Annual Report 2020
Institute of Navigation

INS

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Annual Report 2020

of the

Institute of Navigation (INS)

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Staff in 2020

Management	**Role**
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Dr.-Ing. Aloysius Wehr	Deputy
Prof.i.R. Dr.-Ing. Alfred Kleusberg	Retired professor
Helga Mehrbrodt	Secretary

Academic Staff	**Research Focus**
Dipl.-Ing. Doris Becker	Navigation Systems
Dipl.-Geogr. Thomas Gauger	GIS Modelling and Mapping
M.Sc. Kevin Gutsche	Precise orbit determination
Dr. Tomasz Hadas	GNSS troposphere
M.Sc. Shengping He	GNSS troposphere & PPP
M.Sc. Tomke Jantje Lambertus	Parameter Estimation in Dynamic Systems
M.Sc. Clemens Sonnleitner	Autonomous flight, ADS-B
Dipl.-Ing. (FH) Martin Thomas	Digital Electronics and Hardware Programming
M.Sc. Thomas Topp	Navigation Software Development
M.Sc. Arunprasad Vijayaraghavan	Hardware and FPGA programming
M.Sc. Rui Wang	GNSS, RTK, integrity
Dr.-Ing. Aloysius Wehr	Optical and Wireless Communication

IT	**Responsibility**
Regine Schlothan	Computer infrastructure and programming

Electr. and Mech. Workshop (ZLW)	**Expertise**
Dr.-Ing. Aloysius Wehr	Head of ZLW
Michael Pfeiffer	Mechanician Master
Sebastian Schneider	Electrician
Dipl.-Ing. (FH) Martin Thomas	Electrical engineer

External lecturers	**Affiliation**
Hon. Prof. Dr.-Ing. Hans Martin Braun	RST Raumfahrt SystemtechnikAG, St.Gallen
Dipl.-Ing. Steffen Bolenz	Stadtmessungsamt, Stuttgart
Dr.-Ing. Werner Enderle	ESA / ESOC

Preface

This report summarizes the activities of the Institute of Navigation (INS) in the year 2020. We are happy that we could welcome three new PhD students, who have started work on different research projects and already cooperate with partners from industry. Research highlights, which are also described in greater detail in this report, are definitely our involvement in the establishment of the university's test area for autonomous flight, the use of GNSS for routine weather prediction and the development of a flexible, easy-to-use and extendable software framework that will serve the institute in the coming years in different research and student projects. Despite the challenges that came with the COVID-19 outbreak in the first quarter of the year, we were able to adopt quickly to the new circumstances and provide the content from all our lectures and exercises in different digital formats. Also, supervision of bachelor and master thesis projects could continue, though special measures for lab attendance had to be made in order to follow the hygiene rules set out by the university. As business travel came to an almost complete stop, we were not able to present our results on national and international conferences and had to hold almost all of our internal and external meetings in the form of teleconferences. This preface also serves the purpose to thank all staff of the INS for their strong support, flexibility and high motivation to carry the institute through the Corona year of 2020!

Research

The INS identifies new fields of applications, develops and tests navigation solutions and assigns research projects according to four "focus areas" which were defined in 2018. Figure 1 depicts those areas which are grouped around the topics of "positioning, navigation and timing".

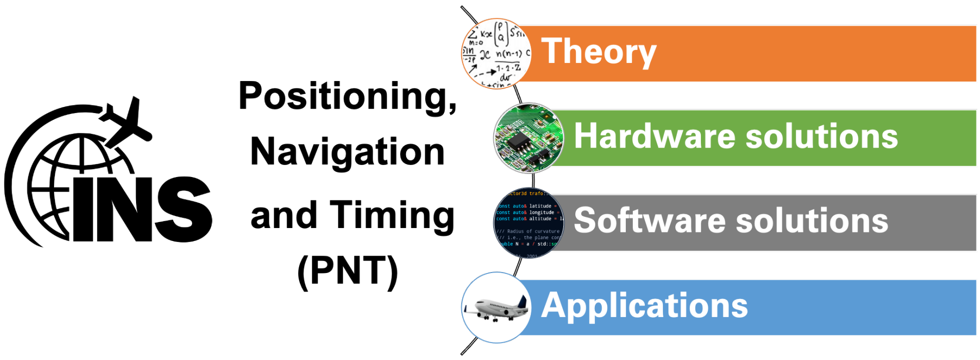


Figure 1: INS focus areas to which the institute is actively contributing with research projects.

While most of the current research projects can be clearly assigned to one or two focus areas shown in the figure, larger research projects, like AREA-BW or AutoCOM, described later in this report, are usually falling under the category "applications" but require intense input from the other three research areas. In the following, the purpose and vision for each research area is presented together with examples of ongoing research projects.

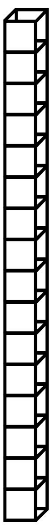
Research focus: Theory

The research area "Theory" involves the investigation and testing of mathematical models in order to improve existing positioning and navigation methods. The adaptation of classical parameter estimation methods and the development of new mathematical algorithms are key elements for innovative navigation applications. In this context the main focus lies on the realization of real-time solutions in order to facilitate mobile navigation applications (e.g. smartphones) or enable highly precise and accurate applications for operation of unmanned vehicles. Investigations concerning the optimal weighting of measurements and statistics-based fusion of sensor arrays are also a field of research. In addition, non-linear systems and their peculiarities are studied as well. The research output from this focus area is a precursor to other research topics but it also benefits from feedback from application-oriented fields of research.

Massive parallel particle filter algorithms

As one of its research focus, the INS has identified the topic of modern dynamic non-linear parameter estimation methods for autonomous navigation applications. Significant improvements in positioning, navigation and timing (PNT) concerning precision, accuracy, integrity, and availability over the last century have enabled a manifold of applications that are part of our daily life. In recent years the requirements of autonomous navigation have led to several challenges that need to be addressed to realize such ground-breaking concepts for aircraft, ship and land vehicle navigation. Most classical estimators rely on the idea that observations errors are following Gaussian normal distributions and third and higher-order moments of the probability distributions are zero. However, as this might not be totally correct for real-world sensors, one faces the challenge to determine the "most likely" state of a navigation system under the consideration of the real stochastic properties. Moreover, the solution space could be bounded or limited to given sets within the mathematical spaces of real or natural numbers. In most standard navigation applications, the extended Kalmanfilter (EKF) is used as it is simple to implement and yields acceptable results. Nevertheless, the EKF relies on a Gaussian white noise distribution in the prediction and update steps which would ensure that the Kalman filter yields a near-optimal solution. Furthermore, one needs to have exact knowledge about the dynamic state-space model and its stochastic properties and their time evolution need to be well understood. In reality, navigation applications are more complex and will typically include non-linear systems and measurements which do not necessarily follow a Gaussian normal distribution.

The EKF uses a linearization around the mean of the current state, and hence, the original problem is transformed into an approximative problem and solved such that it does not have to be the optimal solution of the original problem. The linearization can deteriorate the accuracy of the obtained solution or even lead to the divergence of the solution. In our research project, we focus on particle filters which can be considered as an alternative approach when reflecting on the aforementioned issues. The particle filter belongs to the group of Bayesian filtering techniques and it does not necessarily require the knowledge of the stochastic properties in advance. Hence, it is also suitable for nonlinear prob-



position X [m]	Dynamic model parameters	IRW
position Y [m]		IRW
position Z [m]		IRW
azimut [deg]		RW
velocity horizontal [m/s]		RW
velocity vertical [m/s]		RW
clock offset GPS	GNSS clock parameters	IRW
clock rate GPS		RW
Δ clock GLONASS		RW
Δ clock GALILEO		RW
Δ roll	IMU bias parameters	RW
Δ pitch		RW
Δ yaw		RW
Δ acceleration x		RW
Δ acceleration y		RW
Δ acceleration z		RW

Figure 2: State vector parameters of a particle for a moving vehicle when using GNSS and IMU observations. The process model of these parameters is indicated by IRW (integrated random walk) or RW (random walk).

lems having measurements with non-Gaussian distributions, because it preserves the nonlinear structure of the problem. The basic idea of this filter is to create a set of particles where each particle represents a possible realization of the state vector which is assigned a weight. In each epoch, the states of particles are predicted based on their process model (see Figure 2). If measurements are available, the weight of each particle is recomputed, leading to an update of the PDF based on the residuals between observed and computed measurements. A major drawback of the particle filter is its computational cost which makes it difficult to process a large particle cloud. However, particle cloud processing is well suited for parallelization. To speed up the processing we use a graphics processing unit (GPU) to run the particle filter algorithms on a commercial of-the-shelf computing platform. The implementation of the algorithm is outlined in Figure 3. At every epoch, observational data are obtained and preprocessed on the CPU. Such data are then sent to the GPU where the main steps of the particle filter are performed using multiple threads. After each step, the main information, i.e. the estimated mean state and its stochastic properties are returned to the CPU. The particle filter program is written in C++ and will be part of the INSTINCT software which is described in greater detail the Software development section.

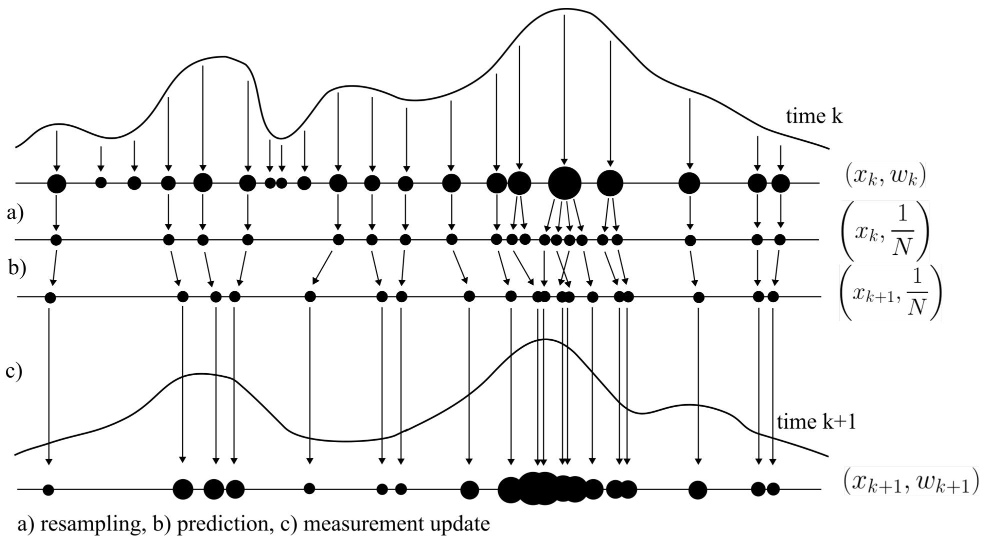


Figure 3: Schematic illustration of an 1D particle filter with N particles where x is the state vector of one particle and w its weight at time t.

Exchange training program at the University of Wrocław, Poland

From February to March 2020 one of our PhD students joined the PROM Programm at the Institute of Geodesy and Geoinformatics, Wrocław University of Science and Technology in Poland. The PROM program aims to support exchanges of PhD candidates and academic staff programs.

This program aims at increasing the competences and qualifications of PhD students. The funding is provided by the Polish National Agency for Academic Exchange. The host institute has vast experience in GNSS observation processing, precise point positioning, orbit determination (ILRS Associate Analysis Center), and especially in atmosphere modeling and parameter estimation. During her stay, our PhD candidate got notable support in terms of real-time GNSS parameter correction models. During this traineeship, GNSS observation correction models were tested and implemented in a GNSS Software developed at the INS. In addition, the BKG Ntrip Client (BNC) was added to the software suite. In particular, BNC was used to generate orbit and clock corrections so that they can be used together with broadcast ephemeris. The purpose of this exchange

Wrocław University of Science and Technology stay was to improve programming skills in C++, implement additional GNSS observations correction models in the GNSS Software, and to work with different real-time correction approaches for GNSS positioning and navigation.

Research focus: Hardware development

The combination of different sensor elements is a crucial approach when designing optimal navigation solutions for safety-critical and highly precise applications. Beside inertial navigation systems and GNSS the usage of novel sensors is therefor examined. Together with results from fundamental research and input from industry, new navigation instruments and sensors are developed and tested for their positioning and navigation abilities on different platforms. The use of software-defined-radio solutions reduces development costs and time and provides realistic estimates of the performance of an instrument that will be later realized in hardware or by the help of field-programmable gate arrays (FPGAs).

ADS-B

One of the research topics at the Institute of Navigation deals with Automatic Dependent Surveillance - Broadcast (short: "ADS-B"). In 2020 a low-cost receiver has been mounted on the roof of the building to monitor the airspace around Stuttgart. Airplanes up to a distance of approximately 120 km can be tracked with this receiver. It was for instance possible to monitor how air traffic declined as a result of the SARS-CoV-2 outbreak. Additionally, preparations for the installation of an high-grade ADS-B receiver from Thales have been made. This system is planned to be installed in Mengen at the "Testfeld eFliegen BW" (see section Testfeld eFliegen BW on page 11) at the end of 2021. One master thesis that dealt with the development of a software-defined ADS-B receiver and one bachelor thesis in which the student investigated the achievable precision of a multilateration ground station networks have been supervised in relation to ADS-B. On a long-term perspective, a network of several ADS-B base stations will be established and the obtained multilateration data shall be fused with the informations from the ADS-B messages. Thereby, it is expected that air traffic monitoring (ATM) will be significantly enhanced concerning reliability, robustness and integrity when using ADS-B, which has less initial and operational costs than traditional ATM systems.

Figure 4: ADS-B antenna on the roof of the building of the institutes building.

Sensors for an alarm system against drowning in a bathtub

This project was initiated by the company Horcher and has been supported by the Central Innovation Programme for small and medium-sized enterprises (SMEs). The project's objective is the development of a system preventing people from drowning in a bathtub as used e.g. by nursing homes for the elderly. Project partners are company Horcher, Institute of Navigation (INS) and the German Institutes of Textile and Fiber Research (DITF). INS was assigned the task to develop and realize the sensor system, which comprises MEMS-Inertial Measurement Units (MEMS-IMUs), air pressure sensors, humidity sensors and an Indoor Microwave Positioning and Data Transmission System (IMPDS). The sensors and the transmitters of IMPDS are mounted on the patient's body. Therefore, the electronic components are developed in close cooperation with DITF regarding the requirements of so-called wearable electronics. In the year 2020, first experiments that considered dipping into water were carried out for evaluating the sensor performance and this study the situation when a body is drowning under water. The experimental setup for automatic testing is shown in Figure 5a.

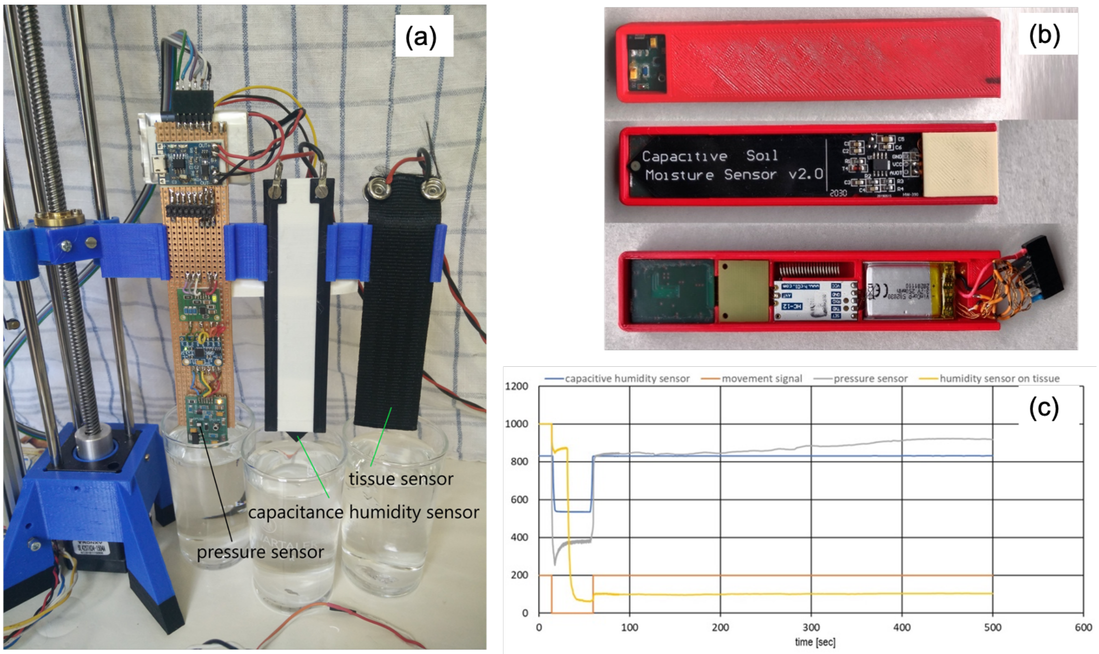


Figure 5: (a) Experimental setup for comparison of different sensors. (b) Demonstration sensor block (upper picture: opening pressure sensor, covered IMU, middle picture: humidity sensor, bottom picture: removed humidity sensor: IMU, transmitter and battery pack). (c) Comparison of different sensors.

The measurement results are plotted in Figure 5c. The red line (movement signal) depicts the position of the sensors. A value of 200 indicated that the object would be out of the water while a value 0 means complete drowning under water. The commercially available capacitance humidity sensor is functioning very precise and fast. Also the pressure sensor shows clearly, when a body goes under water. The diagram makes clear that there is a certain recovery process, if the sensor is out of water. But this feature does not effect the decision, if the body is under water. The humidity sensor on the tissue reacts differently and tests reveals that a clear signal can be obtained with a delay of a 14 sec. The tissue requires more than an hour to become dry which is the requirement to report back the initial zero value. On the basis of this experiment a demonstration sensor block was realized comprising a six degree of freedom inertial measurement unit LSM6DSOX from STMicroelectronics, a pressure sensor DPS368 from Infineon, a humidity sensor and a wireless data link which connects to a central computer. All items were mounted in a compact housing and were powered by a small battery pack (see Figure 5b). Software was implemented for data gathering and transmission in parallel to the electronics development and mechanical setup work. Special emphasis was put on the development of a wearable patch antenna. Here, analytical experiments were carried out concerning the determination of the relative dielectric constant of the used glue fixing for the antenna foil on the backing material. Figure 6 depicts the principle measurement setup.

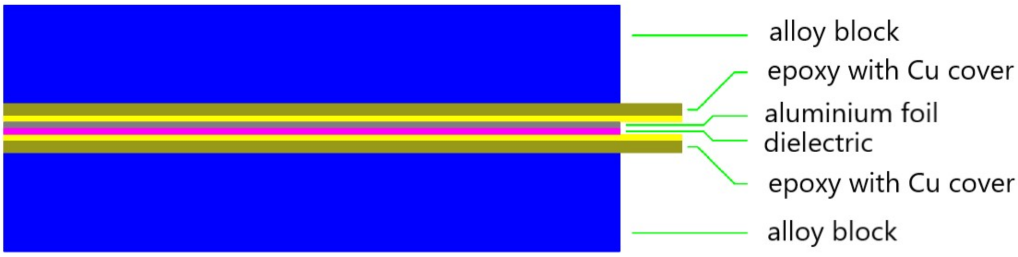


Figure 6: Principle measurement setup for determining dielectric constant

Six foils were studied. The foils had got the physical dimensions 100 mm x 100 mm. According to Table 1 they exhibit different thicknesses of the dielectric material which later will be applied as glue.

Sample	thickness (µm)	solid content (%)
1	100	45
2	200	45
3	300	45
4	100	13.5
5	200	13.5
6	300	13.5

Table 1: Thickness of the studied dielectric material

Figure 7a shows the determined values of the relative permeability as a function of frequency. On the basis of this values a patch antenna (see Figure 7b) can be dimensioned, now.

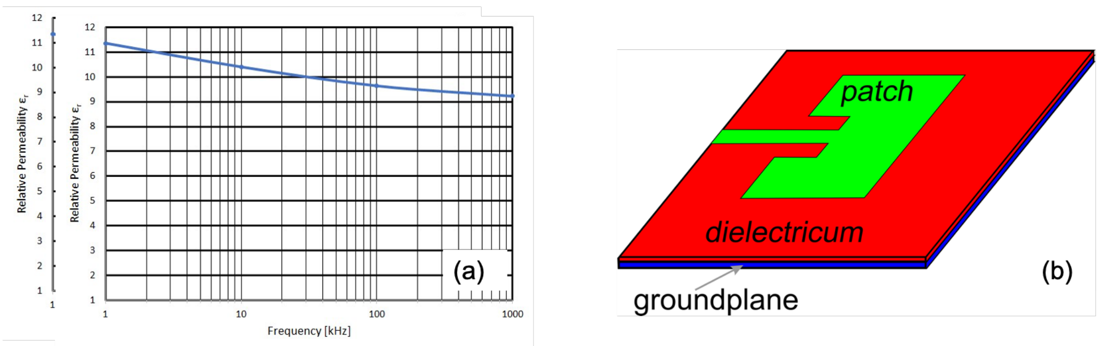


Figure 7: (a) Relative permeability as function of frequency. (b) Patch antenna.

Research focus: Software development

In order to test new algorithms and navigation solutions the institute has started to develop its own software toolchain. All code is based on modern C++ language, optimized for run-time performance while still being simple enough so that navigation software solutions can be easily designed by drag-and-drop style. Thus, the software is usable by non-experts, who have only very little knowledge about the implemented algorithms but need robust and precise navigation solutions, as well as navigation professionals, who adopt the software for their particular need or extend it with new modules to realize new and innovate solutions. Therefore, easy testing and verification of improved algorithms and models for positioning and navigation of static and moving objects is possible. The software development efforts are complemented by studying systematic effects, which set an implicit limit for improving the accuracy of positioning solutions.

INSTINCT - INS Toolkit for Integrated Navigation Concepts and Training

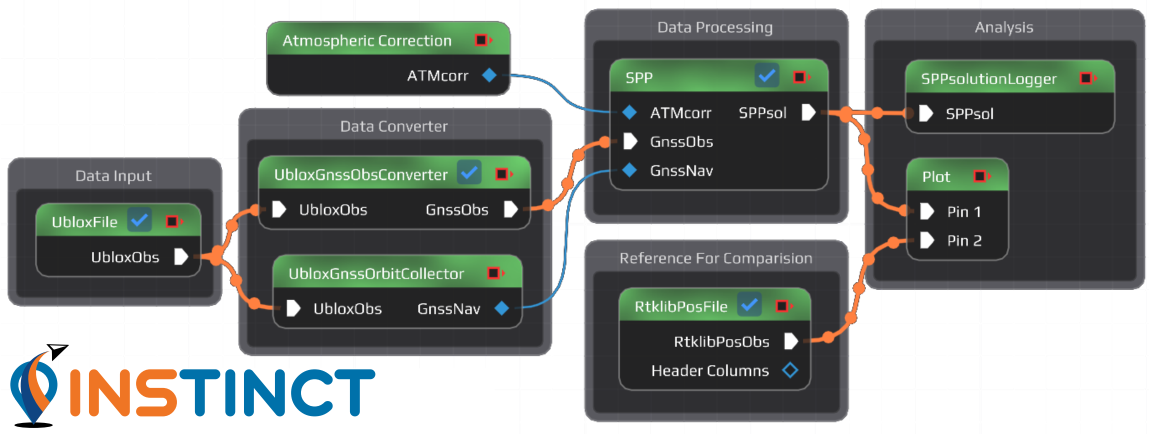


Figure 8: INSTINCT dataflow for a SPP algorithm.

INSTINCT is a software framework written in modern C++ which provides a GUI to design navigation algorithms (Figure 8). The software bases on a node-based approach which follows the data-flow programming paradigm. This means, that functionality which serves the same purpose, like reading a file or sensor, is bundled into a node. These nodes are self-contained and do not know about the functionality of other nodes, which makes it very easy to understand, use and extend them. The only way how nodes exchange information is by their input and output pins. These pins can have different types, ranging from static objects (blue diamond pins in Figure 8) to dynamic data (white arrow pins), which is for example sent every time a new sensor measurement is available. To connect pins, and therefore determine where the data should be passed to, links can be created by drag-and-drop between the node pins. Every time data is passed over these links, an animation (orange dots in Figure 8) is triggered in order to help the user understand the data-flow by such a visual aid. A major advantage of this node-based approach with predefined interfaces is, that it is easy to replace data sources, e.g. switch from an input file to a real sensor node. Therefore flows can be tested with recorded data and then only one node needs to be exchanged to utilize the exact same structure in a real-time scenario. With this simplicity it is easy to create a data-flow and visualize the results. Moreover, it is possible to use the exact same data-flow and run the program without the GUI on e.g. a single-board computer like a Raspberry Pi. This then achieves great performance while using the already tested data-flow without any reconfiguration.

The core of each node is a configuration window where data can be visualized (Figure 9) or parameters can be adjusted on-the-fly. This enables the user to adjust his algorithms and directly see the effects which is much faster than editing setting files, restarting the program and then plotting the data in other tools. The configuration windows are designed with an open source Immediate Mode GUI library which allows the more advanced user to fully customize his own nodes to his needs. INSTINCT is meant to be used for research projects, training and also for real-time vehicle navigation. Researchers can implement their own algorithms inside new nodes and take advantage of a large set of already available functionality. This enables them to focus on the research instead of implementing fundamental things over and over again. Students at universities or trainees in companies can use the

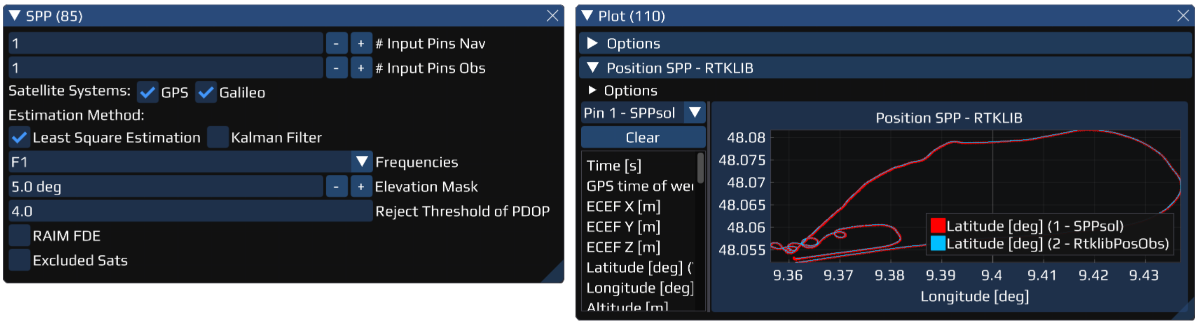


Figure 9: Config windows for the SPP node, where parameters can be adapted and the Plot node, where data can be visualized.

simple user interface to experiment with navigation algorithms and see how different parameters affect the solution. This provides a more practical and deeper learning experience. Finally the software can be used to provide an on-board real-time navigation solution which is customized to the available hardware and mission needs. Therefore it delivers the maximum performance while still being adaptable to future changes.

PODCAST - Precise Orbit Determination for Cutting-edge Adaptive Satellite Technology

PODCAST is a C++ software that is developed at the Institute of Navigation in cooperation with Airbus. The development started in November 2020 and is within the project AutoCom co-funded by the German Aerospace Center (DLR) and Airbus. The software aims to provide Precise Orbit Determination (POD) capabilities for future satellite missions while enabling research activities in its development. The need for POD arises in particular from the requirement of very precise position information in order to acquire high-quality Synthetic-Aperture Radar (SAR) images or altimetry measurements. PODCAST is developed with the goal to provide a POD solution for the ground segment to enable high-quality data in the post-processing of these images and measurements.
PODCAST will implement established concepts of Precise Orbit Determination for non-agile LEO satellites. A further goal of this software is to enable the analysis of the influence of agility and low-thrust station keeping on POD algorithms and how this affects the accuracies of the final estimation. Ultimately, PODCAST shall provide a POD solution for agile satellite missions, which currently does not exist on the market. In a first step, the framework of PODCAST has been set and first estimations with simulated observations have been performed. The software will be subsequently improved to incorporate additional observations and dynamics to reach the required estimation accuracy requirements. From this validated software for POD of non-agile satellites, further work will be done to ultimately provide a software for POD of non-agile as well as agile satellites. The software will be extensively validated with hardware-based and software-based GNSS simulators, real hardware and realistic mission scenarios.

Research focus: Applications

Research and development is either driven by the demand for certain solutions or applications. However, it might also happen that particular unintended applications emerge from research as it turns out that the theoretical foundations of soft- and hardware solutions also serve another purpose. One example for such an application is GNSS meteorology, which allows to derive crucial parameters of the troposphere from GNSS measurements. Thus, atmospheric delay, which is usually an error source that needs to be mitigated carefully when processing GNSS observations for the purpose of positioning and navigation, becomes a valuable source of information, when extracted properly within the parameter estimation process. The next sub-section discusses some recent findings that relate to such an undertaking. On the other side, the institute's involvement in a large research infrastructure for autonomous flight operations, as described in the second sub-section, can be seen an incubator for new applications that will emerge when research projects related to safe, precise and reliable navigation of unmanned air vehicles are carried out.

GNSS meteorology

The H2020 project "Real-Time GNSS for European Troposphere Delay Model" (ReS4ToM) aims to develop a high quality real-time GNSS model of the troposphere delay for Europe (`https://cordis.europa.eu/project/id/835997/en`). It will combine in a consistent and operational way multiple novel aspects of GNSS data processing in real-time, e.g. undifferenced and uncombined multi-GNSS data processing, estimation of horizontal gradients, optimized stochastic modeling and robust outlier detection in real-time. In Hadas et al. (2020), the impact of Precise Point Positioning (PPP) processing parameters on estimated tropospheric products is investigated. It is noticed, that a multi-GNSS solution, with proper intersystem weighting, reduces the a posteriori standard deviation of estimated Zenith Total Delay (ZTD) by up to 37 %. The estimation of real-time gradients improves height precision by 27 % on average and can significantly affect ZTD estimates. Real-time gradients are estimated with an uncertainty of 0.1 mm to 0.3 mm, but their accuracy with respect to an NWP model or post-processing results is not investigated in this study. An advanced strategy for real-time troposphere monitoring is proposed, which is superior to the common approach, i.e. it has 0.9 % more results over the entire year 2019, and the a posteriori error of estimated ZTD is reduced by 41 % on average. The accuracy with respect to the final ZTD product from the International GNSS Service (IGS) improves by 17 % and varies over stations from 5.4 to 10.1 mm (Figure 10). Such performance will legitimate real-time ZTD estimates for assimilation into NWP.

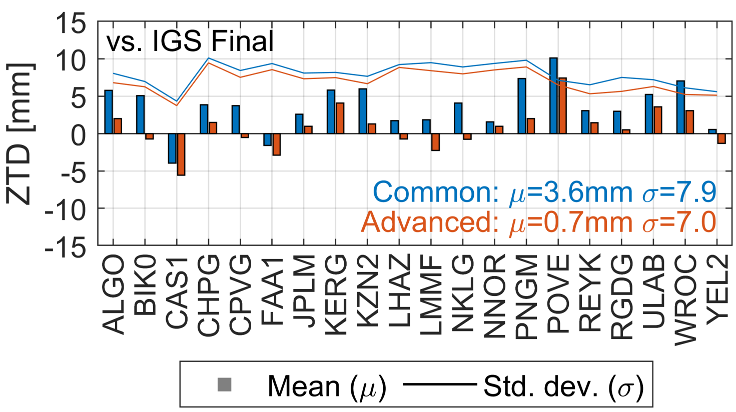


Figure 10: Comparison of real-time ZTD obtained with common and advanced strategy against IGS Final product.

In Hadas and Hobiger (2020), it is demonstrated, that Galileo and supporting services are already mature enough to provide a reliable information on troposphere state in real-time. However, the performance of Galileo-only solution is still not as good as of GPS-only solution in terms of continuous performance, standard deviation of estimated ZTD and accuracy with respect to final products. On the other hand, a combined GPS+Galileo solution can be achieved in real-time without a lot of extra effort, which leads to significantly better results than a GPS-only solution. Processing of nearly twice as much observations in the combined solution leads to the decrease of a ZTD standard deviation by a factor of 1.5 to 2.0. The accuracy with respect to final products improves by 3.7 % to 8.5 %. For IGS stations, the accuracy is 8.0 mm and 6.5 mm with respect to USNO and CODE products, respectively. For European Permanent Network (EPN) stations, the accuracy is 5.4 mm and 5.0 mm with respect to

BKG and MUT solutions, respectively. Finally yet importantly, the spectral analysis of real-time ZTD from GPS-only, Galileo-only and GPS+Galileo solution reveals further advantages of using the combined solution. Whereas single system ZTD products suffer from orbit related artificial signals of high frequency, the combined GPS+Galileo solution suppress such effects. Thus, a combined GPS+Galileo solution is expected to be not only more available over an average day, but the solution itself will be more precise and accurate and is therefore definitely preferable to a GPS-only product when it comes to assimilation of GNSS ZTD in NRT numerical weather models.

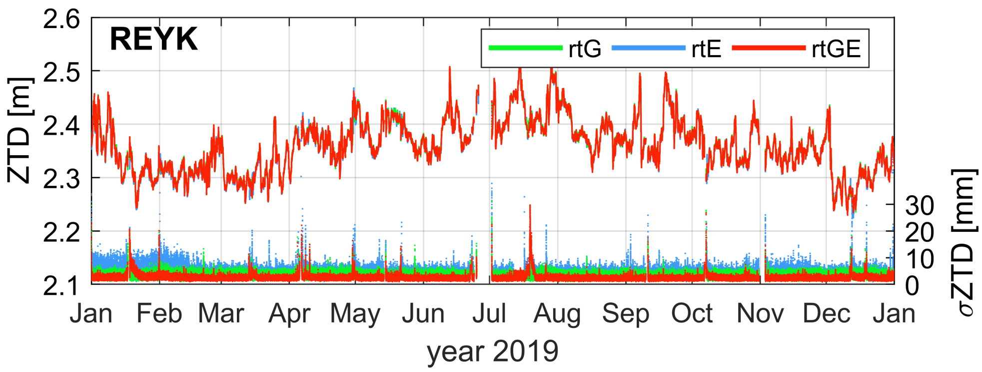
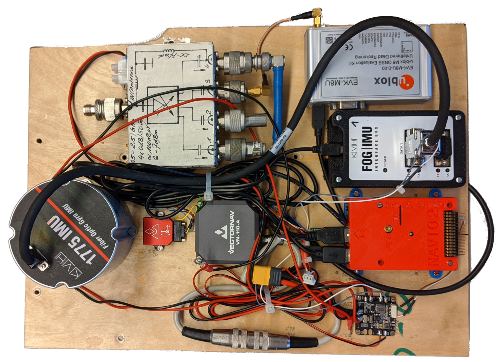


Figure 11: Time series of real-time ZTD for station REYK.

Testfeld eFliegen BW

The INS is one of the institutes of the University of Stuttgart that is building up the “Testfeld für energieeffizientes, elektrisches und autonomes Fliegen” (short: “Testfeld eFliegen BW”) together with partners from industry under the lead of the IfR (www.ifr.uni-stuttgart.de). In the year 2020 the partners founded the association “AREA B.W.” which will manage and operate the project and the two test sites in Mengen and Lahr and represent its members. Furthermore the association provides a framework for usage regulations that apply to the test site and which provide simple access to generic take-off permits.



(a) Platform with the different IMU and GNSS sensors.

(b) Icaré during flight with visible GNSS antenna behind the cockpit.

Figure 12: Research activities of the INS together with other institutes of the University of Stuttgart on the “Testfeld eFliegen BW”

Besides the acquisition of different aeronautic and navigation infrastructure for autonomous flying (see e.g. section ADS-B) which can be used by partners and external parties, which are interested in testing their equipment, first flight test have been performed. In one of these test, the INS equipped the electric solar aircraft Icaré of the IFB (www.ifb.uni-stuttgart.de) with a set of low- and high-grade navigation sensors (see Figure 12). Thus the institute collected data from different IMUs and GNSS sensors for comparison and investigation of reliable, high accuracy sensor fusing algorithms for Urban Air Mobility (UAM) vehicles and autonomous drones.

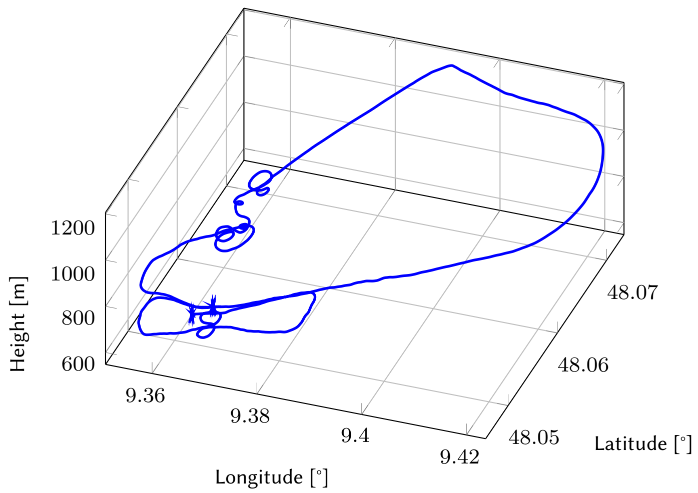


Figure 13: Flight trajectory of one of the performed flights

List of Publications

Klopotek G., T. Hobiger, R. Haas and T. Otsubo, *Geodetic VLBI for precise orbit determination of Earth satellites: a simulation study*, Journal of Geodesy, Vol. 91, Iss. 52, `https://doi.org/10.1007/s00190-020-01381-9`, 2020.

Hadaś T., T. Hobiger and P. Hodryniec, *Considering different recent advancements in GNSS on real-time zenith troposphere estimates*, GPS Solutions, Vol. 24 No. 99, pp. 1-14. `https://doi.org/10.1007/s10291-020-01014-w`, 2020.

Hadaś T. and T. Hobiger, *Benefits of Using Galileo for Real-Time GNSS Meteorology*, IEEE Geoscience and Remote Sensing Letters, pp. 1-5, `https://ieeexplore.ieee.org/document/9141353`, 2020.

Nievinski F., T. Hobiger, R. Haas, W. Liu, J. Strandberg, S. Tabibi, S. Vey, S. Williams and J. Wickert, *SNR-based GNSS reflectometry for coastal sea-level altimetry – Results from the first IAG inter-comparison campaign*, Journal of Geodesy, vol. 94, iss. 70, `https://doi.org/10.1007/s00190-020-01387-3`, 2020.

List of Presentations

Hobiger T., *Navigation of autonomous airplanes*, Geodetic Colloqium at the University of Hannover, Jan. 21, 2020.

Hadaś T. and T. Hobiger, *Contribution of Galileo to real-time GNSS meteorology*, International Workshop on Improving GNSS and SAR Tropospheric Products for Meteorology, Feb. 25-26, 2020.

Teaching and Supervision

The university's regulations due to the COVID-19 pandemic made it necessary to adopt all course content of the summer semester 2020 as well as the winter semester 2020/21 into digital formats. Thus, all lectures had to be filmed and were then provided to the students so that they could attend classes virtually according to their own schedule and pace. Both classroom recordings as well as screencasts with a drawing tablet were provided in order to maximize the learning outcomes, i.e. the specific knowledge, practical skills, areas of professional development, attitudes, or higher-order thinking skills which are expected from students to develop, learn, or master by the end of the particular course. Supervision of bachelor and master thesis projects had to be set into a digital format as well. Some graduate projects which required lab attendance could be organized under consideration of hygiene concepts und special preparations. So, the new software-defined radio LimeSDR funded by the study commission, could be programmed and evaluated in the lab as part of a study about simulation of GNSS jamming attacks. (Figure 14)

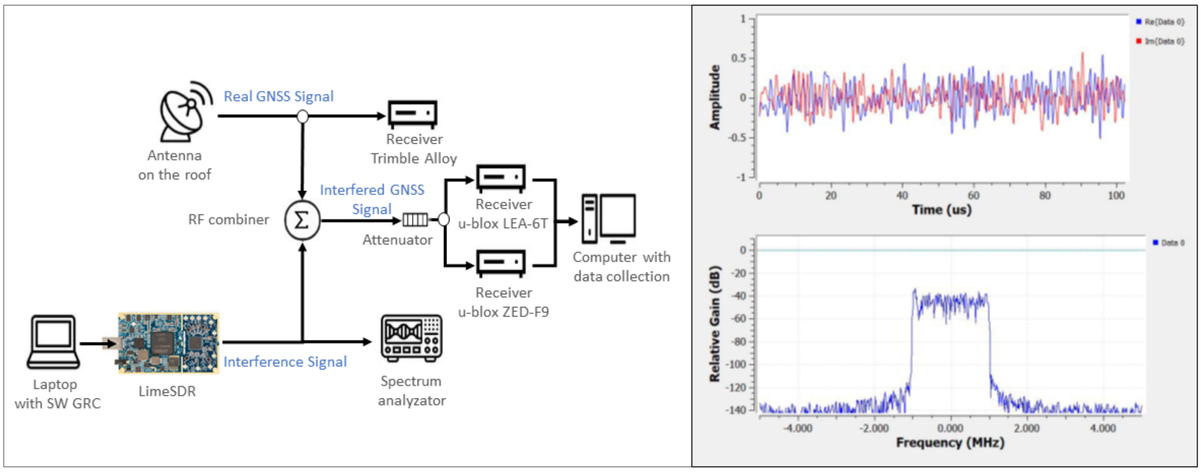


Figure 14: Work flow of the jamming simulation experiment (left) and generated White Gaussian Noise jamming signal (right)

With the purchase of an RC car (Figure 15), remodeling and equipment of GNSS and inertial sensors the institute has now a platform which allows students to test real-time positioning and navigation concepts in different courses and student projects. The RC car has been successfully included into the field work project at the end of the summer semester and one master thesis has been already been completed, dealing with sensor fusion on that platform.

Figure 15: The institute's RC car which has been equipped with electronic for autonomous driving

The following parts of this section list student thesis projects which were completed in 2020 and summarize the teaching activities of the institute.

Bachelor Thesis

- Ernst, Johannes *Robuste Cycle-Slip Detektion bei GNSS Messungen* (Supervisor: T. Lambertus)
- Blei, Torben: *Doppler-bedingte GPS Code Interferenzen* (Supervisor: D. Becker)
- Helfert, Carsten: *Genauigkeitssimulation von Multilaterations-Bodenstationsnetzwerken* (Supervisor: C. Sonnleitner, T. Hobiger)

Master Thesis

- Duan, Yongxu: *Temperature dependency of a low-cost IMU* (Supervisor: C. Sonnleitner, T. Hobiger)
- He, Shengping: *Development of a software-defined ADS-B receiver* (Supervisor: C. Sonnleitner, T. Hobiger)
- Jiang, Zhenbing: *ARAIM – Implementierung eines aktuellen Algorithmus* (Supervisor: D. Becker)
- Jilani, Muhammad Irfan Haider: *Impact of Non-Linearity on IMU/GNSS Sensor Fusion Comparing Different State Estimation Approaches* (Supervisor: T. Hobiger, T. Topp)
- Wei, Yazheng: *Track Verification of Smartphone Users* (Supervisor: T. Hobiger, V. Renaudin (IFSTTAR))
- Xin, Jie: *Analyse der GNSS Integrität mittels Stanford-Diagramm* (Supervisor: D. Becker)
- Yang, Xiaoheng: *Development of a simulator for GNSS jamming attacks* (Supervisor: D. Becker)
- Zhang, Chanjuan: *Accuracy Assessment of Kinematic Precise Point Positioning with Triple GNSS Constellation* (Supervisor: T. Hobiger, M. Naeimi (Bosch))

Lectures offered

Lecture name	BSc /MSc	Person responsible	Lecture (h)	Exercise (h)
Bachelor Geodesy & Geoinformatics:				
Adjustment Theory I	BSc	Hobiger, Lambertus	2	1
Adjustment Theory II	BSc	Hobiger, Lambertus	2	1
Fundamentals of Navigation	BSc	Hobiger, Wang	2	2
Integrated Fieldwork	BSc	Lambertus, Sonnleitner	10 days	
Introduction of Geodesy and Geoinformatic	BSc	Hobiger, Becker	2	2
Measurement Techniques II	BSc	Wehr	2	2
Master Geodesy & Geoinformatics:				
Inertial Navigation	MSc	Hobiger, Sonnleitner	2	1
Integrated Navigation	MSc	Hobiger, Sonnleitner	2	1
Interplanetary Trajectories	MSc	Becker	2	2
Measurement Techniques in Navigation	MSc	Wehr	1	3
Navigation of Air and Surface Vehicles	MSc	Becker	2	1
Parameter Estimation in Dynamic Systems	MSc	Hobiger, Lambertus	2	1
Radar Measurement Methods I	MSc	Braun	1	1
Radar Measurement Methods II	MSc	Braun	1	1
Selected Chapters of Navigation	MSc	Enderle	2	0
Master GeoEngine:				
Dynamic System Estimation	Msc	Hobiger, Lambertus	2	1
Integrated Positioning and Navigation	MSc	Hobiger, Sonnleitner	2	1
Satellite Navigation	MSc	Hobiger, Wang	2	1
Master Aerospace Engineering:				
Inertial Navigation	MSc	Hobiger	2	0
Satellite Navigation	MSc	Hobiger	2	0
Master Electromobility:				
Navigation of Surface Vehicles	MSc	Becker	2	0
Satellite Navigation	MSc	Hobiger	2	0

Activities in National and International Organizations

- Prof. Hobiger
  - Editorial board member “Journal of Geodesy”
  - Editorial board member “Earth, Planets and Space”
  - Editorial board member “Acta Geodaetica et Geophysica”
  - Member of the German Geodetic Commission
  - Corresponding member of the Austrian Geodetic Commission
  - Fellow of the International Association of the Geodesy
  - Member of the Institute of Navigation
  - Member of the Royal Institute of Navigation
  - Member of the German Institute of Navigation
  - Member of the American Geophysical Union
- Prof. Kleusberg
  - Fellow of the International Association of the Geodesy
  - Member of the Institute of Navigation
  - Member of the Royal Institute of Navigation
  - Member of the German Institute of Navigation
- Mr. Gauger
  - Member of VDI/DIN KRdL working group on Deposition parameters [NA 134-02-01-08 UA]
  - Member of ICP Forests
  - Member / Guest scientist of Bund-Länder-Fachgespäch Stickstoffdeposition (FGN)
  - Member of StickstoffBW, AG1 Deposition