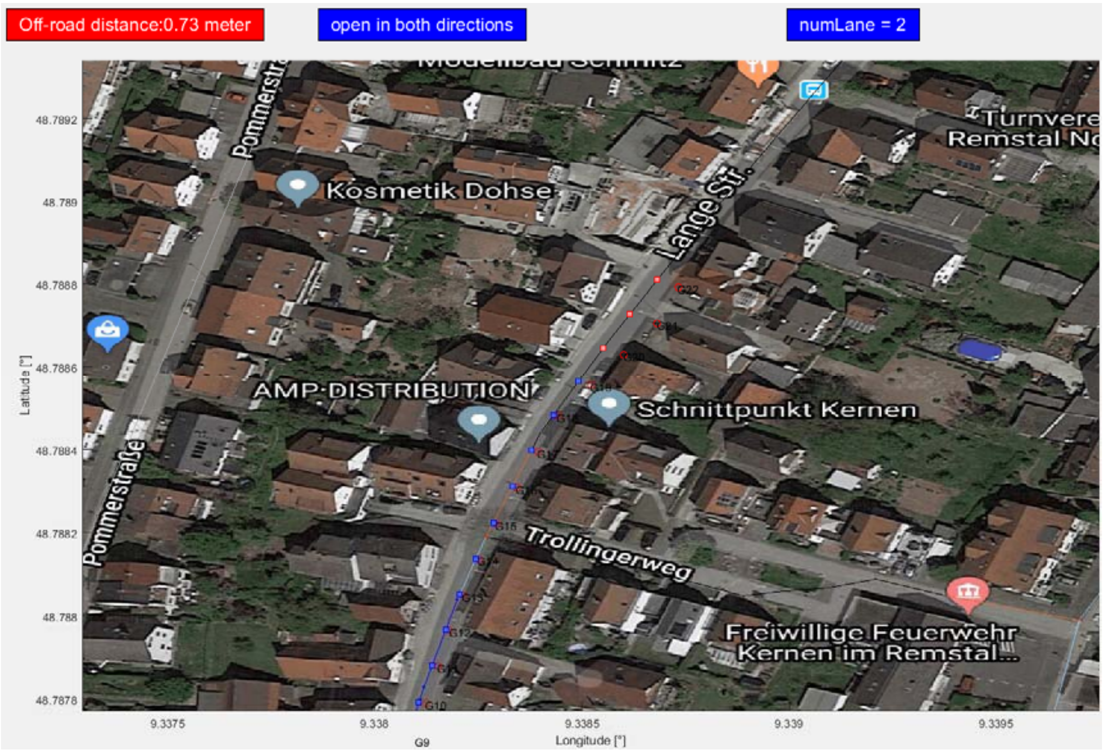

Figure 15: An example of map-aiding result with off-road estimation

As shown in Figure 15, the road on which the truck is travelling consists of two lanes. Even when the estimated deviation exceeds 3.5 meters slightly, the vehicle position (denoted with a small red circle) is identified as off-road. The estimated off-road distance is 0.73 meters for the current vehicle position. The perpendicular foot of the off-road vehicle position on the identified reference link is represented with a light red rectangle symbol.

3.10. Dynamic Location Referencing: Probability- and Fuzzy Logic-Based Decision Systems

Location Referencing is a well-known methodology to transfer geo-objects from one digital map to another and typically used to share traffic information. Here, especially the dynamic methods play a major role, as they are developed to transfer Location References (LR) between different maps in such cases where no common databases and/or common structures are available. Location Referencing Methods follow a one-dimensional three-step process of encoding the LR in the sender system, transferring and decoding the LR in the receiver system without any iterations (Figure 16).

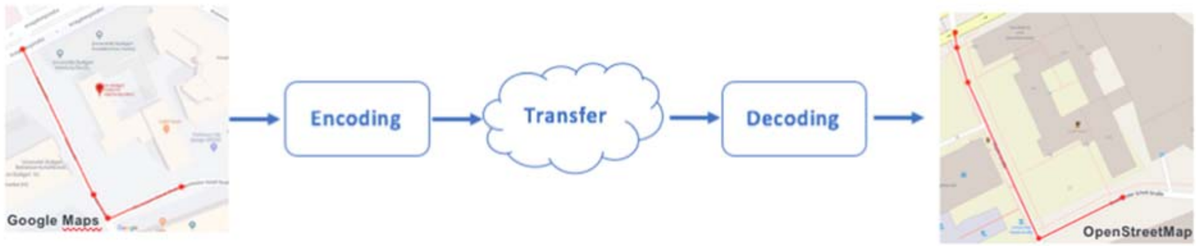

Figure 16: Process of Location Referencing

For dynamic Location Referencing Methods, the key issue is to find the correct geo-object in the target map which corresponds to the geo-object in the source map. So far, in nearly all methods a deterministic algorithm is implemented to perform this. Given the fact that geodata as well as the matching procedure for geodata have some uncertainty, it is obvious to research uncertainty-based algorithms.

As pointed out in the previous annual report, two different uncertainty-based approaches were picked up and investigated in detail. Firstly, a probability-based approach using a specifically formulated decision algorithm based on a predefined set of criteria (geometrical, topological, syntactical and semantical) and secondly a fuzzy-based approach implementing a fuzzy-based decision system based on the same set of criteria. Evaluating the performance in a QGIS-based module, the probability-based and fuzzy-based approaches show similar results with an average hit rate up to 90% and improve the results of a comparable deterministic approach (OpenLR) in average by 12 percentage points. The probability-based approach was presented on LBS Conference 2019 in Vienna and published in the corresponding conference volume.

Based on the results obtained so far and further discussions, additional research and working approaches were identified, which will be investigated in the course of the year.

3.11. Multipath Behavior under Static and Kinematic Conditions

The study of multipath delays and behavior is important to further understand how a GNSS receiver processes them and turn them into errors that are present on the pseudo ranges. Ray tracing techniques are known in the literature to realistically model multipath, considering all the complex changes of the GNSS signals in both time and frequency domain. Most of the ray tracing algorithms for predicting the radio signal strength, phase, and delay are based on the computation of the wave's reflection, diffraction, and scattering. Due to the high accuracy of the method, a ray-tracing software together with a GNSS signal generator were used to study the multipath behavior under static and kinematic conditions.

Figure 17 shows the environment which was used for the ray-tracing simulations. The vehicle is the carrier of the receiving antenna. This is simulated on the rooftop. The white lines represent line-of-sight signals and the blue ones show signal reflections. Signal diffraction is also computed and symbolized by the red lines. The multipath signals are generated by means of a GNSS simulator. GPS and Galileo signals are simulated and the first strongest multipath signals are taken into consideration. The hardware channel number, i.e. the number of GNSS signals which can be physically generated are limiting this method. Nevertheless, literature support the idea that two multipath rays per satellite provide realistic results. The rest of the multipath signals i.e. third, fourth reflection might anyway be too weak to be perceived by the receiver.

The right side of Figure 17 shows the simulation results for static and kinematic simulations using the same 3D scenario and satellite constellation. The delays produced through reflections from all visible satellites are plotted. As expected, the reflection pattern is different. In a static case, multipath reflections change slowly with the satellite movement. In kinematic simulation, the reflections constantly change due to the rapidly changing environment. The results show high multipath delays more often in the static case. This is because due to kinematics, an unfavourable geometry (satellite-environment-receiver) which produces a certain delay occurs only shortly.

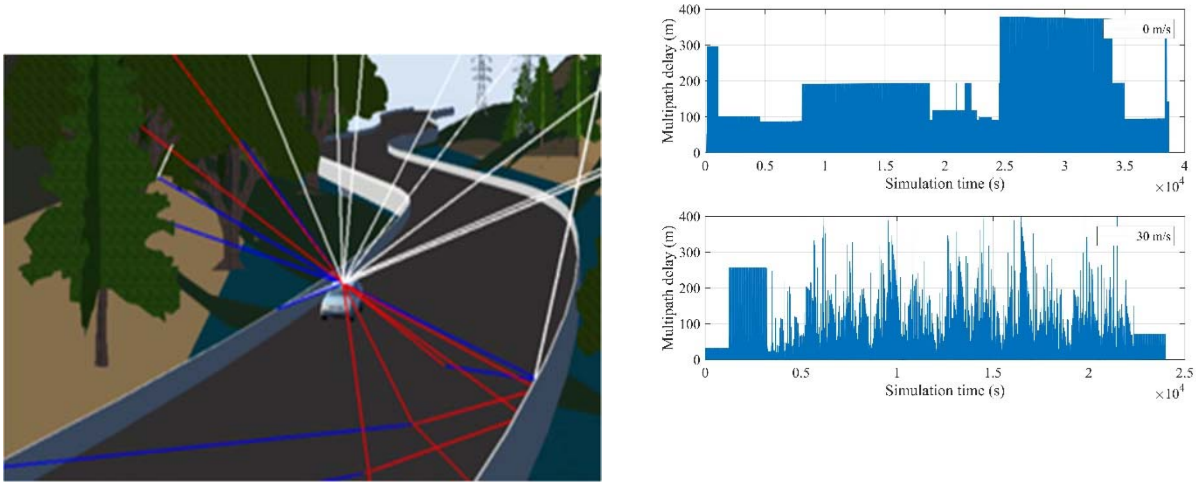

Figure 17: Ray tracing simulation of static and kinematic vehicle. Simulated multipath delays resulting from the simulation are plotted on the right side

3.12. Automated Multi-Sensor Early Warning System on the Three Gorges Dam - DAAD PPP China

In order to realize an automated multi-sensor early warning system near the Three Gorges Dam in China, the project-based personal exchange between IIGS at the University of Stuttgart and the School of Geodesy and Geomatics (SGG) at the University of Wuhan, which started at the beginning of 2017, was extended for one more year (from 01.01. to 31.12.2019). The project is supported by the DAAD (German Academic Exchange Service) and the CSC (China Scholar Council).

During the extension period of the project (in September 2019) a new measurement campaign at the measurement site Lianziya rock fall (Figure 18) was performed. The instruments used in this campaign to investigate the deformation of the rock fall were similar to those used in the former campaign (performed in March 2018). These are (see Figure 19) a GB-SAR (Ground-based Synthetic Aperture Radar), a TLS (Terrestrial Laser Scanning) and GNSS (Global Navigation Satellite System). Besides these instruments, a total station has been used to define a local three dimensional geodetic network, in which the Ground Control Points (GCP) of GB-SAR and TLS and the measurement points of GNSS are measured. This facilitates the transformation of measurement data from the different systems mentioned above into the same local geodetic network and leads to future data fusion.

Figure 18: Lianziya rock fall at the Yangtze River in China

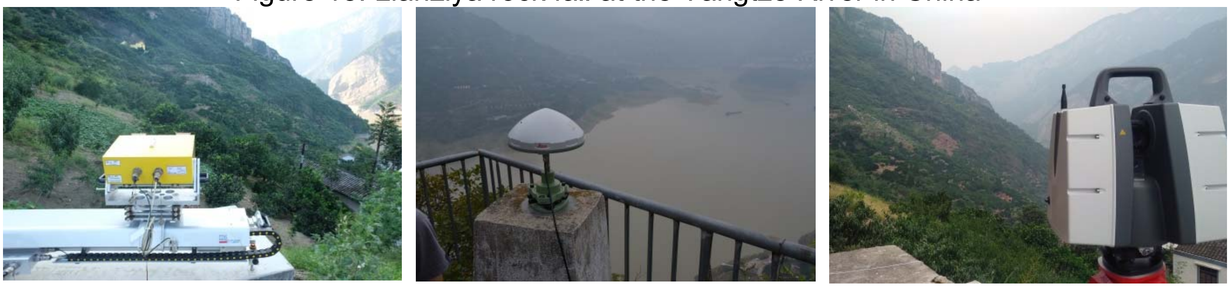

Figure 19: Instruments used for the deformation measurements. From left to right: GB-SAR, GNSS-receiver and TLS

The first results of the deformation analysis were determined by comparing TLS point clouds from 2018 and 2019. This comparison showed no significant displacement in this period. The result was confirmed through analysis of GNSS data gathered in the same epochs.

3.13. Quality Assurance of Geodetic Measuring and Evaluation Methods 2019, 180th DVW Seminar of DVW Working Group 3 "Measuring Methods and Systems” on 27th and 28th June 2019 in Stuttgart

The 180th DVW Seminar on Quality Assurance took place on 27th and 28th June in Stuttgart. Here, four sessions were offered. On 27th June the seminar started with the session on Fundamentals. The first session was followed by the session on quality for BIM, Geodata and TLS. On the second day, the third session on DVW Merkblätter continued at 8:30 am. With presentations on quality assurance in practice the 180th DVW seminar was concluded. In the rooms of the conference hotel “campus guest” both the lectures and the joint dinner took place. The seminar was well attended with 59 participants who came from all over Germany and Austria, with a majority from Baden-Württemberg. In an evaluation that took place at the end, the seminar was rated as a great success and another seminar of this kind was welcomed. All four sessions were rated as good, although in the first sessions (Fundamentals and Quality for BIM, Geodata and TLS) there was partly a lack of practical relevance discussed. In the course of the seminar organization a book on "Quality assurance of geodetic measurement and evaluation methods 2019" was prepared and published. This book includes the written versions of all presentations from all lecturers.

4. Publications

Refereed Publications

Avram, A.; Schwieger, V.; El Gemayel, N.: Experimental results of multipath behavior for GPS L1-L2 and Galileo E1-E5b in static and kinematic scenarios. Journal of Applied Geodesy, Vol. 13, Issue 4, pp. 279-290, deGruyter, Berlin, 2019.

Hassan, A.; Xu, J.; Xing, C.; Schwieger, V.: A contribution to variance analysis of 3D-displacement extracted from GB-SAR measurements. Journal of Geodesy, Cartography and Cadastre - No 10 / 2019, ISSN 1454-1408, Bucharest, Romania.

Hindenberger, P.; Schwieger, V.: Dynamic Location Referencing: Probability-Based Decision System, Adv. Cartogr. GIScience Int. Cartogr. Assoc., 2, 6, https://doi.org/10.5194/ica-adv-2-6-2019, 2019.

Schwieger, V.; Menges, A.; Zhang, L.; Schwinn; T.: Engineering Geodesy for Integrative Computational Design and Construction. ZfV, Heft 4/2019.

Wang, J.; Metzner, M.; Schwieger, V.: Potential Enhancement for Wrong-way Driver Detection using Precise Attribute Information. Journal of Navigation, 1-14. doi: 10.1017/S0373463319000663

Zhang, L.; Schwieger, V.: Reducing Multipath Effect of Low-Cost GNSS Receivers for Monitoring by Considering Temporal Correlations. 4th Joint International Symposium on Deformation Monitoring 2019, Athens, Greece.

Zhang, L.; Wang, J.; Wachsmuth, M.; Gasparac, M.; Schwieger, V.: Die Rolle digitaler Karten für Sicherheitsfunktionen im Straßenverkehr. ZfV, Heft 4/2019.

Non-Refereed Publications

Schwieger, V.; Lerke, O.; Kerekes, G.: Image-Based Target Detection and Tracking Using Image-Assisted Robotic Total Stations. FIG Working Week 2019, Hanoi, Vietnam.

Schwieger, V.; Zhang, L.: Qualität in der Ingenieurgeodäsie – Begriff und Modellierung. 180. DVW-Seminar „Qualitätssicherung geodätischer Mess- und Auswerteverfahren 2019", am 27. und 28. Juni 2019 in Stuttgart, Wißner-Verlag, Augsburg, 2019.

Zhang, L.; Wang, J.; Wachsmuth, M.; Gasparac, M.; Trauter, R.; Schwieger, V.: Role of Digital Maps in Road Transport Security. FIG Working Week 2019, Hanoi, Vietnam.

5. Presentations

Schwieger, V.: Smart Engineering Geodesy - Construction and Monitoring. Wuhan, China; September 11, 2019.

Schwieger, V.: Smart Engineering Geodesy - Construction and Monitoring. Bucharest, Romania; October 29, 2019.

Schwieger, V.: Engineering Geodetic Research Developments and the Romanian-German Story. Bucharest, Romania; October 31, 2019.

Zhang, L.: Automatisierte Prävention von Terrorattacken mit LKW. Intergeo 2019, 17.09.2019, Berlin.

6. Activities at the University and in National and International Organisations

Volker Schwieger

- Dean of the Faculty of Aerospace Engineering and Geodesy, University of Stuttgart
- Full member of the German Geodetic Commission (Deutsche Geodätische Kommission – DGK)
- Member of the section „Engineering Geodesy“ within the German Geodetic Commission (DGK)
- 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
- Coursedirector of the MSc Program GeoEngine at the University of Stuttgart

Li Zhang

- Co-Chair of Working Group 5.6 „Cost Effective Positioning” within FIG Commission 5 (Positioning and Measurement),
- Chair of Working Group „Quality Assurance” within Commission 3 „Measurement Methods and Systems“ of Deutscher Verein für Vermessungswesen (DVW)

7. Doctorates

Florian Zimmermann: Analysis and mitigation of site-dependent effects in static and kinematic GNSS applications. Universitäts-und Landesbibliothek Bonn, 2019. Hauptberichter: Prof. Dr.–Ing. Heiner Kuhlmann, Mitberichter: Prof. Dr.–Ing. Steffen Schön, Prof. Dr.–Ing. habil. Volker Schwieger

8. Master Theses

Buss, Roman: Weiterentwicklung eines selbstfahrenden Messroboters für die Kontrolle von Spalt und Übergang an Karosserien. (Schwieger, Schröder)

Chatterjee, Trisha: Modules for Simulating & Monitoring Autonomous Cars. (Metzner)

Hesham, Mohamed: Application of Accurate Lane-Level Road Maps in vehicle localization. (Wang)

Harb, Jamal: Rendering of 3D Citymodels at runtime based on map data. (Wachsmuth)

Huber, Christina: Kalman Smoothing für inertial-visuelle Fusion. (Schwieger)

Hu, Wenxuan: Potential analysis of industrial CO2 sources for the provision of synthetic fuels. (Metzner)

Li, Yu: Development of Horizon Provider with a focus on critical areas (Metzner)

Marev, Panayot: Entwicklung eines Verfahrens zur Generierung eines Skyplots mit dynamischen Elevationswinkeln aus Bildern. (Luz)

Pfitzenmaier, Tobias: Strahldivergenz- und Footprintuntersuchung von puls-basierten Laserscannerstrahlen mittels experimentellen Messungen unter Labor- und Feldbedingungen. (Kerekes)

Preuß, Sabrina: Entwicklung eines Algorithmus zu einem fahrspurgenauen Map-Matching und Aufbau notwendigen Kartenmaterials mit Matlab und ArcGis. (Luz)

Wein, Isabel: Bestimmung einer GNSS Kombinationslösung aus mehreren individuellen GNSS-Messungen für die Überwachung turmförmiger Objekte. (L. Zhang)

9. Bachelor Theses

Buck, Maximilien: Modellbasierte Leistungserfassung mit Lean Construction gezeigt an einem Praxisbeispiel (Metzner)

Hausmann, Nadine: Untersuchung eines TLS auf Nahbereichskorrektur sowie Einsatzmöglichkeiten bei unterschiedlichen Wetterbedingungen. (Kerekes)

Häusler, Manuel: Evaluierung und Deformationsanalyse des Holzpavillons auf der Bundesgartenschau. (Basalla)

Frolow, Rudolf: Entwicklung einer Applikation zu freien Stationierung mit verdeckten Festpunkten. (Basalla)

10. Education

SS19 and WS19/20 with Lecture/Exercise/Practical Work/Seminar

Bachelor Geodesy and Geoinformatics (German):

Basic Geodetic Field Work (Wachsmuth, Kanzler)	0/0/5 days/0
Engineering Geodesy I (Schwieger, Kerekes, Balangé)	4/2/0/0
Engineering Geodesy II (Schwieger, Lerke)	1/1/0/0
Geodetic Measurement Techniques I (Metzner, Wachsmuth)	3/1/0/0
Geodetic Measurement Techniques II (Wachsmuth)	0/1/0/0
Integrated Field Work (Kerekes, Metzner)	0/0/10 days/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 Deformations (Lerke, Wang)	1/1/0/0
Deformation Analysis (L. Zhang)	1/1/0/0
Industrial Metrology (Schwieger, Y. Zhang)	1/1/0/0
Land Development (Eisenmann)	1/0/0/0
Monitoring Measurements (L. Zhang, Basalla)	1/1/0/0
Monitoring Project (Lerke)	0/0/2/0
Terrestrial Multisensor Systems (L. Zhang, Lerke, Kerekes)	1/1/0/0
Transport Telematics (L. Zhang, Luz)	2/2/0/0

Master GeoEngine (English):

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

Bachelor and Master Aerospace Engineering (German):

Statistics for Aerospace Engineers (L. Zhang, Balangé, Hassan)	1/1/0/0

Master Aerospace Engineering (German):

Industrial Metrology (Schwieger, Y. Zhang)	1/1/0/0
Transport Telematics (L. Zhang, Luz)	2/2/0/0

Bachelor Civil Engineering (German):

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

Master Civil Engineering (German):

Geoinformation Systems (Metzner, Hassan)	2/1/0/0
Transport Telematics (L. Zhang, Luz)	2/1/0/0

Bachelor Technique and Economy of Real Estate (German):

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

Bachelor Transport Engineering (German):

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

Master Infrastructure Planning (English):

GIS-based Data Acquisition (L. Zhang, Luz)	1/1/0/0