# Institute of Engineering Geodesy

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| M.Sc. Aiham Hassan (until 30.06.2020) | Monitoring |
| Dipl.-Ing. Susanne Haußmann (since 01.11.2020) | Kinematic Positioning |
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| M.Sc. Tobias Schröder | Automation of Production Process |
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| M.Sc. Christian Bader | Kinematic Laser Scanning |

## 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 head of the section "Engineering Geodesy" within the DGK since 2020.

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, 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.

The "Integrative Computational Design and Construction for Architecture" (IntCDC) cluster, for which the University of Stuttgart had submitted a funding application as part of the excellence strategy to strengthen cutting-edge research in Germany, was awarded funding in 2018 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 ground breaking innovations for the building sector through a systematic, holistic and integrative computational approach. As a member of the cluster (IntCDC), the institute'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 within 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.

This year was marked by the corona pandemic in research and teaching. In research, almost all face-to-face lectures were cancelled and in teaching, lectures were held digitally. Laboratories and exercises were also carried out digitally, but some exercises were also conducted in presence.

# Research and Development

## Precise Seamless 6-DoF Positioning for Georeferenced Assembly Control

The research project (RP) 16 “Robotic Assembler” is part of the research network II ”Longspan Buildings” within the cluster of excellence “Integrative Computational Design and Construction for Architecture (IntCDC)” funded by the Deutsche Forschungsgemeinschaft (DFG). The cooperating disciplines within the RP are Control Engineering and Haptic Intelligence.

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The overarching task of RP16 is the automated or semi-automated collaboration between a tower crane and a mini-crane. The mini-crane contributes to the assembly process of long span buildings. It is controlled (semi-) automatically. The boom is equipped with a universal manipulator, to which different tools can be attached, as e.g. a gripper with a haptic interface for human/machine collaboration. The IIGS contributes to the project by providing the 6-DoF pose (position and orientation) of the mini-crane or its selected components, such as the boom, through the use of a robotic total station (RTS) network. Further aspects are the investigation of optimal data fusion algorithms, e.g. Gauss-Markov-Model (GMM), Gauss-Helmert-Model (GHM), Extended Kalman Filter (EKF), Unscented Kalman Filter (UKF) and the optimization of geometric network configuration from the point of view of network quality characteristics. Two different configurations for the pose determination have been realized and investigated so far. In the first one, the RTS-network is used to determine the position. An additional inertial measurement unit (IMU) provides the orientations, in order to complement the pose. In the second configuration, the position is determined by the RTS-network, the RTS measurements, however, are also used to determine two of the three orientation angles. The third angle is still provided by the IMU. For this purpose, the mini-crane is equipped with two prisms, i.e. with two RTS tracking and measuring prism No. 1 and the remaining two RTS tracking and measuring prism No. 2. The configurations are depicted in Figure 1.

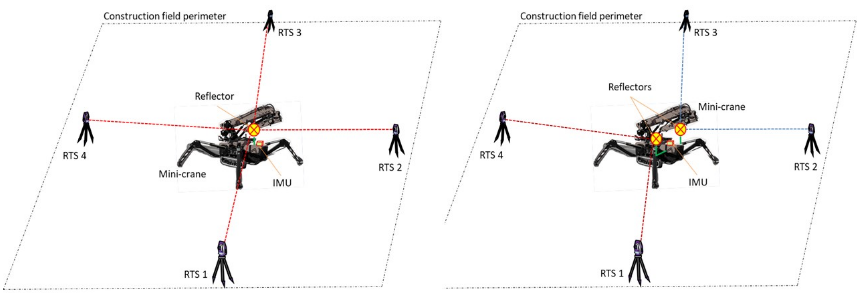


**Figure 1:** Left - configuration A; right - configuration B (modified from Jekko 2020).

These preliminary considerations led to the design of the deterministic model where the vector of observations, the state vector, consisting of the pose as well as the functional and the stochastic model could be defined and established. For the pose adjustment the GMM has been applied. Other approaches (GHM, EKF) are imaginable and will be introduced in the future. Regarding the network quality characteristics, the accuracy of position and orientation is derived from the covariance matrix of the adjusted state vector. For the reliability aspect the redundancy, the minimal detectable error and its impact on the parameter vector have been evaluated. The following tables show some exemplary results, obtained from simulations.

**Accuracy**

| Configuration A | Configuration B | |
|---|---|---|
| $\sigma_{xyz}^{avg} = 0.0024\ m$ | $\sigma_{xyz}^{avg} = 0.0033\ m$ (RTSs 1+4) | Position accuracy |
| | $\sigma_{xyz}^{avg} = 0.0033\ m$ (RTSs 2+3) | |

| Configuration B | | |
|---|---|---|
| Roll angle | Yaw/heading angle | Accuracy of 2 orientation angles, obtained from RTS-network |
| $\sigma_{\phi}^{avg} = 0.080°$ | $\sigma_{\psi}^{avg} = 0.076°$ | |

**Reliability**

Impacts of the minimal detectable error on positions for different observations (values in mm)

| Observation | $s_1$ | $h_1$ | $v_1$ | $s_2$ | $h_2$ | $v_2$ | $s_3$ | $h_3$ | $v_3$ | $s_4$ | $h_4$ | $v_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\nabla_{xi}^{quadsum}$ | 1.28 | 0.46 | 0.83 | 1.26 | 0.42 | 0.63 | 1.32 | 0.53 | 0.76 | 1.23 | 0.42 | 0.62 |

Impacts of the minimal detectable error on orientations for different observations (values in millidegrees)

| Observation | $s_1$ | $h_2$ | $v_1$ | $s_4$ | $h_4$ | $v_4$ | $s_2$ | $h_2$ | $v_2$ | $s_3$ | $h_3$ | $v_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\nabla_{\phi}$ | 31.73 | 1.56 | 41.38 | 21.40 | 1.46 | 29.71 | 22.68 | 1.32 | 30.85 | 27.44 | 1.89 | 37.3 |
| $\nabla_{\psi}$ | 48.66 | 22.19 | 6.82 | 30.88 | 20.39 | 6.18 | 28.30 | 21.33 | 5.94 | 54.32 | 24.85 | 5.44 |

As an interim result, it can be stated that the average effects of the minimum detectable error on the parameters are below the position accuracy.

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## Holistic Quality Model for IntCDC Building Systems

Within the framework of the Cluster of Excellence IntCDC, this project in cooperation with the Institute of Acoustics and Building Physics (IABP) and the Institute of Social Sciences (SOWI), deals with the development of a Holistic Quality Model (HQM). For this purpose, a concept was developed in which the social, environmental and technical quality requirements are first defined. Based on this concept, the quality characteristics, parameters and criteria are determined, and the interrelations between them are defined. The evaluation and assessment of the quality will be carried out at defined control and decision points in the co-design construction process (Figure 2).

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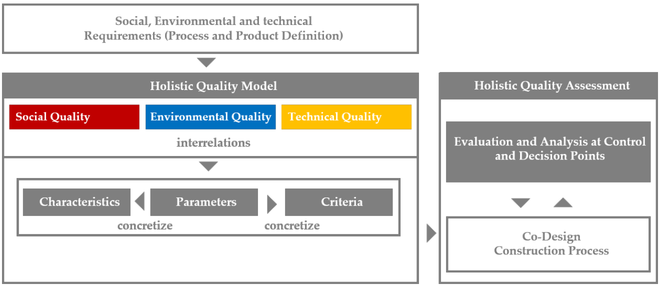


**Figure 2:** Quality assurance concept for the Co-Design construction process.

In contrast to the linear construction process, in which the steps of construction with definition, planning, execution, use and end-of-life are passed through linearly, these are no longer passed through linearly in co-design (Figure 3). This means that by performing a quality assessment in the planning phase at important decision points, a predicted quality assessment can serve as a decision-making aid for further planning and execution.

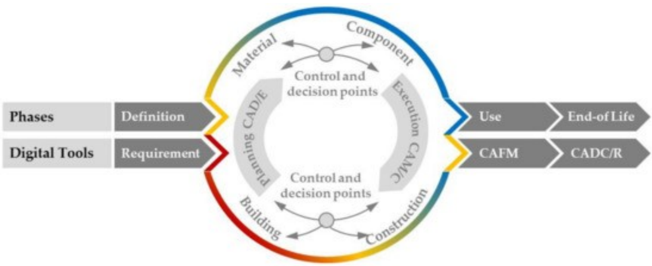


**Figure 3:** Holistic quality assessment in the Co-Design construction process.

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## Monitoring of the Production Process of Graded Concrete Components by means of Terrestrial Laser Scanning

Accepting the ecological necessity of a drastic reduction of resource consumption and greenhouse gas emissions in the building industry, the Institute for Lightweight Structures and Conceptual Design (ILEK) at the University of Stuttgart is developing graded concrete components with integrated concrete hollow spheres. These components weigh only a fraction of the usual conventional components for the same performance. Throughout the production process of a component, the positions of the hollow spheres and the level of the fresh concrete have to be monitored with high accuracy and almost in real-time, in order to guarantee the quality and structural performance of the component. In this study, effective solutions of multiple sphere detection and concrete surface modeling based on the technology of terrestrial laser scanning (TLS) during the casting process are developed and implemented. A complete monitoring concept is presented to acquire the point cloud data quickly and with high quality. The data processing method for multiple sphere segmentation based on the efficient combination of region growing and RANSAC algorithms shows great performance in terms of computational efficiency and robustness.

The feasibility and reliability of the proposed methods are verified and evaluated by an experiment to monitor the production of an exemplary meso-graded concrete component (as shown in Figure 4). During the production process of the component in this experiment, all hollow spheres were detected and estimated in a few seconds with submillimeter accuracy. Future work includes investigating the quantitative relationship between sphere size and parameter tuning for sphere segmentation. In addition, the spatial correlations of the point cloud can be taken into account when building the stochastic model for sphere fitting. Thus optimized parallel processing of multiple-sphere detection is possible for production monitoring of large-scale graded concrete components with hundreds of hollow spheres.


(a) (b) (c)

**Figure 4:** The process of automatic detection of multiple hollow spheres in the production of a meso-graded concrete component.

## Quality Control of the Manufacturing Geometry for Fiber Components

Laser scanning measurements were carried out as part of the investigation into the manufacturing accuracy of fiber components (Figure 5). On the one hand, a column of the BUGA pavilion and various components of a biennale installation in 2021 were scanned. The difficulty here was the evaluation of the measurement results, since no classic CAD model was available for comparison and the individual point measurements had to be assigned to the line model from the design in order to obtain information about the geometry of the individual lines of the element.

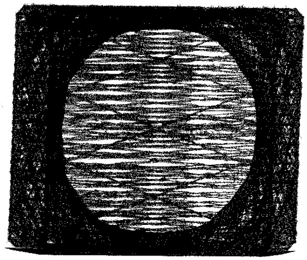

**Figure 5:** Scanned Fiber Component.

## Collaborative Scanner Test and Calibration on the Bonn Reference Wall

Within the framework of the project “Collaborative scanner test and calibration on the Bonn reference wall” (COLLECTOR) carried out by the Gesellschaft zur Kalibrierung Geodätischer Messmittel (GKGM) a comparison of various Laser scanners from different universities will be made. The IIGS participates in this project with four Laser scanners (Leica HDS7000, Leica BLK, Trimble X7, Riegl 2000V). All four scanners are used to survey the exterior of the Bonn wall (Figure 6 and Figure 7).

**Figure 6:** Measurement setup at Bonn reference wall.

Measurements are made in two faces from three instrument points. The aim is to estimate the wall parameters from all scanner measurements and compare the results with other universities. In addition, calibration measurements were performed with three of these scanners in the calibration area in Bonn. In order to obtain comparable results all participants have to use a provided software for the evaluation.

**Figure 7:** Scanned wall from Trimble X7.

## Monitoring of the Urbach tower

Similar to the previous year, the wooden tower of ICD in Urbach is to be monitored at least twice a year. To achieve a detailed look at possible deformations, the tower was scanned using the HDS7000 from Leica. In addition, the tower was scanned several other times, bringing the total number of scans to four during the year. The working process was disturbed, since reference points in the surrounding area, which helped to compare scans (deformation analysis), were removed. No major deformations were detected during the year (Figure 8). The tower will continue to be monitored over the next 3 - 4 years.

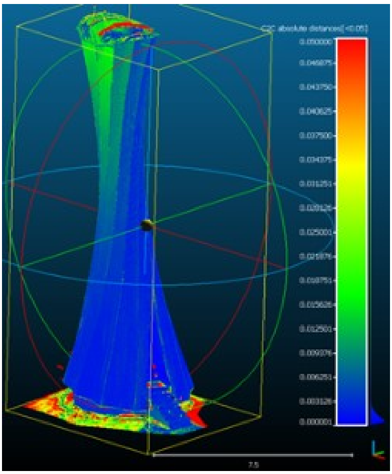

**Figure 8:** Deformation analysis of a two epoch measurement.

## Perceived Space Representation using Brain Activity Analysis, Eye-Tracking and Terrestrial Laser Scanning (Brain TLS)

Is the human a measurement instrument (Figure 9)? Within this RISC (Research Seed Capital - Blue Skies Research) project, it is considered that the brain activity and eye movement analysis of a person in combination with a space-calibration method can be used to represent the perceived space.

Humans describe reality with the help of vertical perception and pre-knowledge. Nowadays, brain activity analysis may be done through non-invasive methods. Most studies in the field of neuroscience are related to extracting information after observing the state of the brain. Eye-Tracking, on the other side, is used to analyze fixations and saccades by recording pupil movements with external cameras. This can be done for a multitude of purposes, but this project focuses on the gaze positions in a defined area. The question arises if the signals captured with a Brain Computer Interface (BCI) combined with eye-tracking information and corrected by an existing 3D model of the observed space can be used to create a digital representation of the same space.

**Figure 9:** Is the human a measurement instrument?

The scale and geometry of the perceived space are firstly defined with the help of a 3D terrestrial laser scanner (TLS). The implied methods and experiments aim at establishing a connection between instrument-measured space and human-perceived space. Defining geometric relationships between the observer (person) - observed objects and finding a correlation of the geometric attributes with the brain activity and eye-tracking data are the main goals of this project. If these goals are achieved, an innovative measurement method may be developed and a better insight into how the human brain perceives the surrounding space may be gained.

## Integrated space-time modeling based on correlated measurements for the determination of survey configurations and the description of deformation processes (IMKAD II)

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This DFG (Deutsche Forschungsgemeinschaft) project foresees the establishment of a stochastic model for scans acquired with high-end Terrestrial Laser Scanners (TLS). The resulting stochastic model is based on the elementary error (EE) theory and describes uncertainties and correlations in form of a synthetic variance-covariance matrix (VCM). With this information, B-Spline surfaces are estimated for each epoch according to individual variances and covariances of the point cloud.

As explained in previous reports, several measurement campaigns are necessary during the whole project. In July 2020, the first measurements of the "Urbach Tower" were completed. This wooden tower was erected for the "Remstal Gartenschau 2019" and is perfectly suitable for B-Spline modeling. The outer shell is made out of double curved self-forming wooden panels.

Shortly after, in August 2020, the second measurement campaign of the Kops water dam in Austria was successfully completed. Specifically, for this object, a new approach for computing the VCM is introduced (Kerekes & Schwieger, 2020). Environmental parameters like air temperature, air pressure, and vertical temperature gradient (VTG) are treated as stochastic correlating influences. As known from trigonometric leveling and EDM measurements, distances and zenith angles are mostly affected by air temperature and VTG. This effect has recently gained much attention in the scientific TLS community. The overall contribution of environmental parameters (Atmospheric EE) on single points using the EE theory can be seen in Figure 10. Points that are closer to the ground are strongly affected by the intense variations in air temperature and VGT (especially in summer), whilst points on the dam crown are less influenced by the variations in the lower VGT layers.

## Statistical investigation of Boehm's algorithm for B-Spline Modeling

In the context of forming rectangular grid structures as the basis of a uniform control grid for NURBS (non-uniform rational B-Splines) surface generation, two node insertion algorithms are examined in more detail. These are on the one hand Boehm's algorithm and on the other hand Oslo algorithm. While Boehm's algorithm inserts one node at a time in one computation pass, Oslo algorithm inserts several nodes in one pass, but this requires the formation of n +1 matrices where n corresponds to the degree of curvature. A comparison of the computation times of both algorithms has shown that Boehm's algorithm has a shorter computation time compared to the version of the Oslo algorithm used here. Therefore, Boehm's algorithm will be used for the filling of control points for NURBS curves and surfaces.

Apart from the mathematical consideration of Boehm's algorithm, which shows that the shape of the NURBS curve or surface is identical before and after node insertion, this statement

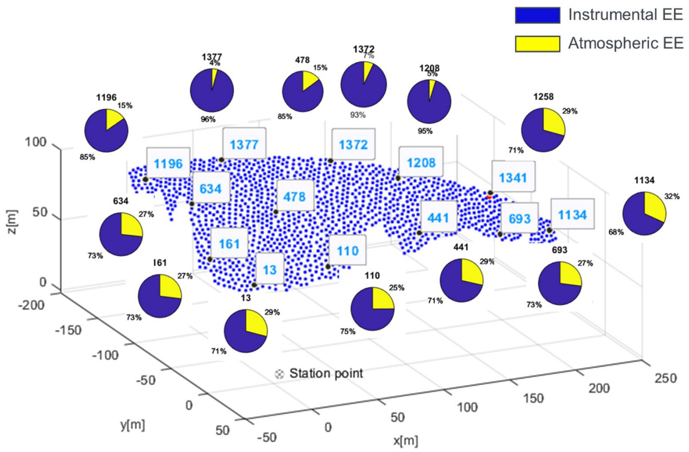


**Figure 10:** Contribution to the error budget of individual points according to the EE theory.

shall be verified by means of a statistical procedure. By covariance propagation the standard deviation of the newly formed control points and thus the influence of Boehm's algorithm can be determined. For the standard deviation of the old control points before applying Boehm's algorithm, a variance of 1 $mm^2$ is assumed in the first instance.

Figure 11 shows a third degree B-spline curve and its control polygon in gray before applying Boehm's algorithm, and in black after its execution. The two newly formed control points $q_4$ and $q_5$ have a standard deviation of 0.75 mm instead of a value of 1 mm. The standard deviations of the two new control points are thus 0.25 mm smaller than the original standard deviation. When calculating the standard deviations of the new control points of a NURBS surface, a similar behavior appears. Depending on how many control points have to be inserted into a polygon using Boehm's algorithm, the standard deviation decreases step by step.

## Automated gap and flush measurement between car parts assisted by a high flexible and accurate robot system

This research is the result of a partnership between the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart and the Tec-Fabric at the Mercedes-Benz AG plant in Sindelfingen. In general, the measuring tool is attached to a lightweight robot (LBR), which is mounted on a driverless platform KMP. Gap and flush measurements between two structural car components are part of the quality assurance process in Daimler AG's production. Measurement data is collected in three manufacturing phases during the car body construction, car varnishing and body assembly. As a result of observing the gap and flush values throughout the entire process, functional as well as customer-specific requirements can be guaranteed.

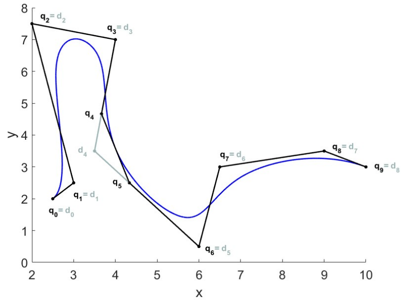


**Figure 11:** Third degree B-spline curve with control polygon before and after application of Boehm's algorithm.

At the assembly line, full automatic gap measuring installations or hand-held instruments measure gap and flush values. Car bodies, in which errors are identified during the measurement process, will be channeled out of the production line. Adjacent to the production line, two employees process the rework and repeat the required quality measurements in order to assure that they comply with the quality targets. Once the required corrections are successfully executed, the car is channeled back into the production line. The gap measurement with mobile devices (SME, Figure 12), realized with a lightweight robot in human-robot interaction (MRK), enhances the automation and the flexibility within the production. The mobile units today are mounted at a fixed position in the assembly line, but can easily be moved to another location. In the future, systems like the SME are supposed to replace the static measurement cells. Likewise, the measurement outside the production line is supposed to be scalable and autonomous. In order to accomplish this, two of the main components from the SME are used: measurement devices and the lightweight robot (LBR) are mounted on a driverless platform (KMP). The aim of this research was to develop a measuring system, which is precise enough to satisfy the quality requirements of a Mercedes-Benz car. We were able to patent the system mentioned above this year.


**Figure 12:** Mobile device for gap measurement.

## Multi-Sensor Fusion for Environment Perception

For autonomous vehicles and automated safety functions, a comprehensive environment perception is necessary. This applies in particular for urban situations with multiple dynamic objects, like in many of the TransSec use cases. Different Sensor systems are able to detect objects with different accuracies in spatial position and classification. Lidar sensors offer high spatial precision with low classification accuracy, while cameras show great classification performance, but lack in spatial accuracy. To overcome the uncertainties of both measurement principles, object detections of Lidar and Camera are fused on object level. The fusion is done during the data assignment step of a multi-object tracker. Different three-dimensional geometrical shapes, like oriented bounding boxes or point cloud segments can be incorporated through the usage of turning functions for spatial association (Figure 13). The multi-object tracker is based on an interacting multiple model with unscented Kalman filter. This allows a motion model based trajectory prediction with a time horizon of 1 s for all dynamic objects. GNSS and map data allow an extension of this time horizon by making long time predictions based on the provided street network. Each dynamic object is assigned to a street segment under the assumption that the object will follow the road trajectory. Next, a combined trajectory of the motion model prediction and the road trajectory prediction is calculated with a high weight on the motion model for short term predictions and a high weight on the road trajectory prediction for long term prediction.

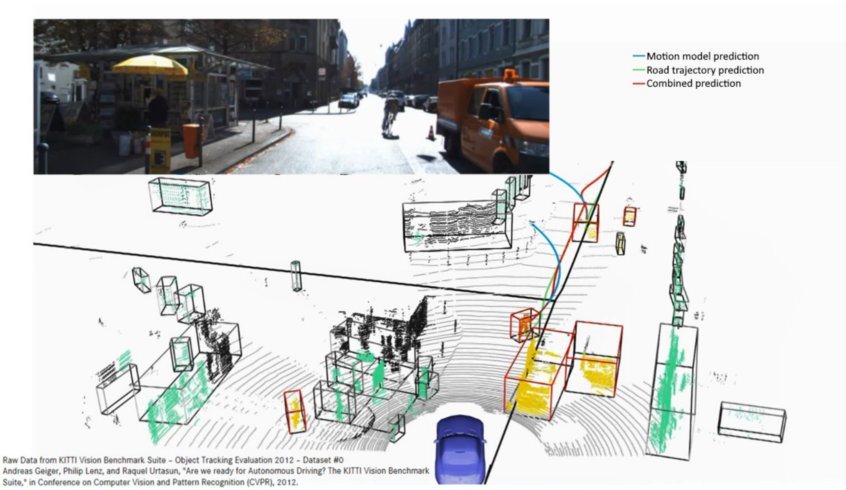


**Figure 13:** Multi-Sensor Fusion for Environment Perception.

## 3D Lidar based road curb detection with adapted geometry constrains

A 3D Lidar based road detection is usually realized by detecting distinctive road boundaries such as road curbs. An example for road geometry and road curb measured by a 3D Lidar sensor is shown in the figures below (Figure 14).

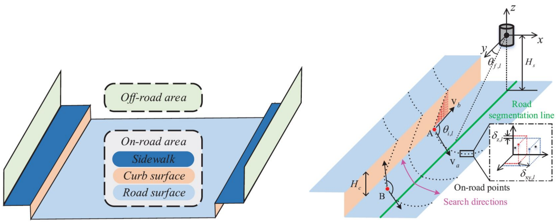


**Figure 14:** left: road geometry description; right: curb scenario description. (Source: Zhang, Yihuan, et al. "Road-segmentation-based curb detection method for self-driving via a 3D-LiDAR sensor". IEEE transactions on intelligent transportation systems 19.12 (2018): 3981-3991.

The state-of-the-art 3D Lidar based curb detection algorithm utilizes the spatial relation of adjacent laser points for curb candidate searching, and accomplishes the eventual detection task by filtering out noisy curb candidates with an estimated road shape. A typical algorithm pipeline mainly includes the following steps:

- Data pre-processing: as the first step the input 3D point cloud will be rectified through sensor calibration and vehicle motion compensation, then a ground plane will be fitted to the input point cloud in order to segment all 3D points as either on-road or off-road.
- Road shape recognition: the purpose of this step is to estimate the road shape (the rough centerline of the road), as this will be required to filter out noisy curb candidates from the detection result.
- Curb candidate detection: each laser ring is treated as an independent processing unit, and several filtering criteria are then applied to detect all curb candidates within a laser ring:
  - a) horizontal distance threshold: $\delta_{xy,l} = H_s \cdot \cot \theta_{f,l} \cdot \frac{\pi \theta_a}{180}$, where: $H_s$ is sensor height, $\theta_{f,l}$ is the vertical pointing angle of $l$th laser ring, and $\theta_a$ the horizontal angular resolution of the Lidar.
  - b) vertical distance threshold: $\delta_{z,l} = \delta_{xy,l} \cdot \sin \theta_{f,l}$
  - c) horizontal adjacent angle: $\theta_{I,l} = \cos^{-1} \frac{v_a \cdot v_b}{|v_a| \cdot |v_b|}$, where $v_a$ and $v_b$ represents adjacent horizontal vectors in both scan- and counter-scan directions. Usually a constant threshold is set for this calculated horizontal adjacent angle, e.g. 150°.

Notably, the assumption behind these calculated thresholds is that the projected geometry of each laser ring onto ground is a perfect circle. However, depending on factors such as sensor installation, road slope and vehicle dynamics, the projected geometry of a particular laser ring may vary between circle, ellipse, parabola and hyperbola. Figure 15 demonstrates this change caused by the relative angle between sensor horizontal plane (X-O-Y) and the ground plane (in green).

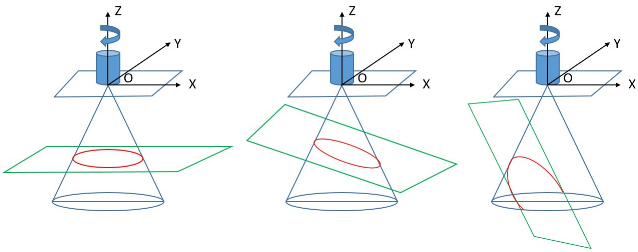


**Figure 15:** The projected geometry (in red) of a laser ring onto a ground plane (in green). From left to right the projected geometry: circle, ellipse and parabola.

Therefore, an optimization has been conducted with respect to a state-of-the-art algorithm, where the adapted geometry is used for calculating these thresholds. The performance of this optimized detection algorithm was primarily evaluated on a public 3D Lidar dataset, and the results are summarized as follow (Table 1).

**Table 1:** Performance evaluation of the optimized algorithm w.r.t. the original algorithm.

| **Algorithm** | Optimized | | Original (Zhang, et al. 2018) | |
|---|---|---|---|---|
| **Road type** | Straight | Curve | Straight | Curve |
| **Precision** | 0.8773 | 0.8686 | 0.8230 | 0.8764 |
| **Recall** | 0.7801 | 0.8701 | 0.7716 | 0.8227 |
| **F1** | 0.8247 | 0.8688 | 0.7597 | 0.8483 |

It is notable that, for straight road type, the optimized algorithm surpasses the state-of-the-art algorithm in all three metrics. However, as can be seen from Figure 16, some of the detected curb points are actually correct but the corresponding ground truth are missing in this dataset, and this could result in a lower detection precision. In future, the developed algorithm will be further optimized and evaluated in a larger open dataset, e.g. Semantic KITTI dataset.

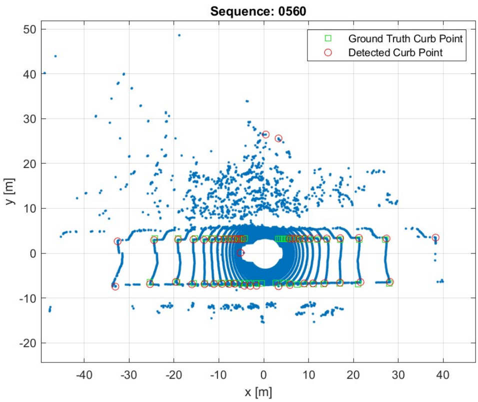


**Figure 16:** One example of the detection result from the optimized algorithm.

## Ghosthunter II - Telematics System against Ghost Drivers using GNSS

The aim of the Ghosthunter II research project is to develop a detection system to extend current car navigation systems detecting ghost drivers on freeways and their ramps and warning both the ghost drivers themselves and other road users. This 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.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

For this purpose, an android-based app was developed as a demonstrator. The app is used to detect wrong-way drivers and to send a warning via mobile radio to a server. This server distributes the warning to all other app users. The developed app, that is currently providing a warning to a wrong-way driver, is shown in Figure 17.

As mentioned above, a central goal is to detect wrong-way drivers reliably and as early as possible on freeway ramps. However, previous approaches and implementations could only perform this detection if there was a constructional separation of the lanes. In order to circumvent this limitation and to be able to start the detection earlier, the previous algorithms were further developed in this direction. The idea here is to use statistical tests to detect whether the vehicle is significantly to the left or right of the centerline of the lane. This statement is made based on the standard deviation of the vehicle position and the map as well as the current road geometry.

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.


**Figure 17:** Ghosthunter app for wrong-way driver detection.

## TransSec - Autonomous Emergency Maneuvering and Movement Monitoring for Road Transport Security

The European Project TransSec (Autonomous Emergency Maneuvering and Movement Monitoring for Road Transport Security) is funded by the European Commission under the Horizon H2020 program for three years. This project was launched in February 2018 and aims to design and implement a built-in intelligent safety system to prevent trucks and transports of goods from being misused for illegal purposes such as terrorist attacks. The Institute of Engineering Geodesy (IIGS) at the University of Stuttgart is one of the five partners involved in the TransSec project. The project concluded with an online event in January 2021. The deliverables were all defined within 2020.

European Commission

European Global Navigation Satellite Systems Agency

One task of the IIGS was to obtain the precise positioning of the trucks by integrating data from GNSS and other additional sensors such as IMU. IIGS focuses on an error-state Kalman-filter with strapdown algorithm in the positioning module. The other task of the IIGS was to design and implement a map-aiding approach that takes into account on-road and especially off-road scenarios as well as wrong-way driver detection for trucks. The final parts of 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), who is one of the project partners. Since the GNSS availability decreases and even complete outages occur in urban city canyons or 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 performed by using an error-state Kalman filter. In the last year of the project the positioning module was tested in real case scenarios. Here, the results of urban and sub-urban test drives with a length of 13 km are presented. For the test drives we used a u-blox C099-F9P application board with a ZED-F9P chip in combination with an XSens Mti 100 IMU, generating stand-alone code solutions as input for the filter. A Leica GS15 receiver with SAPOS-RTK correction signals was used as reference. The comparison between the filter result and the reference situation results in an RMS of 1.1 m. The accuracy was not significantly improved over the GNSS to reference comparison, but the availability was considerably improved. In addition, the solution was smoother and the difference between filter solution and GNSS stand-alone solution was 0.46 m RMS, indicating the difference. The challenge in tunnels remains because the low-cost IMU shows drift effects (e.g., up to a few deca m deviation). Figure 18 shows blue dots for the reference solution and a green line for the filtered solution. The figure shows an obvious alignment of the two trajectories and the tunnel challenge.


**Figure 18:** Tunnel drive (green: 100 Hz filter solution, blue: 10 Hz reference solution).

**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 trucks. This includes the identification of the driven lane. Figure 19 shows the geometrical relationship for a road with four lanes including the rough knowledge about the lane width as well as the geometrical on-road/off-road decision. Recent developments include statistical testing and error probabilities for on-road/off-road decision making as well as for correct/opposite lane driving. For these decisions, the accuracy of the position, either determined by GNSS or by a sensor fusion such as the aforementioned error-state Kalman-filter, as well as the map accuracy are taken into account. For the latter, one has to rely on assumptions about e.g. the width of a lane. It is assumed that these assumptions will be filled with real data in the future. In this case, the algorithm can be adopted without problems to newly available stochastic models.

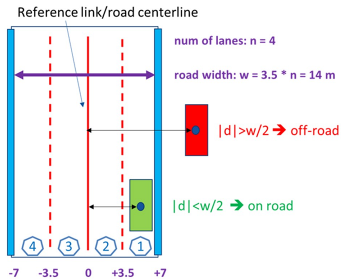


**Figure 19:** On-/Off-Road Decision ad lane detection.

## Dynamic Location Referencing: Probability and Fuzzy Logic Based Decision Systems

To share geo-objects between digital maps, location referencing is a well-known methodology typically used to exchange traffic information such as traffic jams, road works, etc. In very many cases, there is no common database between the systems (maps) to be exchanged. For this purpose, dynamic (on-the-fly) methods are developed to exchange Location References (LR, geo-objects based on digital maps) between different maps in such special cases where no common databases and/or common structures are available.

In general, location referencing methods follow a one-dimensional three-step process of encoding the LR in the sender system, transmitting it, and decoding it in the receiver system without iterations and typically limited bandwidth. Given the fact that there are no dedicated links/common data structures between maps, the key issue in Dynamic Location Referencing is to find the correct LR in the target map that corresponds to the LR in the source map (see Figure 20).

To accomplish this, deterministic algorithms are defined and implemented in almost all methods.

Following the uncertainty in matching procedures for geodata, uncertainty-based decision systems are explored. Thus, a probability-based and a fuzzy-based approach have been specified and studied in detail as two different uncertainty-based concepts. For both, a set of decision criteria (geometric, topological, syntactic and semantic) was defined and the decision algorithms were formulated. Both approaches were implemented and analyzed in an

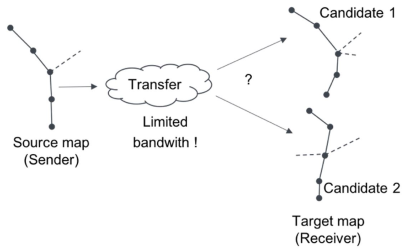


**Figure 20:** Identification of Location Reference.

evaluation system. As published in the conference proceedings of the LBS Conference 2019 in Vienna, 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) by 12 percentage points on average.

As stated in the last report, further aspects were discussed to validate the previous results as well as to extend the research approach. This is still in progress and will be finalized in the course of this year.

## Multipath effects influence on the position

In order to investigate the influence of multipath effects on the position, real test drives were completed and the data was analyzed. To understand the critical situations for an urban roadway, a representative situation was considered: tall buildings. The reference coordinates of the test vehicle were obtained using iTraceRT F402-E. These were compared to the GNSS position obtained using DGNSS based on the pseudo-range.

### Buildings

The main challenge related to multipath in the urban environment is represented by the tall buildings that are present along the roadway. An example of such a situation is illustrated in Figure 21. On the left side of the figure, the GNSS position based on pseudo ranges which drifts due to multipath effects is shown in red. The car reference position is shown in green. A deviation from the car reference trajectory occurs along the left building between the intersections. This is probably the effect of signal reflections, due to the tall building. The vehicle velocity is shown along with the satellite availability on the right side of Figure 21. It is shown that the number of satellites used varies between 7 and 10. Due to the proximity of the vehicle to the tall building on the left, the satellites on the right suffer strong reflections, therefore there is an increased signal time-of-arrival.

The multipath delay caused by such a situation is short due to the proximity of the vehicle to the building. At the same time, the satellites on the left side are obscured and cannot compensate for the multipath error. Consequently, the position drift occurs in the opposite direction of the building.

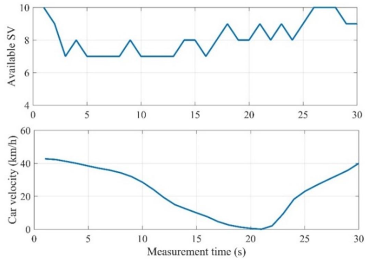


**Figure 21:** Position drift due to multipath reflections on an urban highway scenario, satellite availability and vehicle velocity. Reference position (green) and position changed by multipath (red) are shown based on Google Earth®.

Figure 22 shows the deviation in latitude, longitude, and height, as well as the RMS error for the investigated segment. The errors in latitude and longitude increase with about 4 meters as the vehicle begins to travel parallel to the building. The height is the most affected with a value around 10 meters. Overall, the RMS increases from 3.5 meters up to a maximum of 16.9 meters.

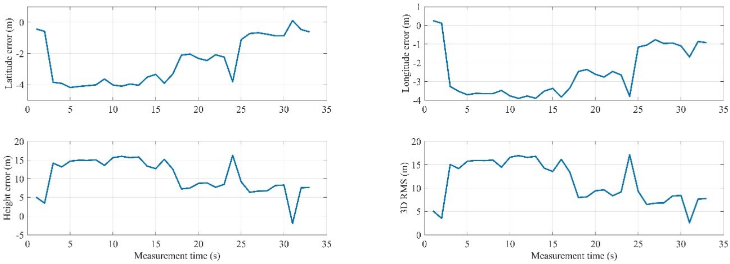


**Figure 22:** Deviation of the ellipsoidal 3D coordinates and RMS error in the multipath environment determined by the tall building.

## PhD Seminar

The 10th PhD Seminar of the Engineering Geodesy Section of the DGK was organized by the IIGS and had to be realized in a fully digital format. More than 50 participants from Austria, Switzerland, Croatia and Germany attended the event on October 22 and 23, 2020. Ten presentations were followed by lively discussions. Digital meetings were possible in so-called virtual subspaces of the video conferencing tool. This worked surprisingly well. The only thing missing was the social event in the evening, which could not be replaced by digital means.

# Publications

## Refereed Publications

Balangé, L.; Zhang, L.; Schwieger, V. (2021): First Step Towards the Technical Quality Concept for Integrative Computational Design and Construction. In: Kopáčik, A.; Kyrinovič, P.; Erdélyi, J.; Paar, R.; Marendić, A. (eds) Contributions to International Conferences on Engineering Surveying. Springer Proceedings in Earth and Environmental Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-51953-7_10

Kerekes, G.; Schwieger, V. (2021): Determining Variance-Covariance Matrices for Terrestrial Laser Scans: A Case Study of the Arch Dam Kops. In: Kopáčik A., Kyrinovič P., Erdélyi J., Paar R., Marendić A. (eds) Contributions to International Conferences on Engineering Surveying. Springer Proceedings in Earth and Environmental Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-51953-7_5

Kerekes, G.; Schwieger, V. (2020): Elementary Error Model Applied to Terrestrial Laser Scanning Measurements: Study Case Arch Dam Kops. Mathematics 2020, Vol. 8(4), 593.

Lerke, O.; Schwieger, V. (2020): Genauigkeitsanalyse der automatischen Werkzeugsteuerung eines Laderaupenmodells. In: Ingenieurvermessung 20, Beitragsheft zum 19. Internationalen Ingenieurvermessungskurs München 2020, Thomas A. Wunderlich (Hrsg.). Wichmann, VDE Verlag GmbH, Berlin, Offenbach. ISBN 978-3-87907-672-7.

Luz, P.; Metzner, M.; Schwieger, V. (2020): Development of a new lane-precise map matching algorithm using GNSS considering road connectivity. Online proceedings of Virtual ITS European Congress, 9-10.11.2020

Schwieger, V.; Kerekes, G.; Lerke, O. (2020): Image-Based Target Detection and Tracking Using Image-Assisted Robotic Total Stations. In: Sergiyenko O., Flores-Fuentes W., Mercorelli P. (eds) Machine Vision and Navigation.

Zhang, L.; Balangé, L.; Braun K.; Di Bari, R.; Horn, R., Hos, D.; Kropp, C.; Leistner, P.; Schwieger, V. (2020): Quality as Driver for Sustainable Construction - Holistic Quality Model and Assessment. Sustainability 2020, 12(19), 7847; doi: 10.3390/su12197847.

Zhang, L.; Schwieger, V. (2020): Reducing Multipath Effect of Low-Cost GNSS Receivers for Monitoring by Considering Temporal Correlations. Journal of Applied Geodesy, Band 14, Heft 2, ISSN (Online) 1862-9024, ISSN (Print) 1862-9016, doi: 10.1515/jag-2019-0059.

## Non-Refereed Publications

Scheider, A.; Schwieger, V.; Brüggemann, T. (2020): Entwicklung eines Multisensorsystems zur Georeferenzierung von hydrographischen Messdaten auf Binnengewässern. In: Ingenieurvermessung 20, Beitragsheft zum 19. Internationalen Ingenieurvermessungskurs München 2020, Thomas A. Wunderlich (Hrsg.). Wichmann, VDE Verlag GmbH, Berlin, Offenbach. ISBN 978-3-87907-672-7.

Wachsmuth, M.; Koppert, A.; Zhang, L.; Schwieger, V. (2020): Development of an error-state Kalman Filter for Emergency Maneuvering of Trucks. European Navigation Conference. 23.-24.11.2020.

## Monographs, books and book chapters

Kuhlmann, H.; Holst C.; Zhang, L.; Schwieger, V. (2020): Ingenieurgeodasie. In: Kummer, K.; Kötter, T.; Kutterer, H.; Ostrau, S. (Hrsg.): Das deutsche Vermessungs- und Geoinformationswesen 2020. Wichmann Verlag, Berlin.

## Presentations

Balangé, L., Di Bari, R., Deniz Hos, P.: Holistic Quality Model for IntCDC Building Systems, Status Colloquium 2020, 17.02.2020

Di Bari, R., Deniz Hos, P.: Holistic Quality Model, Status Seminar 2020, 12./13.11.2020

Lerke, O.: Project Status - Precise Seamless 6DoF Positioning for Georeferenced Assembly Control, General Meeting RP16, 28.09.2020

Lerke, O.: Research Progress - Precise Seamless 6DoF Positioning for Georeferenced Assembly Control, Status Meeting RP 2, RP 8, RP 16: RP16, 10.12.2020

Lauer, A., Lerke, O., Mohan, M., Gong, Y.: RP16 - Robotic Platform for Cyber-Physical Assembly of Long-Span Fibre-Composite Structures, Research Update on Robotic Total Station Network for Seamless 6DoF determination, 2020 IntCDC Status Colloquium Research Networks, 17.02.2020

Lauer, A., Gong, Y., Mohan, M., Javot, B., Ortenzi, V., Lerke, O.: RP16 - Research Update on Precise Seamless 6DoF Positioning for Georeferenced Assembly Control, 2020 IntCDC Status Seminar,12./13.11.2020

Schwieger, V.: Map Matching Applications. Seminar SE 3.05 "GPS/INS-Integration und Multisensor-Navigation", Carl-Cranz-Gesellschaft e.V., Oberpfaffenhofen, 21.10.2020.

Schwieger, V.: Varianzfortpflanzung und Elementarfehlermodell (am Beispiel TLS) - Möglichkeiten und Grenzen. Joint Workshop DGK - Abteilung Ingenieurgeodäsie & GKGM "Unsicherheitsmodellierung beim Einsatz komplexer Messsysteme", 21.09.2020.

Schwieger, V.: Vorstellung der Abteilung Ingenieurgeodäsie, Jahressitzung des Ausschusses Geodäsie (DGK), Bayrische Akademie der Wissenschaften, 23.11.2020.

## Activities at the University and in National and International Organizations

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)
Head 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 the Editorial Board "Journal of Applied Geodes"
Member of the Editorial Board "Journal of Applied Engineering Science"
Member of the 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
Course Director of the MSc Program GeoEngine at the University of Stuttgart

Li Zhang

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

## Doctorates

Lerke, Otto: Entwicklung eines Steuerungssystems für eine Laderaupe zur Durchführung vollautomatisierter Ladeprozesse unter Einsatz bildverarbeitender Robottachymeter und adaptiver Regelung. Main reviewer: Prof. Dr.-Ing. habil. V. Schwieger, co-reviewers: Prof. Dr.-Ing. Hans Neuner, Prof. Dr. Andreas Wieser

Pham, Trung Dung: Use of Non-linearity as a Characteristic in the Selection of Filtering Algorithms in Kinematic Positioning. Main reviewer: Prof. Dr.-Ing. habil. V. Schwieger, co-reviewer: Prof. Dr.-Ing. Uwe Sörgel

Stefan Cavegn: Integrated Georeferencing for Precise Depth Map Generation Exploiting Multi-Camera Image Sequences from Mobile Mapping. Deutsche Geodätische Kommission, Reihe C, Nr. 863, München 2020. Main reviewer: Prof. Dr.-Ing. Norbert Haala, co-reviewers: Prof. Dr.-Ing. habil. Volker Schwieger, Prof. Dr. Stephan Nebiker

## Master Theses

Mohammed Ismail: Integration of constraints in filters for navigation purposes (M. Wachsmuth)

Pascal Kaiser: KI-basierte und AR-gestützte Nachbearbeitung von Spalten beim Einbau von Kotflügeln (V. Schwieger)

Nian Liu: Development of a Real-Time Magnetometer Calibration Solution (V. Schwieger)

Christoph Pfeil: Qualitätsverbesserung im Hochbau gezeigt an einem Praxisbeispiel (L. Balangé)

Andreas Pfemeter: Entwicklung von Sensorsystemen zur Umfelderkennung von automatischen Türen und Klappen (O. Lerke)

Daniele Roos: Objekterkennung von Bauteilzuständen in der Rohbauphase von Hochbauprojekten mit Hilfe von künstlichen neuronalen Netzen (L. Balangé)

Mansoor Sabzali: Improving the modeling of atmospheric effects on long-range TLS measurements (G. Kerekes)

## Bachelor Theses

Christine Dräger: Robuste Dienstplanung an Flughäfen (V. Schwieger)

Ivan Hybsch: Projektübergreifende Datenanalyse von Verzögerungen und Störungen in Bauprojekten durch den Einsatz von Machine Learning (M. Metzner)

## Education

SS20 and WS20/21 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, Basalla) | 4/2/0/0 |
| Engineering Geodesy II (Schwieger, Lerke) | 1/1/0/0 |
| Geodetic Measurement Techniques I (Metzner, Hausmann) | 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, Balangé) | 2/2/0/0 |

### Master Geodesy and Geoinformatics (German)

| | |
|---|---|
| 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 (Schwieger, Kerekes) | 1/1/0/0 |
| Terrestrial Multisensor Systems (L. Zhang, Lerke) | 1/1/0/0 |
| Transport Telematics (Metzner, Luz) | 2/2/0/0 |

**Master GeoEngine (English)**

| | |
|---|---|
| Kinematic Measurement Systems (Schwieger, Basalla) | 2/2/0/0 |
| Monitoring (Schwieger, Balangé) | 1/1/0/0 |
| Thematic Cartography (L. Zhang, Hausmann) | 1/1/0/0 |
| Transport Telematics (Metzner, Y. Zhang) | 2/1/0/0 |
| Terrestrial Multisensor Systems (L. Zhang, Lerke) | 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 (Metzner, Luz) | 2/2/0/0 |

**Bachelor Civil Engineering (German)**

| | |
|---|---|
| Geodesy in Civil Engineering (Metzner, Hassan, Kanzler) | 2/2/0/0 |

**Master Civil Engineering (German)**

| | |
|---|---|
| Geoinformation Systems (Metzner, Luz) | 2/1/0/0 |
| Transport Telematics (Metzner, 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, Y. Zhang) | 1/1/0/0 |