Annual Report 2021

Institute of Engineering Geodesy (IIGS)

1. Members of Staff

Head of Institute:	Prof. Dr.-Ing. habil. Dr. h.c. Volker Schwieger	
Secretary:	Elke Rawe Désirée Schreib	
Scientific Staff:	M.Sc. Laura Balangé	Quality Modeling
	M.Sc. Urs Basalla	Terrestrial Laser Scanning
	Dipl.-Ing. Lyudmila Gorokhova (since 15.10.2021)	Kinematic Positioning
	Dipl.-Ing. Susanne Haußmann	Kinematic Positioning
	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. Christoph Sebald (since 01.11.2021)	GIS for Climate Data
	Dr.-Ing. Li Zhang	Engineering Geodesy
	Dr.-Ing. Yin Zhang (until 31.05.2021)	Monitoring
Technical Staff:	Dipl.-Ing. (FH) Andreas Kanzler Martin Knihs, Mechanikermeister Dipl.-Geogr. Lars Plate	
External Teaching Staff:	Dipl.-Ing. Jürgen Eisenmann	Geschäftsbereichsleiter Landratsamt Ostalbkreis, Geoinformation und Landentwicklung
	Dr.-Ing. Frank Friesecke	Prokurist der STEG Stadtentwicklung GmbH
	Jonas Stadler M.Eng.	Landratsamt Alb-Donau-Kreis Flurneuordnung der Landkreise Alb-Donau-Kreis und Biberach
	Dipl.-Math. Ulrich Völter	Geschäftsführer intermetric - Gesellschaft für Ingenieurmessung und raumbezogene Informationssysteme mbH
	Dr.-Ing. Thomas Wiltschko	Daimler AG, Mercedes-Benz Cars; Research and Development
PhD-Students:	M.Sc. Julia Aichinger	Terrestrial Laser Scanning
	Dipl.-Ing. Patric Hindenberger	Location Referencing
	M.Sc. Yu Li	Digital Map
	M.Sc. Annette Schmitt	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”. Until October 2021, he was 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 and Master). Furthermore, lectures are given in English to students within the Master course “Infrastructure Planning”.

The cluster “Integrative Computational Design and Construction for Architecture” (IntCDC), that is 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 geodetic 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.

Again, this year was marked by the corona pandemic in research and teaching. In research, almost all face-to-face meetings were cancelled and in teaching, lectures were held digitally. Laboratories and exercises were mainly carried out presence. In the winter semester all lectures taught by the institute are given in presence.

3. Research and Development

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

Within the framework of the Cluster of Excellence IntCDC, the research project (RP) 16 investigates automated and semi-automated assembly processes of long span buildings. The geodetic contribution is the provision of 6-DoF pose (position and orientation) of the assembly robot's (mini-crane) jib, by a real time robotic total station network (RTS-N). After the completion of the methodical preparations on data fusion procedures and pose determination, the realization phase is currently in progress. Therefore, the appropriate RTS-N control scheme has been developed and implemented. The scheme is depicted in Figure 1.

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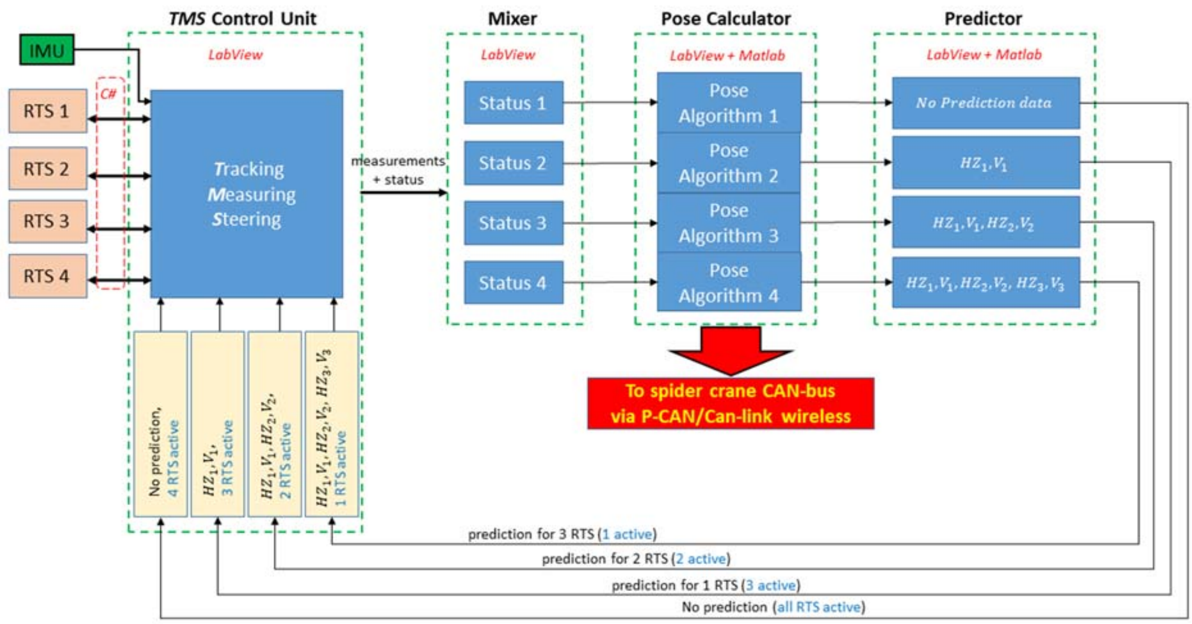

Figure 1: RTS network control scheme

The four items TMS control unit, mixer, pose calculator, and the predictor handle the measurement data in order to provide the position and orientation (pose) to the construction robot in real-time. Dependent on the number of RTSs, which are actively contributing to the pose determination and have the line-of-sight to the robot, appropriate pose algorithms and predictor states are chosen. The real-time capability requires temporal synchronisation between different RTSs. Two different synchronisation issues are present which are 1) between different RTSs (extrinsic) and 2) between individual RTS functionalities, as angle and distance measurement (intrinsic). Among these, the extrinsic issue is solved. The intrinsic issue is stil under investigation.

The network performance has been evaluated in real-world tests, where the construction robot picked a payload from and transported it to a certain position. The RTS-N pose has been processed within the robot control-loop to position its tool center point (TCP), according to the planned trajectory. The results showed satisfactory accuracy levels for positions and orientations in both implemented configurations, which are: configuration A - 4 RTSs – 1 prism, for position + IMU for orientation and configuration B - 4 RTSs – 2 prisms, for position and 2 orientation angles, 3rd orientation angle is stil provided by the IMU.

Table 1:

Config A	**4 RTSs**	**3 RTSs**	**2 RTS**	**1 RTS**	**IMU (data sheet)**
	2.1 mm	2.6 mm	3.0 mm	3.1 mm	0.05° Pitch/Roll, 0.8° Yaw
Config B	**2 RTS per prism**		**1 RTS per prism**		**From RTS-N**
	2.2 mm		3.3 mm		0.03° - 0.1° Pitch/Yaw

These values confirm and partly overtop the simulated results from the preparation phase, as published in Lerke and Schwieger (2021).

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

The research project “Holistic Quality Model for IntCDC Building Systems” is part of the cluster of excellence for Integrative Computational Design and Construction for Architecture (IntCDC). In this project, a Holistic Quality Model regarding social, environmental and technical quality characteristics is developed in cooperation with the Institute of Acoustics and Building Physics (IABP) and the Institute of Social Sciences (SOWI). Together, a holistic quality assessment, which takes into account the individual aspects as well as the interdependencies between the disciplines, was carried out within the framework of a graded concrete case study.

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In the case of technical quality, the focus is on an assessment of the geometric quality. Compared to conventional construction methods, a standardized nominal/actual comparison is often not possible for the construction systems developed in the project. The focus of the research here was on generating a measurement and evaluation workflow to estimate the geometry of fiber composite systems. Here, on the one hand the position and orientation of the individual fibers is of major importance, and on the other hand the shape of the fiber itself with a special focus on the cross-sectional area is needed. Therefore, two different experiments were carried out to determine the change in geometry during the manufacturing process as well as the shape of the individual fiber bundles after the production process.

For the monitoring of the fiber interaction, laser scanner measurements were taken after each fiber was added. In each epoch the intersection point of several fibers is calculated and then assigned to the corresponding intersection of the following epoch. This can then be used to determine the deformation within the production process.

Another important point is the determination of the final geometry of the components after production. In addition to the position of the individual fiber bundles, their cross-sectional area is of great interest here, too. For this purpose, TLS measurements were carried out, as shown in Figure 2, and the cross-sectional area was estimated using various methods.

Figure 2: Measuring set-up for the geometric quality control after the production.

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

3.3. Freiburg Pavilion

The Institute for Computational Design and Construction (ICD) and the Institute of Building Structures and Structural Design (ITKE) have constructed the LivMatS Pavilion at the botanical garden in Freiburg. It consists of a load-bearing structure that is entirely made of robotically wound flax fibre. The pavilion was scanned twice by the IIGS. The pavilion was scanned in June after construction and again in July after the acrylic glass façade had been installed. A fixed point field was installed on site to allow an easier comparison of the scanning epochs. The HDS7000 from Leica was used for on-site scanning, and the TS16 (Leica) was used for measuring the fixed point field. These two epochs were then compared to each other and to the CAD (Fig. 3).

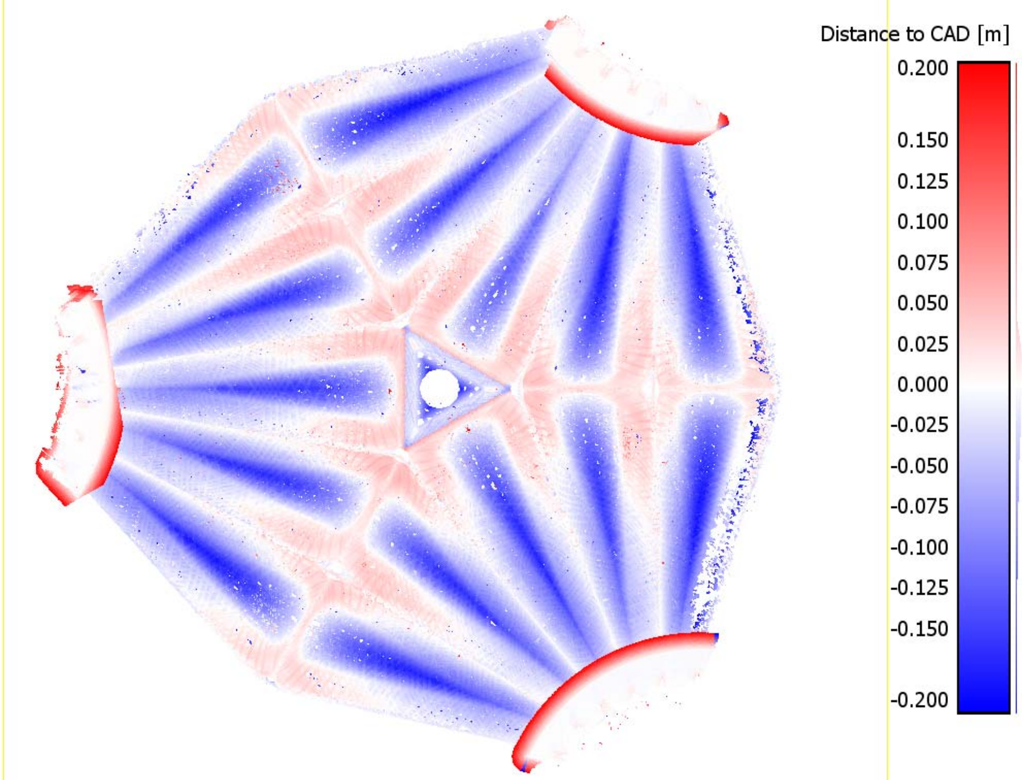


Figure 3: Cloud to mesh distance between measurements of epoch 1 and the designed CAD

The comparison of the two epochs was considerably simplified by the fixed point field. The comparison between the epochs shows almost no change. Deviations between the epochs are less than 3 mm. Unfortunately, the fixed point field could not be applied for the comparison with the CAD, as the CAD does not have the same fixed points. In this case, the foundation blocks were initially matched by hand. This could then be more accurately oriented using ICP. Again, only the foundation blocks and the lowest section of the pavilion up to a height of 0.5 m were used for orientation. With the transformation now known, the entire pavilion can be oriented to the CAD and compared to it. Here, the deviations are in the range of up to 15 cm (fig. 3). These deviations are mainly in the middle of the curved structure of the individual beams. These were constructed with more curvature than was originally planned in the CAD. However, this does not affect the stability of the structure.
The next and final scan is scheduled for March/April 2022 to assess the stability of the building over a longer period of time. For better comparability the same equipment will be used here as well.

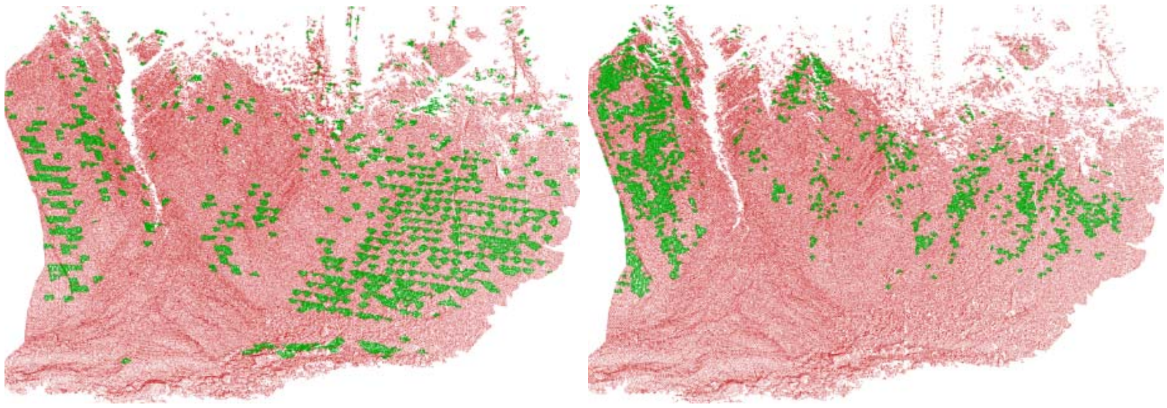
3.4. Collaborative Scanner Test and Calibration at Bonn Reference Wall

Within the framework of the project "Collaborative Scanner Test and Calibration at Bonn Reference Wall" (COLLECTOR) carried out by the Society for Calibration of Geodetic Devices (SOGD) a comparison of various laser scanners from different universities should be carried out. Therefore, a reference wall in Bonn was measured with a predefined set-up. The set-up can be seen in Figure 4. In addition, calibration measurements were done inside the hall. In total, measurements were carried out with approximately 20 different devices and then a predefined evaluation process was carried out. Our institute participate in this project with four laser scanners (HDS7000, BLK, X7, Riegel2000V). All four scanners were used to measure the exterior of the Bonn wall. The results of all institutes are now compared and questions like "What is the real reference of the wall?"," What is the effect of calibration?" or "How can we describe cyclic effects?" raised and are still part of the current research.

Figure 4: Measurement set-up at Bonn reference wall

3.5. Targetless Registration and Identification of Stable Areas for Deformed TLS Point Clouds

Accurate and robust 3D point cloud registration is the crucial part of the processing chain in terrestrial laser scanning-based (TLS-based) deformation monitoring that has been widely investigated in the last two decades. For the scenarios without signalized targets, however, automatic and robust point cloud registration becomes more challenging, especially when significant deformations and changes exist between the sequence of scans which may cause erroneous registrations. A fully automatic registration algorithm for point clouds with partially unstable areas is proposed, which does not require artificial targets or extracted feature points. In this method, coarsely registered point clouds are firstly over-segmented and represented by supervoxels based on the local consistency assumption of deformed objects. A confidence interval based on an approximate assumption of the stochastic model is considered to determine the local minimum detectable deformation for the identification of stable areas. The significantly deformed supervoxels between two scans can be detected progressively by an efficient iterative process, solely retaining the stable areas to be utilized for the fine registration. The proposed registration pipeline is demonstrated on the TLS point cloud dataset (with two-epoch scans) of the Nesslrinna landslide close to Obergurgl, Austria. The experimental results show that the proposed algorithm exhibits a higher registration accuracy and thus a better detection of deformations in TLS point clouds compared with the existing voxel-based method and the variants of the iterative closest point (ICP) algorithm. Figure 5 shows the identification results of stable areas within the TLS point clouds of Nesslrinna landslide from July 2015 to July 2017.



(a) (b)

Figure 5: Identification of stable (green) and unstable (red) areas of the TLS point clouds of Nesslrinna landslide by the voxel-based method (a) and the proposed method (b).

3.6. Integrated Space-Time Modeling based on Correlated Measurements for the Determination of Survey Configurations and the Description of Deformation Processes (IMKAD II)

Within the DFG (Deutsche Forschungsgemeinschaft) project IMKAD II, further steps have been made towards establishing a stochastic model for Terrestrial Laser Scanner (TLS) monitoring. This project is carried out in cooperation with research division Engineering Geodesy at the department of Geodesy and Geoinformation at the TU Vienna.

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TLS point clouds acquired under laboratory conditions of a B-spline specimen (test object) were used to understand and validate the role of the stochastic model in the estimation process. Specifically, the stochastic model was represented by the synthetic variance covariance matrix (SVCM). It was used as a weighting matrix for the estimated B-spline control points. Different versions of the same matrix (e.g. fully populated SVCM and diagonal matrix D) were used and compared with the identity matrix.

The magnitude of the elementary errors that are introduced in the SVCM was verified w.r.t. a reference scan of the same test specimen within the same coordinate system. The focus was set on instrument (TLS) specific errors. Results indicate that TLS non-correlating errors, here angular and range noise had the biggest impact on the accuracy of the estimated control points. Detailed findings are presented in Raschhofer et al. (2021). The complete workflow is shown in figure 6.

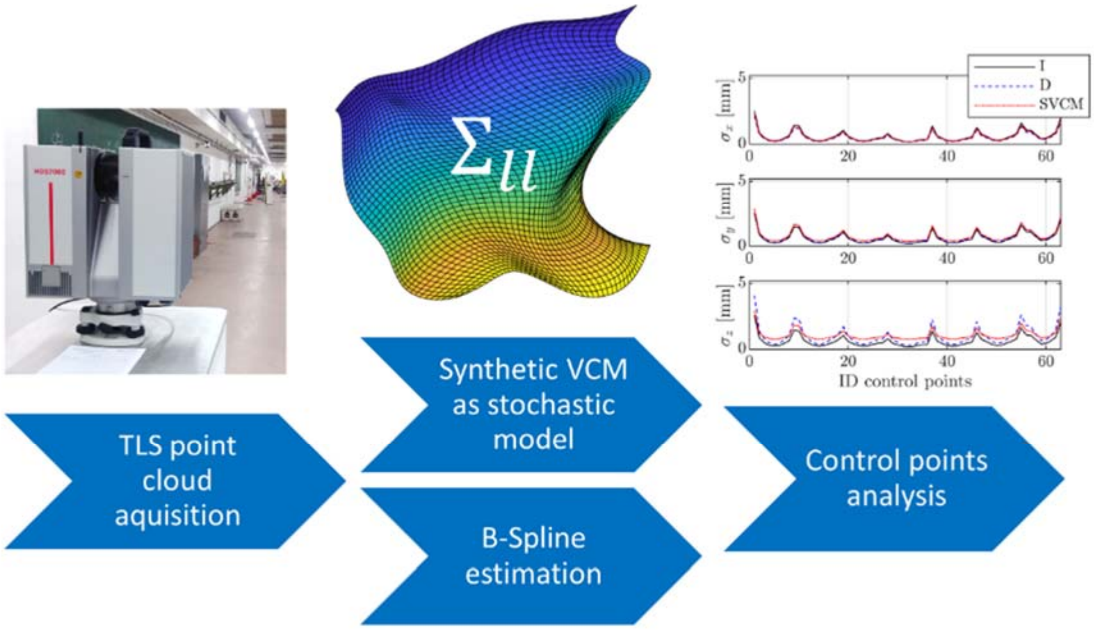

Figure 6: Workflow used for the validation of the SVCM for a B-spline test specimen in laboratory conditions.

This research was funded by DFG (German Research Foundation), SCHW 838/7-3.

3.7. B-spline Curvature Matching based on Rank Correlation Analysis

Terrestrial laser scanning offers the possibility of scanning objects by means of high-resolution object discretization. However, the acquisition of identical points over multiple epochs is not possible, and therefore object deformations cannot be detected directly. As a consequence, a method is developed to generate and overlay B-spline curves from laser scan data in order to detect differences in the object shape over multiple epochs.

One step of this method is to perform a correlation analysis using curvature values of the B-spline curve points to obtain a 1D shift position of two B-spline curves to be compared. The curvature values are calculated using the second derivative of the B-spline curve, which can be generated by the second derivative of the B-spline basis functions. In the correlation analysis, Spearman's rank correlation coefficient is applied, where the rank of the curvatures is used instead of the curvature value itself. In contrast to the Pearson correlation coefficient, Spearman's rank correlation coefficient offers the advantage of evaluating non-linear but monotonic relationships.

3.8. Map-supported Road Boundary Detection from 3D Point Cloud

This research is the result of a partnership between the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart and the Daimler Truck AG. Road detection is a fundamental task for vehicle autonomy. In most of the well-constructed urban areas, road curb is usually regarded as a representative road boundary feature as it separates a road into driveable and non-driveable areas. One key hardware component used in a typical autonomous vehicle is the Lidar sensor, which is capable of measuring precisely the surrounding environments in a 3D manner. This property makes it suitable for detecting the road boundaries surrounding the ego vehicle, especially the road curbs with significant height jump from road surface. During the last decades, different work pipelines have been developed to detect curbs from 3D point cloud. However, most of the works focus mainly on the simplified driving scenarios, e.g., straight road without complex intersections, with less or even no other road participators, and

ego vehicle (assumed) with ideal sensor mounting position. These simplifications rule these methods out of situations where traffic condition becomes complicated, or when the sensor-to-ground geometry changes drastically.
To overcome the limitations of the existing approaches, several improvements have been proposed in this study. Firstly, a fast and efficient range image based object detection module was adapted to remove the noisy object points from the given 3D point cloud. This results in a “clear” point cloud where the points are mainly lying on the ground. Then, a curb detector with adaptive threshold was applied, to detect and extract all curb candidates from the point cloud. In order to cope with curvy roads and intersections, the existing road geometry and topology information from a standard definition (SD) map is also retrieved and utilized. In particular, the map geometry is used as an approximation of the actual road geometry, thus helps to filter out noisy curb candidates from the second step; while the map topology can help the detection system to adapt its searching strategy at a road intersection. The overall system is implemented using C++ in Linux ROS environment, and a preliminary evaluation shows that the developed system can run at 50 fps on a single CPU core, which meets the real-time requirement given that the typical data rate of a Lidar sensor is 10Hz.

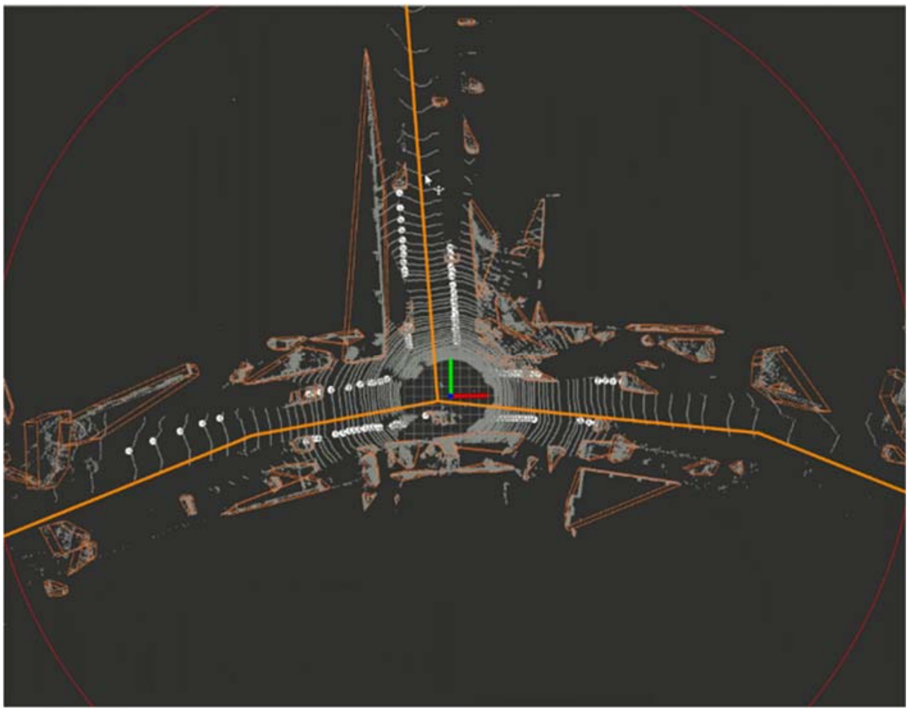

Figure 7: Detected road curbs at an intersection. White dot: detected road curbs; dark orange polygon: detected 3D object; bright orange polyline: map geometry; red circle: 50 meter range.

3.9. Dynamic Location Referencing: Probability- and Fuzzy Logic-based Decision Systems

Dynamic (on-the-fly, map-agnostic) Location Referencing is a well-known methodology for sharing geo-objects between digital maps, used in such cases when there are no common databases and/or common structures between the systems (maps) to be exchanged. Here, dynamic methods are developed to share *Location References* (*LR*, digital-map based geo-objects) between different, non-corresponding maps.
Generally, *Location Referencing Methods* follow a one-dimensional three-step process of encoding the *LR* in the sender system, transfer and decoding the *LR* in the receiver system without any iterations and typically limited bandwidth. Given the fact, that there are no dedicated links/common data structures between the maps, the key issue for *Dynamic Location Referencing* is to find the correct *LR* in the target map which corresponds to the *LR* in the source map (see Figure 8).

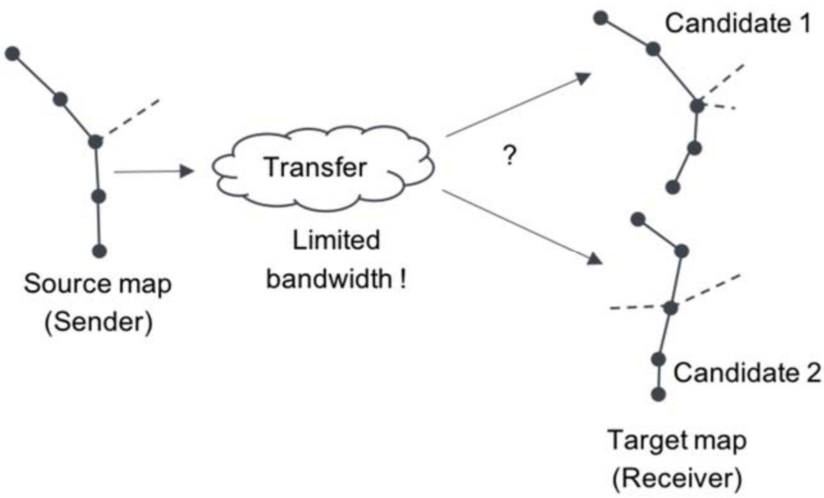

Figure 8: Identification of Location Reference

Typically, deterministic algorithms are defined and implemented in nearly all known methods developed and implemented so far.

Based on the fact that there are uncertainties in matching geospatial data matching methods, uncertainty-based decision systems are in the research process and the thesis of the research work. That means in specific, a probability-based and a fuzzy-based approach were specified and investigated in detail as two different uncertainty-based concepts. For both, a set of decision criteria (geometrical, topological, syntactical and semantical) were defined and the decision algorithms were formulated. Both approaches were implemented in an evaluation system and analyzed.

As a result, 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 in average.

The new research approaches formulated in the last report, which resulted from the previous state of research, were continued and brought to an intermediate state. New principles have been developed that provide a broader basis for the previous approaches and help to validate the results and place them in a broader context. This will be continued in the course of the year and implemented in the existing methods.

3.10. Ghosthunter II and its Successor Ghosthunter III

The aim of the Ghosthunter II project and its successor Ghosthunter III is to develop an app for Android smartphones that can be used for to reliably detect of wrong-way drivers on highways and their ramps. In addition, both the wrong-way drivers themselves and other drivers, are to be warned. 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.

In the Ghosthunter II project, an app for Android smartphones was developed for this purpose. A warning case, which was recognized by the app is shown in Figure 9. The app's wrong-way driver detection was extensively evaluated with real and simulated trajectories during the course of the project. Using simulated trajectory data, it was also possible to test trajectories of wrong-way driving. In its final state, the app achieved a false alarm probability of $7 \cdot 10^{-4}$ % and a sensitivity of 98.89 %.

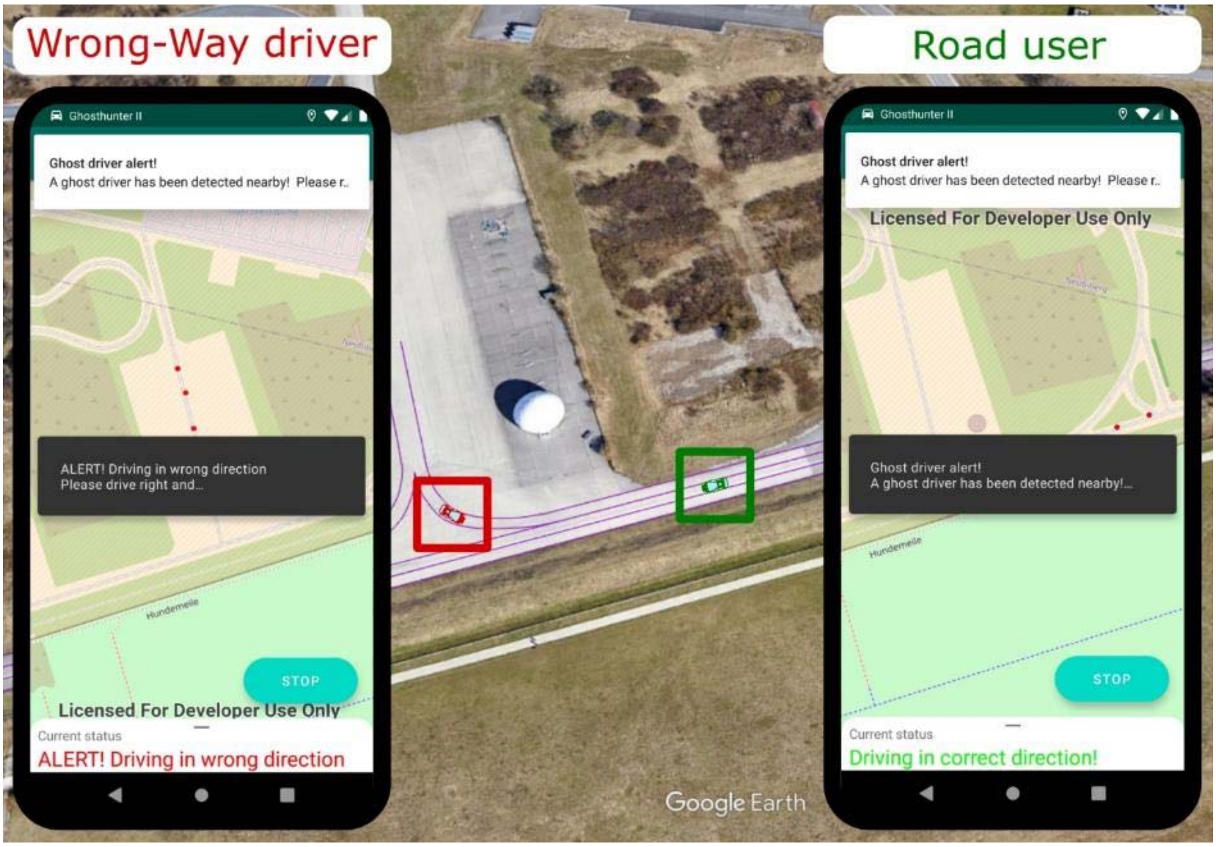

Figure 9: Ghosthunter app for wrong-way driver detection. The wrong-way driver (red car, left smartphone) generates a warning. Both the wrong-way driver and another road user (green car, right smartphone) are warned.

In the follow-up project Ghosthunter III, the goal is to develop this app from its function as a demonstrator to a ready-to-use product. A crucial aspect is the exchange of commercial map data with freely available open source data. Here, OSM (Open Street Maps) data will be used to generate a map specifically adapted to our use case. In the next steps, the algorithms of the app will be adapted to these map data.

The Ghosthunter II and Ghosthunter III research project are funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) and the German Aerospace Center (DLR) under grant number 50 NA 1802 resp. 50 NA 2109.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

3.11. The CoKLIMAx Project

The CoKLIMAx project started in November 2021 it deals with the use of COPERNICUS data for climate-relevant urban planning by the example of water, heat and vegetation. The project consortium consists of the City of Konstanz as consortium leader, supported by the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart, the Konstanz University of Applied Sciences for Technology, Economics and Design (HTWG) Konstanz, and the Climate Service Center Germany (GERICS) at the Helmholtz Center Hereon. At the municipal level only a low utilization of the available data has been observed so far. In this context, it is difficult for potential users from municipal administrations to identify the data sets relevant for them from the extensive offer of the C3S Climate Data Store and to recognize the interpretability/meaning. In the everyday application context of urban planning, practical tools are needed that serve to merge and meaningfully combine Copernicus data with local data and to further process and use the results in municipal planning activities.

Based on this background, CoKLIMAx aims to develop new products and procedures, such as the development of practice-oriented technical tools for data acquisition from Copernicus services and merging with heterogeneous locally available data sets.
CoKLIMAx envisions to develop an Advanced Municipal Climate Data Store toolbox (AMCDS Toolbox) and make it available as a freely available software kit. The implementation will be exemplary based on the concrete local needs of the city of Konstanz in the above mentioned focus areas water, climate and vegetation. Relevant data and products will be developed for concrete applications in these areas and implemented, applied and validated in a practice-oriented manner.
During November and December 2021, architectural planning and development took place on how to structure and install the CoKLIMAx ArcGIS Enterprise platform in the CODE-DE IT infrastructure. As of today, the GIS Enterprise Platform is fully installed and functional. It consists of ten instances (virtual machines), which are connected for overall functionality. The installation is made up of an ArcGIS Base deployment with additional server capabilities, such as the ArcGIS Data Stores (relational and spatio temporal), a GeoEvent, GeoAnalytics, and Notebook Server. From a technical point of view, these components shall be in the center having ingoing and outgoing data streams and services available. At the same time, available tools, such as Survey123 or StoryMaps, and ArcGIS HUB (and SITES) are being used for later deployment and communication. For instance, Enterprise Sites is like a subset of the capabilities that is available with ArcGIS Hub. Sites simply provide the ability to create tailored websites and subpages and are more or less equivalent to ArcGIS Open Data. Meanwhile, the development to derive data from the Copernicus Climate Data Store (C3S) is under construction.

The CoKLIMAx research project is funded by the German Federal Ministry for Digital and Transport (BMDV) and the German Aerospace Center (DLR) as part of the "Climate Adaptation Strategies for Municipal Applications in Germany" under grant number 50EW2103C.

Supported by:

Federal Ministry
for Digital
and Transport

on the basis of a decision
by the German Bundestag

3.12. Evaluation of 5G Mobile Phone Positioning

As part of the cooperation with Nokia Bell-Labs, the position of an Omron robot is to be determined via the 5G mobile radio standard. In order to support the measurements of the position of the robot itself and the 5G position measurements, IIGS has been contracted to provide reference measurements. For this purpose, a 360° prism was positioned on the robot, which was mounted exactly under the mobile phone antenna. This prism was tracked by a tachymeter (TS16) and thus a position was provided for reference. The measurements took place entirely in ARENA2036, in which a local fixed point field was installed. All elements such as robots, mobile radio and total stations operate in this fixed point field, which simplifies the comparison of the data. Both static and kinematic tests were performed in Arena2036 and will be evaluated and published next year. The ARENA2036 project was the winner in the "Research Campus Public-Private Partnership for Innovation" competition of the Federal Ministry of Education and Research. In order to make room for the newly emerging Research Campus, a new building was constructed, which offers a production environment in which approaches, ideas and results from researches can be tested and directly converted into practicable prototypes for industrial purposes. The total construction costs of the new building were equally shared between the European Union (EFRE funds) via the state of Baden-Württemberg and the University of Stuttgart.

3.13. Advanced Automated Gap and Flush Measurement 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 Mercedes-Benz AG. Mercedes is responsive in fulfilling the market needs in SUV cars. The expected market-share of SUVs in the United States is 75% in the year 2021. The autonomous mobile robot system with triangulation scanners to measure gap and flush between car-parts (SME-S) that was presented in the last year's annual report, operates in production sites within Europe and China. However, it is not able to capture every measurement position, especially considering the dimensions of a modern SUV vehicle and is not capable to measure on every surface finish.
We evolved the SME-S in two main directions to cope with the two new requirements regarding reachability of measurement points and the new surface finishes.
The first direction is selecting the hardware (manipulator, platform and sensor) driven by the application but with an independent and easy-to-use human machine interface and an orchestration platform for programming and commissioning. The robot and platform selection is determined by reachability requirements. The vehicle-surface leads to the sensor selection. The second direction delivers the same high precision with more inaccurate robot-hardware that includes a non-holonomic platform (MIR) and a new manipulator (Doosan).
Overall, the SME-S and SME-SL share the same user-interaction and orchestration platform with hardware selection based on business-requirement firsts. In addition, with the new hardware-setup, the SME-SL is capable of performing gap and flush measurements at any position on the vehicle surface on any surface finish with the same precision as the previous SME-S. The next steps include a fully autonomous measurement of different vehicles in different locations. Therefore, the SME-SL must move autonomously outside its working cell and interact with other systems and unknown dynamic environments on the shop floor to perform its measurement task in another working cell.

3.14. Combining Geometric Segmentation and Neural Network Approaches for Lidar Environment Perception

For modern advanced driver assistant systems (ADAS) and automated vehicles, a comprehensive environment perception is necessary. More and more systems use lidar sensors, since they offer high spatial precision. Using the point clouds, neural networks nowadays achieve high accuracies on object detection datasets, like the KITTI benchmark, but may fail to detect objects of untrained classes or in untrained environments. To overcome this issue, the detection pipeline is split into a geometric segmentation approach and a neural network for classification and bounding box regression. In the first step, a traditional geometric approach segments the point cloud into physical objects and thus generates a point cloud segment for each object, as shown in figure 10.

Figure 10: Segmentation of lidar scan into point cloud segments using a geometric approach

The second step is based on a neural network, since these are the most accurate solutions for classification and regression on point clouds. The network architecture is shown in figure 11 and consists of three parts. Three encoder networks of different grid sizes extract voxel features from the point cloud segment. A point based implementation is used, so no prior data transformation has to be applied.

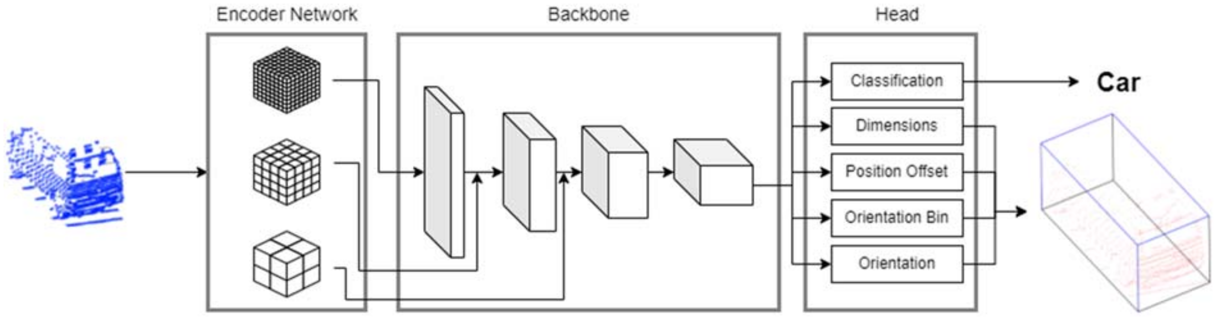

Figure 11 Network architecture for classification and bounding box regression

The backbone consists of a 3-dimensional convolution and pooling layers, while the voxel features from the encoder networks are injected at the corresponding stages. The head is then spitted into multiple branches with different tasks. The classification head is responsible to distinguish between the classes "car", "pedestrian", "cyclist" and "background". The other branches together regress the oriented bounding box. The classification is evaluated separately on the real world lidar segments of the Stanford Track Collection and achieves a classification accuracy of 96.8 %. The regressed bounding boxes are further evaluated on the KITTI 3D detection benchmark where a mAP (mean Average Precision) score of 79.3 % is achieved for cars using a custom data split. Both the segmentation and the neural network are capable of running in real time. Overall, this combination of a geometric segmentation approach and a neural network for refinement offers high classification and regression performances combined with the safety of a geometric detection.

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

This RISC (Research Seed Capital – Blue Skies Research) project aims to use brain activity and eye movement of humans to represent the perceived space and possibly replace or enhance existing reality capture methods. The project is funded by the Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg.

Up to now, the conducted experiments yielded some interesting findings. Eye-tracking data are used obtained with a Pupil Core eye-tracker and brain activity was recorded with an 8-chanel electroencephalography (EEG) brain computer interface (BCI) from Neuroelectrics. The experiments can be briefly described as follows: a person equipped with the BCI and Eye-tracker stands in front of a wall at short distance (~ 4m) with small black & white targets fixed on it. While BCI and eye-tracker data is recorded, the subject focuses on each target in succession. The goal is to reconstruct the position of targets using EEG and eye-tracking data. Based on eye tracking, the position of each target can be reproduced with differences w.r.t. the true position in lower dm-level (< 20 cm) on the observed wall. The EEG data shows interesting artifacts when the person changes his or hers gaze point. It is possible to interpret if a target is on the left or on the right side w.r.t. an egocentric coordinate system based on the signal patterns (see figure 10). Data from further experiments with different subjects is still being analyzed.

All in all, the project reflects an old saying of the pre-Socratics - "Man is the measure of all things…", this time literally.

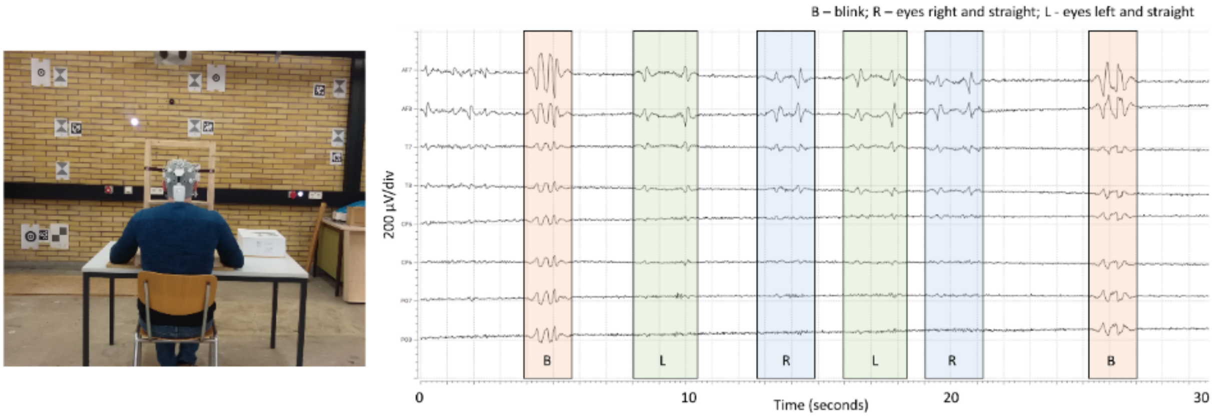

Figure 12: Left: person during the experiment;
right: EEG Signals and patters for different eye movements (see legend)

3.16. PhD Seminar

The 11th Doctoral Seminar of the Engineering Geodesy Section of DGK was organized by the Institute of Geodesy of Leibniz Universität Hannover. Although the entire scientific community was confronted with challenging times and overwhelmed by digital events, the DGK PhD Seminar of Engineering Geodesy Section was organized as a live event. It took place from October 6 to 7, 2021, under strict 3G rules and an appropriate hygiene concept at the Royal Horse Stables (Königlicher Pferdestall) in Hannover, a communication and meeting center of Leibniz Universität Hannover for science and culture. A total of 12 presentations mirrored the work of PhD candidates from Austria, Switzerland, and Germany. Fruitful discussions between the 50 participants were possible during the coffee breaks and in the evening at the much anticipated get-together for “Beer & Brezel”. After the successful participation of the IIGS members with contributions from Christian Bader and Julia Aichinger, a long minibus ride back to Stuttgart crowned the experience.

4. Publications

Refereed Publications

Bader, C.; Dingler, S.; Schwieger, V. (2021): PVENet: Point Voxel Encoder Network for Real-Time Classification of Lidar Point Cloud Segments. In: 2021 20th International Conference on Advanced Robotics (ICAR), pp. 492-498, https://doi.org/10.1109/ICAR53236.2021.9659376

Balangé, L.; Zhang L.; Schwieger V. (2021): First Step Towards the Technical Quality Concept for Integrative Computational Design and Construction. In: Kopácik A., Kyrinovic P., Erdélyi J., Paar R., Marendic 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;

Bühler, M.; Sebald, C.; Rechid, D.; Baier, E.; Michalski, A.; Rothstein, B.; Nübel, K,; Metzner, M.; Schwieger, V.; Harrs, J.; Jacob, D.; Köhler, L.; Panhuis, G.; Tejeda, R.; ;Herrmann, M.; Buziek, G (2021): Application of Copernicus data for climate-relevant urban planning using the example of water, heat, and vegetation. Remote Sensing, 13(18), 3634; https://doi.org/10.3390/rs13183634

Kerekes, G.; Schwieger V. (2021): Determining Variance-Covariance Matrices for Terrestrial Laser Scans: A Case Study of the Arch Dam Kops. In: Kopácik A., Kyrinovic P., Erdélyi J., Paar R., Marendic 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

Lauer, A. P. R., Blagojevic, B., Lerke, O., Schwieger, V., Sawodny, O. (2021): Flexible Multibody System Model of a Spider Crane with two Extendable Booms. In Proceedings of the 47th Annual Conference of the IEEE Industrial Electronics Society.

Lerke, O., Bahamon-Blanco, S., Metzner, M., Martin, U., Schwieger, V. (2021): Vorarbeiten zur Entwicklung eines Gleisfehlerdetektionssystems mit Regelzügen und Low-Cost Sensorik. Zfv 3/2021. 10.12902/zfv-0339-2021

Lerke, O., Schwieger, V. (2021): Analysis of a kinematic real-time robotic total station network for robot control. Journal of Applied Geodesy 2021; 15(3). doi.org/10.1515/jag-2021-0016

Luz, P.; Zhang, L.; Wang, J.; Schwieger, V. (2021): Lane-Level Map-Aiding Approach Based on Non-Lane-Level Digital Map Data in Road Transport Security. Sustainability 2021, 13, 9724. https://doi.org/10.3390/su13179724

Raschhofer, J.; Kerekes, G.; Harmening, C.; Neuner, H.; Schwieger, V. (2021): Estimating Control Points for B-Spline Surfaces Using Fully Populated Synthetic Variance–Covariance Matrices for TLS Point Clouds. Remote Sensing. 2021; 13(16):3124. https://doi.org/10.3390/rs13163124

Scheider, A.; Hassan, A.; Brüggemann, T.; Schwieger, V. (2021): Lückenlose Positionsbestimmung zur Georeferenzierung von hydrographischen Messdaten. AVN, Heft 3, 123-132.

Yang, Y.; Balangé, L.; Gericke, O.; Schmeer, D.; Zhang, L.; Sobek, W.; Schwieger, V. (2021): Monitoring of the Production Process of Graded Concrete Component Using Terrestrial Laser Scanning. Remote Sens. 2021, 13, 1622. https://doi.org/10.3390/rs13091622

Non-Refereed Publications

Kerekes, G.; Schwieger, V. (2021): Towards Perceived Space Representation using Brain Activity, Eye-Tracking and Terrestrial Laser Scanning. In A. Basiri, G. Gartner, & H. Huang (Eds.), LBS 2021: Proceedings of the 16th International Conference on Location Based Services. https://doi.org/10.34726/1788

Wagner, H.-J., Aicher, S., Balangé, L., Basalla, U., Schwieger, V., Menges, A. (2021): Qualities of the Unique: Accuracy and Process-Control Management in Project-based Robotic Timber Constructions. WCTE 2021, Santiago de Chile, 9.-12. August 2021

Presentations

Balangé, L., Di Bari, R., Hos, P. D.: RP18: Holistic Quality Model for IntCDC Building Systems, Status Colloquium 2021, 26.02.2021

Balangé, L., Di Bari, R., Hos, P. D.: RP18: Holistic Quality Model, Status Seminar 2021 Bad Boll, 11.11.2021

Balangé, L., Di Bari, R., Hos, P. D.: RP18: Holistic Quality Model, Joint Meeting RPA-B1, RPA-C, RP18, 02.03.2021

Balangé, L.: Results of the University of Stuttgart in the framework of the COLLECTOR ring trial, COLLECTOR Workshop 1 and 3, 27.05.2021 and 16.11.2021

Faulkner, R., Gong, Y., Javot, B., Lerke, O., Lauer, A., Mohan, M., Ortenzi, V., Sanchez, N.: Robotic Platform for Cyber-Physical Assembly of Long-Span Fiber-Composite Structures, IntCDC Status Colloquium 2021, 26.02.2021

Faulkner, R., Gong, Y., Javot, B., Lauer, A., Lerke, O., Mohan, M.: Robotic Platform for Cyber-Physical Assembly of Long-Span Fiber-Composite Structures, 2021 IntCDC Status Seminar Bad Boll, 11-12.11.2021

Kerekes, G.: Elementary Error Model for TLS Measurements, Workshop on Error Sources and Corrections in Permanent Laser Scanning, digital at Optical and Laser Remote Sensing Group, Department of Geoscience and Remote Sensing, Delft University of Technology, 18.03.2021.

Kerekes, G.: Perceived Space Representation using Brain Activity Analysis, Eye-Tracking and Terrestrial Laser Scanning, Strategiedialog 2021 Universität Stuttgart - Bold research, 20.04./03.05.2021.

Kerekes, G.: Presentation of work experience and research experience at the Polytechnic University of Timisoara for Geodesy Students, digital event, 17.05.2021.

Kerekes, G.: Successful Graduates Speech at the Polytechnic University of Timisoara – 100 years anniversary of the university and 80 year anniversary of the faculty of construction, digital at the Polytechnic University of Timisoara, 11.11.2021

Lerke, O.: Precise Seamless 6-DoF Positioning for Georeferenced Assembly Control, IntCDC RP16 Status Meeting, 08.01.2021

Lerke, O.: Quality aspects related to Engineering Geodesy, IntCDC Research project area (RPA - C) Meeting, 20.01.2021

Schwieger, V.: Beyond BIM – Integrative Computational Design and Construction, Jahressitzung des Ausschusses Geodäsie (DGK), Bayrische Akademie der Wissenschaften, 24.11.2021.

Schwieger, V.: Vorstellung der Abteilung Ingenieurgeodäsie, Jahressitzung des Ausschusses Geodäsie (DGK), Bayrische Akademie der Wissenschaften, 25.11.2021.

Schwieger, V.: Integrative Computational Design and Construction – Geodetic Contributions, Geodätisches Kolloquium der Universität Bonn, 02.12.2021.

Zhang, L.: Quality as Driver for Sustainable Construction — Holistic Quality Model and Assessment, IntCDC Best Publication Awards 2020/21, Status Seminar 2021 Bad Boll, 11.11.2021

5. Activities at the University and in National and International Organizations

Volker Schwieger

- 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 Geodesy”
- 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)”

6. Doctorates

Scheider, Annette
Identifikation von Systemmodellen zur dreidimensionalen Zustandsschätzung eines Peilschiffs mit Propellerantrieb unter Verwendung eines Multi-Sensorsystems. Deutsche Geodätische Kommission, Reihe C, Heft Nr. 868, ISBN 978-3-7696-5280-2, ISSN 0065-5325, Verlag der Bayerischen Akademie der Wissenschaften
https://dgk.badw.de/fileadmin/user_upload/Files/DGK/docs/c-868.pdf
Main reviewer: Prof. Dr.-Ing. habil. Dr. h.c. Volker Schwieger,
Co-reviewers: Prof. Dr.-Ing. Harald Sternberg (HCU Hamburg), Prof. Dr.-Ing. Andreas Eichhorn (TU Darmstadt);

Alexandra Avram
A contribution to multipath modelling and simulation for kinematic trajectories. Universität Stuttgart: Universitätsbibliothek der Universität Stuttgart
https://elib.uni-stuttgart.de/handle/11682/11848
Main reviewer: Prof. Dr.-Ing. habil. Dr. h.c. Volker Schwieger,
Co-reviewer: Univ.-Prof. Mag. Dr. habil. Thomas Pany;

Chaudhry, Sukant
Surface related uncertainties of laser scanning: a simulation-based and experimental study. ETH Zürich, Research Collection, Dissertation 2021.
https://www.research-collection.ethz.ch/handle/20.500.11850/533401
Main reviewer: Prof. Dr. Andreas Wieser (ETH Zürich),
Co-reviewers: Prof. Dr.–Ing. habil. Dr. h.c. Volker Schwieger, Dr. David Salido Monzu (ETH Zürich)

7. Master Theses

Ahmeti, Shkelqim

Improvements of lane exact Map-Matching by considering past GNSS epochs (Luz/Metzner)

Andrews, Akosah

Examining the pixel positions of the camera measurements of the crosshairs of the telescopic line of sight of the Leica TS16I (Basalla/Schwieger)

Buck, Maximilien

Prozessoptimierung beim Einsatz der Methode Building Information Modeling. (Metzner)

Li, Bilin
Radar-Sensorsimulation zur Validierung autonomer Fahrfunktionen (Schwieger)

Irslinger, Maximilien
Automatisierte Ermittlung des baulichen Nutzungsmaßes und der daraus resultierenden Wertunterschiede (Metzner)

Miseke, Ariane
The use of geospatial analysis to evaluate the locations and distribution patterns of COVID-19 in Baden-Württemberg (Metzner)

Xu, Bingqing
Development of a Map-based Constrained Extended Kalman Filter Algorithm for Train Positioning (Lerke/Schwieger)

Zheng, Yifei
Sensor integration with magnetic data and improvement of an extended Kalman filter (Luz/Zhang)

8. Bachelor Theses

Schmid, Frieder
Erfassung von Baustellenfahrzeugen mittels Verfahren der Bildverarbeitung (Basalla/Schwieger)

Speidel, Pauline
Evaluierung von unterschiedlichen Verfahren zur Bestimmung der Pose eines Bauroboters mittels eines RTS Netzwerks (Lerke/Schwieger)

Sprügel, Nadine
Detektion und Verfolgung eines Laserspots im Kamerabild eines TS16 (Basalla/Schwieger)

Tao, Yihan
Evaluierung der Möglichkeiten für die Erstellung eines BIM-Modells mittels Trimble X7 und der Software RealWorks (Balangé/Metzner)

Wilczynski, Martin Jan
Verwendbarkeit von mobilen Eye-Tracking Systemen in der geodätischen Messtechnik (Kerekes/Schwieger)

9. Education

SS21 and WS21/22 with Lecture/Exercise/Practical Work/Seminar

Bachelor Geodesy and Geoinformatics (German):

Basic Geodetic Field Work (Haußmann, 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, Haußmann)	3/1/0/0
Geodetic Measurement Techniques II (Haußmann)	0/1/0/0
Integrated Field Work (Kerekes, Metzner)	0/0/10 days/0

Reorganisation of Rural Regions (Stadler)	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, Gorokhova)	1/1/0/0
Land Development (Eisenmann)	1/0/0/0
Monitoring Measurements (Schwieger, Gorokhova)	1/1/0/0
Terrestrial Multisensor Systems (L. Zhang, Lerke)	1/1/0/0
Geomobility (L. Zhang, Luz)	2/2/0/0
Projekt Geodäsie und Geoinformatik (Schwieger, L. Zhang, Basalla, Haußmann)	0/0/0/6

Master GeoEngine (English):

Kinematic Measurement Systems (Schwieger, Basalla)	2/2/0/0
Monitoring (Schwieger, Balangé)	1/1/0/0
Thematic Cartography (L. Zhang, Sebald)	1/1/0/0
Transport Telematics (Metzner, Sebald)	2/1/0/0
Terrestrial Multisensor Systems (Lerke, Haußmann)	2/1/0/0

Bachelor and Master Aerospace Engineering (German):

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

Master Aerospace Engineering (German):

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

Bachelor Civil Engineering (German):

Geodesy in Civil Engineering (Metzner, Luz, Kanzler)	2/2/0/0

Master Civil Engineering (German):

Geoinformation Systems (Metzner, Sebald)	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, Haußmann)	1/1/0/0