Commission 4 - Positioning and Applications

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President: Paweł Wielgosz (Poland)
Vice President: Xingxing Li (China)

Commission 4 website - www.com4.iag-aig.org

1 Terms of Reference

IAG Commission 4 is dedicated to uniting scientists, researchers, and professionals across the expansive field of Positioning, Navigation, Timing (PNT), and their various applications. To this end, it commits to fostering research that harnesses both current and evolving positioning methods and technologies, aiming to offer theoretical and practical advancements in positioning technologies, multi-frequency and multi-constellation Global Navigation Satellite Systems (GNSS), positioning integrity and quality assurance, GNSS alternatives and backups, sensor integration, atmospheric remote sensing and modeling, as well as innovative engineering geodesy technologies and applications derived from geodetic methods. Commission 4 will execute its mission closely with the IAG Components and Services and through connections with entities across scientific and professional organizations.

With the pivotal role of GNSS in meeting today's and future positioning needs in mind, Commission 4 will prioritize research that refines models and methodologies to improve and secure GNSS-based positioning performances for a broadening range of end-user applications. It recognizes the growing threats and vulnerabilities to GNSS-only positioning systems and seeks to explore technologies and strategies to counteract these challenges. The Sub-Commissions are tasked with developing theories, strategies, and tools for modeling or mitigating interference, signal disruptions, and atmospheric disturbances relevant to precise GNSS positioning technologies. They will tackle both technical and institutional challenges essential for establishing GNSS alternatives, integrated PNT solutions, automated processing capabilities, and quality assurance protocols. Moreover, Commission 4 will explore geodetic remote sensing through the use of Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR), and Satellite Altimetry (SA) for geodetic and engineering purposes.

Commission 4, at the start of the new period, consists of four Sub-Commissions (SCs) with their Working Groups (WGs), plus one Joint Study Group (JSG) and three Joint Working Groups (JWG), all of them jointly with other Commissions and/or services. Additional WGs and Study Groups (SGs) can be established as needed, and existing ones may be dissolved should they become inactive.

1.1 Objectives

The main objectives of Commission 4 are as listed in the IAG Bylaws:

- Terrestrial and satellite-based positioning systems development, including sensor and information fusion
- Navigation and guidance of platforms
- Interferometric laser and radar applications
- Applications of geodetic positioning using three-dimensional geodetic networks, including monitoring of deformations
- Applications of geodesy to engineering
- Atmospheric investigations using space geodetic techniques

1.2 Program of Activities

Commision 4 “Positioning and Applications” fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing Symposia, either independently or at major conferences in geodesy. The activities of its sub-entities, as described below, constitute the activities of the Commission, which will be coordinated and summarized in annual reports to the IAG Bureau.

The status of Commission 4, with links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the web site: https://com4.iag-aig.org/.

1.3 Structure

Sub-Commissions

SC 4.1 Emerging Positioning Technologies and GNSS Augmentation
Chair: Heidi Kuusniemi (Finland)
SC 4.2 Multi-frequency Multi-constellation GNSS
Chair: Jianghui Geng (China)
SC 4.3 Atmosphere Remote Sensing
Chair: Ningbo Wang (China)
SC 4.4 Engineering Geodesy
Chair: Janis Kaminskis (Latvia)

Working Groups

WG 4.1.1 Integrity Monitoring of Collaborative Positioning
Chair: Liang Li (China)
WG 4.1.2 Upcoming GNSS services for accuracy, reliability and resilience
Chair: Paolo Zoccarato (Italy)
WG 4.1.3 LEO-PNT Systems
Chair: Fabricio S. Prol (Finland)
WG 4.1.4 Low-Cost GNSS receiver systems
Chair: Dinesh Manandhar (Japan)
WG 4.1.5 Wireless positioning with terrestrial instruments
Chair: Andrea Masiero (Italy)
WG 4.1.6 Smart Wearable Positioning
Chair: You Li (China)

WG 4.2.1 Precise GNSS time and frequency transfer
Chair: Jiang Guo (Belgium)
WG 4.2.2 Advances and unification of PPP-AR
Chair: Marcus Franz Wareyka-Glaner (Austria)
WG 4.2.3 Mass-market high-precision GNSS and applications
Chair: Guangcai Li (China)
WG 4.2.4 Quality Control and Integrity Monitoring of Precise Positioning
Chair: Krzysztof Nowel (Poland)
WG 4.2.5 Multi-GNSS for Natural Hazards and Disaster Resiliency
Chair: Xiaoming Wang (China)
WG 4.3.2 Ionospheric state predictions and early warnings for space weather services
Chair: Murat Durmaz (Türkiye)
WG 4.3.3 Analysis and prediction of ionospheric scintillations
Chair: Dmytro Vasylyev (Germany)
WG 4.3.4 Indices for characterizing ionospheric perturbations
Chair: Grzegorz Nykiel (Poland)
WG 4.3.5 Ionosphere and space weather monitoring using ground and spaceborne GNSS
Chair: Zhe (Jenny)Yang (China)
WG 4.3.8 Troposphere Modeling and Monitoring
Chair: Cuixian Lu (China)
WG 4.3.9 Observing convective and volcanic clouds with geodetic remote sensing techniques
Chair: Hugues Brenot (Belgium)
WG 4.3.10 Remote sensing using GNSS reflected signals
Chair: Milad Asgarimehr (Germany)
WG 4.4.1 Novel GNSS applications in engineering geodesy
Chair: Junbo Shi (China)
WG 4.4.2 InSAR engineering geodesy for infrastructure health monitoring
Chair: Liming Jiang (China)
WG 4.4.3 Multisensor Displacement and Deformation Monitoring
Chair: Maya Ilieva (Bulgaria)
WG 4.4.4 TLS and LiDAR Scanning for Building Information Modelling (BIM) Services
Chair: Janina Zaczek-Peplinska (Poland)

Joint Working Groups

JWG 4.3.1 Real-time ionosphere monitoring and modeling
(joint with IGS and GGOS)
Chair: Zishen Li (China)
JWG 4.3.6 Validation of ionospheric models for positioning applications
(joint with IGS)
Chair: Anna Krypiak-Gregorczyk (Poland)
JWG 4.3.7 Machine learning for the atmosphere
(joint with GGOS)
Chair: Yury Yasyukevich (Russia)

Joint Study Groups

JSG 4.1.7 Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)
(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)

1.4 Steering Committee

- President Commission 4: Paweł Wielgosz (Poland)
- Vice President Comm. 4: Xingxing Li (China)
- Chair Sub-Comm. 4.1: Heidi Kuusniemi (Finland)
- Chair Sub-Comm. 4.2: Jianghui Geng (China)
- Chair Sub-Comm. 4.3: Ningbo Wang (China)
- Chair Sub-Comm. 4.4: Janis Kaminskis (Latvia)
- ICCM representative: Kaifei He (China)
- Member-at-Large: Safoora Zaminpardaz (Australia)
- Member-at-Large: Daniele Barroca Marra Alves (Brazil)
- ISPRS representative: Charles Toth (USA)
- FIG representative: Allison Kealy (Australia)
- ION representative: Dorota Grejner-Brzezinska(USA)
- Representative of Early Career Scientists: Artur Fischer (Poland)

1.5 Overview of Working Groups and Study Groups

Groups related to SC 4.1

WG 4.1.1 Integrity Monitoring of Collaborative Positioning
Chair: Liang Li (China)
WG 4.1.2 Upcoming GNSS services for accuracy, reliability and resilience
Chair: Paolo Zoccarato (Italy)
WG 4.1.3 LEO-PNT Systems
Chair: Fabricio S. Prol (Finland)
WG 4.1.4 Low-Cost GNSS receiver systems
Chair: Dinesh Manandhar (Japan)
WG 4.1.5 Wireless positioning with terrestrial instruments
Chair: Andrea Masiero (Italy)
WG 4.1.6 Smart Wearable Positioning
Chair: You Li (China)
JSG 4.1.7 Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)
(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)

Groups related to SC 4.2

WG 4.2.1 Precise GNSS time and frequency transfer
Chair: Jiang Guo (Belgium)
WG 4.2.2 Advances and unification of PPP-AR
Chair: Marcus Franz Wareyka-Glaner (Austria)
WG 4.2.3 Mass-market high-precision GNSS and applications
Chair: Guangcai Li (China)
WG 4.2.4 Quality Control and Integrity Monitoring of Precise Positioning
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WG 4.2.5 Multi-GNSS for Natural Hazards and Disaster Resiliency
Chair: Xiaoming Wang (China)

Groups related to SC 4.3

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Chair: Hugues Brenot (Belgium)

WG 4.3.10 Remote sensing using GNSS reflected signals
Chair: Milad Asgarimehr (Germany)

Groups related to SC 4.4

WG 4.4.1 Novel GNSS applications in engineering geodesy
Chair: Junbo Shi (China)

WG 4.4.2 InSAR engineering geodesy for infrastructure health monitoring
Chair: Liming Jiang (China)

WG 4.4.3 Multisensor Displacement and Deformation Monitoring
Chair: Maya Ilieva (Bulgaria)

WG 4.4.4 TLS and LiDAR Scanning for Building Information Modelling (BIM) Services
Chair: Janina Zaczek-Peplinska (Poland)

2 Sub-Commisions, Working Groups and Study Groups

SC 4.1: Emerging Positioning Technologies and GNSS Augmentation

Chair: Heidi Kuusniemi (Finland)
Vice-Chair: Fabricio S. Prol (Finland)

Terms of Reference

Emerging technologies in positioning and applications play a crucial role in addressing location determination limitations and enhancing the capabilities beyond traditional solutions like standalone GNSS. Urban environments and indoor navigation, where GNSS signals may be weak, unreliable or unattainable, need to utilize a variety of location information solutions, for example in the context of Augmented Reality (AR), Indoor Positioning Systems (IPS), and Computer Vision (CV) within buildings or densely populated urban areas. Autonomous vehicles and systems require high-precision and real-time navigation information for safe operation via harnessing technologies such as LiDAR, Radar, 5G, inertial systems, V2X communication and sensor fusion approaches complementing GNSS for accurate and resilient positioning. The work of this Sub-Commission focuses on the benefits of various emerging positioning technologies extending to improved safety, efficiency, security, and overall advancements in society, industry, and geodesy.

Objectives

- Development of new techniques for positioning;
- Analyzing the integrity levels of PPP and PPP-RTK for collaborative positioning;
- Enhancing PPP for real-time applications;
- Providing perspectives of how the positioning and augmentation technologies should develop utilizing, e.g., LEO systems;
- Advancing solutions for low-cost receivers as well as smart wearable systems;
- Exploring the future opportunities of quantum navigation.

Program of Activities

- Promote international collaboration to advance emerging positioning solutions.
- Organize and/or participate in scientific events (workshops, conferences, seminars etc.)
- Organize special issues on the emerging technologies for positioning.
- Increase cooperation with international organizations, such as Institute of Navigation (ION), International Federation of Surveyors (FIG), Nordic Institute of Navigation (NNF), Nordic Geodetic Commission (NKG), and the United Nations (UN).

WG 4.1.1: Integrity Monitoring of Collaborative Positioning

Chair: Liang Li (China)
Vice-Chair: Liang Wang (China)

Terms of Reference

With the rapid development of automatic and intelligent transportation, the collaborative positioning become increasingly indispensable to provide high-precision and credible positioning information. This WG mainly focuses on the integrity monitoring structure design, algorithms development for the signal, information, data processing and critical nodes of collaborative positioning. The PPP/PPP-AR/PPP-RTK will be one of critical components of collaborative positioning. The accurate integrity of multiple risks of collaborative positioning requires to be estimated, evaluated, and validated. The integrity risk resources include the high accuracy correction products generated from service providers, the user terminal based on multi-sensor system, and the communication link between the cloud and the user.

Objectives

- Develop integrity monitoring algorithms and software for PPP/PPP-AR/PPP-RTK correction products including the satellite orbit, clock, code/phase bias corrections, and atmospheric corrections.
- Integrity monitoring of GNSS/INS integrated navigation based on multiple hypothesis solution separation.
- Development of autonomous integrity monitoring methods for multi-sensor integrated navigation under different collaborative modes.
- Data processing and statistical evaluation of integrity risk parameters like the priori fault probability.
- Integrity risk allocation framework construction among multiple potential risks which results in collaborative positioning failure.
- Integrity risk estimation, evaluation, and validation of collaborative positioning.
- Investigate the integrity of collaborative positioning for the liability-critical applications, including autonomous vehicles and precision ocean engineering.

Members

Liang Li (China); Chair
Liang Wang (China); Vice-Chair
Yiping Jiang (China-Hong Kong)
Yang Gao (Canada)
Fuxin Yang (China)
Kazuma Gunning (USA)
Chun Jia (China)
Mathieu Joerger (USA)
Liuqi Wang (China)
Mingqiang Xie (China)
Zhen Lyu (China)
Xin Li (China)

WG 4.1.2: Upcoming GNSS services for accuracy, reliability and resilience

Chair: Paolo Zoccarato (Italy)

Terms of Reference

By integrating advanced facilities and data processing directly into the system architecture, GNSS is starting to offer freely-available firsthand services to sustain user needs on accuracy, reliability and resilience in navigation. Examples of these services are the Galileo High Accuracy Service (HAS), in its initial phase since 24th January 2023, or the Galileo Open Service Navigation Message Authentication (OSNMA). These services, anticipating fundamental technological advancements in GNSS signals and infrastructures, are extending not only the consolidated GNSS capabilities but also the perimeter of the system support, providing reference algorithms, guidelines, and standards to be implemented by the users to achieve the service goals. This WG focuses on research targeting the adoption of these emerging real-time GNSS services to support geodetic applications, survey and monitoring (e.g. earthquake and tsunami events). The investigation aims to improve the performance and resilience of GNSS-based Position Navigation and Timing (PNT) solutions by extending algorithms and technologies and integrating alternative systems with the emerging GNSS services.

Objectives

- Promote algorithms, technologies and alternative systems for PNT to be integrated with the emerging GNSS services for improving performance and resilience in geodetic applications and monitoring.
- Identify geodesy applications in need of the emerging GNSS services and develop methodologies for their utilization (e.g. catastrophes/atmosphere/tsunami monitoring, Earth dynamics, climate change analysis).
- Propose recommendations for future developers and users of emerging GNSS services in geodetic applications.
- Evaluate and extend established real-time methodologies for PNT enhanced by emerging GNSS services to achieve accurate and reliable (including integrity of message) PNT solutions.
- Explore limitations on the guidelines and standards about the utilization of the emerging GNSS services and collect feedback, requests and ideas to be provided to the GNSS services for better sustaining/fitting the user needs in geodesy applications.
- Establish open processing campaigns and dataset sharing for testing and comparison of the identified solutions and dissemination of the results through the IAG community.

Members

Paolo Zoccarato (Italy); Chair
Ignacio Fernandez Hernandez (Spain)

Gianluca Caparra (Italy)
Sophie Damy (France)
Beatrice Mottella (Italy)
Nicola Laurenti (Italy)
Dimitrios Psychas (Greece)
Francesco Darugna (Italy)
Patrick Henkel (Germany)
Lotfi Massarweh (Netherlands)
André Hauschild (Germany)
Adria Rovira (Spain)
Urs Hugentobler (Germany)
Mirko Reguzzoni (Italy)

WG 4.1.3: LEO-PNT Systems

Chair: Fabricio S. Prol (Finland)
Vice-Chair: Elena Simona Lohan (Finland)

Terms of Reference

Given the current interest in deploying multiple satellites within low Earth orbit (LEO), the time is opportune to understand the advantageous implications of LEO-PNT missions for Geodesy. This WG is focused on understanding the possible enhancements that LEO-PNT systems can provide for navigation solutions when compared to classic GNSS systems. We aim to understand the contributions of communication, augmentation, and dedicated LEO satellite systems for PNT. To this end, new methods, instrumentation, and data analysis will be developed.

Objectives

- Advance instrumentation to collect data and perform PNT through LEO satellites;
- Development of algorithms to enable PNT solution based on current and upcoming LEO satellite missions;
- Explore limitations of the LEO-PNT systems and possible enhancements in comparison to GNSS;
- Propose recommendations for future developments in the field.

Members

Fabricio S. Prol (Finland); Chair
Elena Simona Lohan (Finland); Vice-Chair
Francesco Menzione (Italy)
Heidi-Kuusniemi (Finland)
Miguel Cordero Limon (Netherlands)
Lotfi Massarweh (Netherlands)
Jindrich Dunik (Czech Republic)
Mayank Mayank (Finland)
Miquel Garcia Fernandez (Spain)

WG 4.1.4: Low-Cost GNSS receiver systems

Chair: Dinesh Manandhar (Japan)
Vice-Chair: Bruno Nava (Italy)

Terms of Reference

This WG will focus on low-cost GNSS receiver systems for high-accuracy PNT and associated applications. We target receiver systems with cost of a few hundred dollars, which include all necessary components and are easy to use in the field without requiring expert knowledge. This type of system will further enhance capacity building, deployment of base-station, and new application development at a large scale. The team will collaborate closely with the United Nations Office for Outer Space Affairs (UNOOSA).

Objectives

- Explore different types of receivers, antennae, data processing devices, software, and other necessary tools for high-accuracy PNT and associated applications for GNSS augmentation, such as space weather (TEC, S4 computation), EWS (Early Warning System) message, and signal authentication;
- Design and develop prototype receiver systems for base-station and rover units;
- Evaluate existing software and customize for low-cost receiver system;
- Promote the discussion of the future perspectives of low-cost receiver developments.

Members

Dinesh Manandhar (Japan); Chair
Bruno Nava (Italy); Vice-Chair
Sharafat Gadimova (Austria)
Alison Moraes (Brazil)
Andrzej Krankowski (Poland)
Anindya Bose (India)
Kaito Kobayashi (Japan)
Avinab Malla (Nepal)
Eugenio Realini (Italy)
Ayman Mahrous (Egypt-Japan)
Jorge Del Rio Vera (Austria)
Roberto Capua (Italia)
Ayoub Ben-Adim (Morocco)

WG 4.1.5: Wireless positioning with terrestrial instruments

Chair: Andrea Masiero (Italy)
Vice-Chair: Kai-Wei Chiang (China-Taipei)

Terms of Reference

PNT systems had a remarkable impact on a number of applications, including a visible influence on the everyday life of most of the World population and causing an increasing interest in location based services (LBSs). Most of the PNT systems currently available on the market are satellite-based: they do exploit GNSS in order to assess their own position and to synchronize on a common time. Nevertheless, the usability of GNSS-based systems for accurate positioning is currently mostly limited to open-sky scenarios, whereas the performance of such systems dramatically decreases indoors, in urban canyons, and in the other GNSS-denied environments. Extending accurate localization to scenarios challenging for GNSS typically implies the use of additional sensors, including inertial ones, radio-based, cameras, LiDAR. The goal of this WG is to investigate the contribution of radio-based positioning with terrestrial instruments in applications where GNSS is not available or not reliable, including outdoor-to-indoor (and vice versa) transitions. Such investigation aims at exploiting in particular the interconnection between smart devices, which, also thanks to the spread of technologies such as 5G, is expected to become increasingly common for most of the devices provided with positioning tools available in the market in the near future. WiFi solution will take advantage of the RTT (round-trip-time) measurements, recently available on several devices on the market. In addition to WiFi, the WG will investigate the use of radio transceivers in general, such as Bluetooth and UWB, as standalone or integrated solutions, involving for instance also vision and LiDAR. The goal is to improve the overall positioning performance of the system, focusing on the potential of device interconnection, leading to collaborative solutions, which can be particularly useful to enable positioning in devices working in critical conditions (e.g. not fully provided of sensors, and/or when the radio-based positioning system is associated to a low density infrastructure of anchors of known position). In such investigation several navigation platforms will be considered, including smartphones, drones and ground vehicles.

Objectives

- Development of algorithms for positioning based of WiFi, focusing in particular on the evaluation of RTT-based solutions;
- Development of algorithms for positioning with radio-based solutions, exploiting sensors currently mounted on smart devices such as WiFi, Bluetooth, UWB;
- Explore collaborative positioning strategies, reporting on the selection of best algorithms in terms of performance and to ensure scalability of the proposed approach;
- Assessment of the performance of WiFi and other radio-based methods once integrated with other sensors;
- Establishing links between this WG and other IAG, FIG and ISPRS WGs addressing the positioning problem with alternative sensors with respect to GNSS.

Members

Andrea Masiero (Italy); Chair
Kai-Wei Chiang (China-Taipei); Vice-Chair

Charles Toth (USA)
Vassilis Gikas (Greece)
Harris Perakis (Greece)
Salil Goel (India)
Jelena Gabela (Austria)
Paolo Dabove (Italy)
Vincenzo Di Pietra (Italy)
Wioleta Blaszczak-Bak (Poland)
Czeslaw Suchocki (Poland)

WG 4.1.6: Smart Wearable Positioning

Chair: You Li (China)
Vice-Chair: Baoding Zhou (China)

Terms of Reference

Smart wearable devices have been applied in Earth observation, smart cities, internet-of-things (IoT), mobile healthcare, public security, augmented reality/virtual reality, and other fields. They have become important platforms for human-computer interaction, environmental perception, life, and entertainment. Based on the integrated sign, movement, computing, communication, and other sensor chips in wearable devices, it is expected to greatly expand human perception and cognitive ability, accurately locate and perceive personalized and unstructured data of different users, coordinate the relationship between people and the environment, and even change the lifestyle of modern people. The popularity of wearable platforms also brings new opportunities and challenges for the realization of intelligent, ubiquitous navigation and space-time services.

Objectives

- Scalable and intelligent wearable positioning and motion-tracking sensors, algorithms, and systems;
- Smart human-computer interaction and human-in-the-loop motion and environmental perception;
- Self-improving and adaptive wearable navigation systems;
- The combination of intelligent wearable devices, artificial intelligence and robots;
- Geo-centric cloud/edge computing with wearable data;
- Wearable motion sensing for the smart city, smart home and smart transportation;
- Application of smart wearable motion sensing in IoT, mobile healthcare, public security, AR/VR, and other fields;
- Precise positioning and mobile mapping with sensors in capsule robots.

Members

You Li (China); Chair
Baoding Zhou (China); Vice-Chair

Xin Xia (USA)
Wei Liu (USA)
Yiran Luo (Canada)
Fuqiang Gu (China)
Weisong Wen (China-Hong Kong)
Zengke Li (China)
Chi Chen (China)
Shengjun Tang (China)
Jianping Li (Singapore)
Zhouzheng Gao (China)
Bing Wang (China-Hong Kong)

JSG 4.1.7: Evaluating the Potential of Next Generation Quantum Sensors for Positioning, Navigation, and Timing (PNT)

(joint with QuGe and FIG)
Chair: Allison Kealy (Australia)
Vice-Chair: Jelena Gabela (Austria)

Terms of Reference

PNT stands as an essential utility of modern society, spanning across sectors such as defense, disaster management, finance, telecommunications, agriculture, and energy. The precise determination of absolute location, a cornerstone of PNT, traditionally relies on GNSS and their timing signals. However, a paradigm shift is underway, powered by compact quantum sensors. Leveraging the principles of quantum physics, these sensors encompass a wide range of functionalities, including ultra-precise atomic clocks, accelerometers, gyroscopes, magnetometers, and gravitometers. Their emergence heralds a transformative era in PNT, promising unparalleled precision and resilience, particularly in GNSS-denied environments. This imminent revolution necessitates a comprehensive exploration of quantum sensors' capabilities and their potential impact on PNT.

Objectives

- Quantum Sensor Assessment: Conduct a thorough evaluation of the performance, precision, and resilience of next-generation quantum sensors, dissecting their individual capabilities, limitations, and real-world applications.
- Quantum Sensors in GNSS-Challenged Environments: Investigate the suitability and robustness of quantum sensors for PNT applications in GNSS-deprived or compromised environments, addressing the challenges of signal degradation and signal loss.
- Interplay of Quantum Sensing Technologies: Explore the interplay and synergy among different quantum sensing technologies, such as atomic clocks, accelerometers, gyroscopes, magnetometers, and gravitometers, elucidating their combined potential for enhancing PNT.

- Recent Advances in Quantum Sensing: Analyze recent advancements in quantum sensor development, providing insights into cutting-edge research, technological breakthroughs, and potential cross-disciplinary applications.
- Anticipating Future Quantum Sensor Developments: Predict and anticipate future developments in quantum sensor technology, assessing their potential impact on PNT and emerging use cases, including quantum communication and quantum computing.
- Integration Strategies: Develop strategies and recommendations for the seamless integration of next-generation quantum sensors into existing and evolving PNT infrastructures, considering compatibility, inter-operability, and standards.
- Technical Report and Knowledge Dissemination: Summarize research findings, recommendations, and best practices in a comprehensive technical report, facilitating knowledge dissemination within the scientific and engineering communities.
- Scientific Publications: Explore opportunities for scientific publications to share research outcomes and insights with a broader scientific audience, contributing to the advancement of quantum sensor technology and its applications.

SC 4.2: Multi-frequency Multi-constellation GNSS

Chair: Jianghui Geng (China)
Vice-Chair: Panagiotis Psimoulis (UK)
Secretary: Kunlun Zhang (China)

Terms of Reference

The GNSS has witnessed rapid development in recent years, providing increasingly refined PNT services worldwide. The construction of multi-constellations and the utilization of multi-frequency have expanded the spatial coverage, catering to the diverse application requirements across various scenarios and levels. These applications encompass autonomous driving, instantaneous high-precision positioning, precise time and frequency transfer, as well as meteorological disaster monitoring and early warning, highlighting the immense potential of GNSS. Furthermore, GNSS chips integrated into consumer devices are progressively supporting multi-system and multi-frequency carrier phase observations, presenting extensive prospects for application.

However, these advancements have also introduced new technological challenges. For instance, GNSS positioning performance is vulnerable to fragility, the issue of ambiguity resolution remains persistently challenging, and consumer device data often suffers from significant degradation. SC 4.2 aims to facilitate research activities and focuses on addressing multi-level application issues, including high-precision global time and frequency transfer, valid and reliable ambiguity resolution, high-accuracy positioning in consumer devices, and precise monitoring of meteorological disasters. SC 4.2 will coordinate various activities to provide both theoretical and practical solutions for engineering and scientific applications, thereby bridging the gaps in the application domain.

Objectives

The main objective of SC 4.2 is to facilitate collaborative research on innovative and diverse applications within the evolving landscape of GNSS, characterized by multiple systems and frequencies. It aims to promote the dissemination and translation of scientific research accomplishments and foster close cooperation among researchers, international organizations, and industry stakeholders.

Program of Activities

- Identify and investigate theoretical, methodological, and technological issues arising from the development of multi-constellation and multi-frequency systems;
- Promote and facilitate close collaboration among researchers, fostering knowledge exchange and cooperation;
- Organize international conferences and workshops to provide platforms for sharing research findings and advancements;
- Promote interdisciplinary scientific research and encourage the application of engineering solutions in various domains.

WG 4.2.1: Precise GNSS time and frequency transfer

Chair: Jiang Guo (Belgium)
Vice-Chair: Giulio Tagliaferro (France)

Terms of Reference

In the realm of precise time transfer, GNSS has played a pivotal role, enabling synchronization across the globe with remarkable accuracy. The commonly employed methods such as Common-View (CV)and Two-Way Time Transfer (TWTT) have been instrumental in achieving this, yet they come with certain limitations. CV and TWTT have significantly contributed to global time transfer, primarily by utilizing shared satellite observations. However, they heavily rely on a limited set of common-view satellites, which restricts their applicability in wide regions with obstructed satellite visibility.

Precise Point Positioning Ambiguity Resolution (PPP-AR) holds the key to independent global time transfer, free from the constraints of common-view satellites. By resolving ambiguities in GNSS signals, we empower precise time transfer without the need for synchronized satellite observations. This breakthrough enables us to disseminate time information seamlessly across the world, enhancing the accessibility and accuracy of time transfer. This WG will mainly work on the technique details of PPP-AR; it is dedicated to verifying the effects of related GNSS error sources to PPP-AR time and frequency transfer.

Objectives

- Combining multi-constellation GNSS (GPS/GLONASS/Galileo/BDS-3) as well as multi-frequency signals (L5/E6/B1C/B2a) for PPP-AR time /frequency transfer. To harness their combined capabilities to improve the reliability and availability of time transfer service.
- Decreasing the effects of multipath errors on short- and medium-term (tens of minutes to several hours) frequency stability by generating multipath mitigating or correcting products.
- Mitigating the long-term (more than one day) frequency stability limitations inherent in GNSS-based time and frequency transfer. Analyse the factors that are deteriorating the long-term stability of GNSS time links from the aspects of the error of precise satellite orbit and clock products, troposphere delay and the receiver-end phase hardware bias.
- Working for the method to precisely align the integer daily boundaries between the time links of two adjacent days originating from the discontinuities of satellite clock products. Most importantly, trying to mitigate the fractional day boundaries which cannot be aligned directly like integer ones.

Members

Jiang Guo (Belgium); Chair
Giulio Tagliaferro (France); Vice-Chair
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Elisa Pinat (Belgium)
Bin Jian (Canada)
Xiaolong Mi (China)
Ahmed Elmaghraby (Germany)

WG 4.2.2: Advances and unification of PPP-AR

Chair: Marcus Franz Wareyka-Glaner (Austria)
Vice-Chair: Tomasz Hadaś (Poland)

Terms of Reference

GNSS enable a worldwide positioning and navigation service independent of time, location, and weather. Nowadays, multiple GNSS transmit various signals on 3+ frequencies, enabling innovative developments and techniques. Over the past decades, the principle of Precise Point Positioning (PPP) has proven itself as a substantial GNSS method. PPP is an absolute positioning method using complex observation models and relying on precise satellite orbits, clocks, and biases. Various analysis centers and agencies publicly provide such satellite products in real-time and post-processing with slightly different computation strategies. This circumstance provides some challenges for the PPP user because consistency is essential.

Nowadays, multiple PPP software packages, mostly publicly available, offer innovative approaches. Discussing and linking these advantages should benefit the whole PPP community. Typically, PPP achieves accuracies similar to relative positioning methods like Real-Time Kinematic (RTK) and offers several benefits in comparison (e.g., global corrections). However, the convergence time of PPP is still an issue limiting its application in real-time and time-critical applications. It must be reduced to way below one minute ("instantaneous convergence") to make PPP completely competitive with relative positioning methods. PPP with integer ambiguity fixing (PPP-AR) has proven to effectively reduce or even eliminate the convergence time. In particular, approaches besides the ionosphere-free linear combination based on 2+ frequencies are currently heavily investigated. Fully utilizing all current GNSS constellations and their signals on 3+ frequencies for PPP and ambiguity resolution is an ongoing topic.

Objectives

- To discuss effective methods for reducing the convergence time of PPP;
- To give a recommendation for defining PPP convergence and coordinate accuracy;
- To create an overview and comparison of satellite products and software packages enabling PPP-AR;
- To define test cases to compare different PPP algorithms and software packages;
- To disseminate the major findings through journal papers and conference proceedings.

Members

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Berkay Bahadur (Türkiye)
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Yuanxin Pan (Switzerland)
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WG 4.2.3: Mass-market high-precision GNSS and applications

Chair: Guangcai Li (China)
Vice-Chair: Himanshu Sharma (Germany)

Terms of Reference

Mass-market GNSS chips embedded into consumer devices, such as smartphones, now offer broad support for multi-frequency and multi-constellation high-precision carrier phase observations. This advancement is opening up opportunities for them to be effectively utilized in high-precision positioning applications. Since Google announced the availability of GNSS raw measurements in the Android N operating system in 2016, there has been a proliferation of research on mass-market GNSS signal quality, positioning algorithms and applications. This emerging trend gives a glimpse of the potential for centimeter positioning using mass-market GNSS data. The achievement of such high-precision positioning will significantly improve the user navigation experience and facilitate the emergence of new location-based applications such as assisted driving and semi-professional tasks, and even become a favorable complement to geodetic grade receivers in geosciences applications. Nonetheless, attaining precise positioning in mass-market GNSS devices like smartphones remains a substantial challenge. These obstacles encompass severe multipath errors, frequent cycle slips, emerging phase biases, unknown antenna phase center offsets and variations, among others. Consequently, this WG is committed to confronting these issues and delving into their prospective applications in navigation, positioning, and selected geosciences fields.

Objectives

- To perform a thorough assessment of the quality of mass-market/smartphone GNSS signals, and identify and investigate anomalies present in the observation data;

- To develop innovative methods and techniques for mass-market/smartphone GNSS multipath mitigation;
- To estimate and calibrate the Phase Center Offset (PCO) and Phase Center Variation (PCV) parameters of mass-market/smartphone GNSS antennas;
- To devise robust ambiguity resolution methods and verification techniques tailored to the challenges posed by mass-market/smartphone GNSS data;
- To explore and implement the integration of mass-market GNSS data with inertial and visual sensors to enhance the availability and reliability of positioning solutions;
- To investigate and unlock the potential of mass-market GNSS applications across various domains, including navigation, positioning, meteorology and geological disaster monitoring.

Members

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Paolo Dabove (Italy)
Francesco Darugna (Germany)
Anja Hesselbarth (Germany)
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Martin Hakansson (Sweden)
Roland Hohensinn (Switzerland)
Zhetao Zhang (China)
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WG 4.2.4: Quality Control and Integrity Monitoring of Precise Positioning

Chair: Krzysztof Nowel (Poland)
Vice-Chair: Ahmed El-Mowafy (Australia)

Terms of Reference

GNSS are the prime source of precise position information for a variety of applications including intelligent transport systems, autonomous driving, precision agriculture, civil aviation drones, marine and deformation monitoring. For such applications, the position information needs to be highly reliable; even small errors may have serious consequences like the loss of human lives, liability, and damage to infrastructure.

Any positioning platform, either based on standalone- or augmented-GNSS, is subject to a series of vulnerabilities, e.g. signal faults, interference, satellite orbital and clock biases, carrier phase cycle slips and wrong integer ambiguity resolution. All these can dramatically deteriorate the reliability and disruption of the positioning and timing solutions. As such, it is crucial to have proper quality control mechanisms in place for the timely detection of hazardous threats and faults. In addition, monitoring the integrity of the system is an essential part of this quality control procedure, to ensure that the resulting positioning errors are bounded by protection levels that are determined according to the application's allowable risk probability.

The components of a quality control and integrity monitoring procedure will vary depending on the positioning sensors in use, the positioning method, and the performance requirements. This will in turn raise the need for thorough research into factors contributing to the quality of a positioning platform as well as their interactions, so as to enable the development of optimal application-dependent quality control and integrity monitoring procedures.

Objectives

- To derive optimal statistical testing regimes, capable of detection and exclusion of multiple alternative fault hypotheses using the underlying positioning models;
- To develop integrity monitoring algorithms for precise positioning methods using carrier phase measurements such as RTK and PPP;
- To consider new elements in integrity monitoring of the augmented-GNSS positioning, for example, the involvement of LEO satellites;
- To disseminate the developed algorithms and numerical results through journal papers and conference proceedings.

Members

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Kan Wang (China)
Amir Khodabandeh (Australia)
Nobuaki Kobu (Japan)
Ivandro Klein (Brazil)
Ling Yang (China)
Artur Fischer (Poland)
Anja Hesselbarth (Germany)
Safoora Zaminpardaz (Australia)
Sandra Verhagen (Netherlands)
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WG 4.2.5: Multi-GNSS for Natural Hazards and Disaster Resiliency

Chair: Xiaoming Wang (China)
Vice-Chair: Haobo Li (Australia)

Terms of Reference

Climate change is resulting in heightened intensity and frequency of hazardous weather and climate extremes such as severe storm, drought, tropical cyclone, and flood. Numerous challenges, e.g., major gaps in the observing networks, continue to impede the provision of sound observations, effective early warning systems, as well as comprehensive climate and weather services. It is therefore imperative to improve our understanding of weather and climate systems and the ability to reduce detrimental impacts on current and future generations.

With the rapid development of multi-frequency multi-constellation GNSS and the explosion in new data streams and information, this WG focuses on improving the analysis of climate change process and the monitoring of weather and climate extremes by fully harnessing the potential and capabilities of the next-generation space/air/ground-based GNSS atmospheric sounding techniques, thereby constructing weather- and climate-resilient communities.

Objectives

- Collect multi-GNSS observations through international collaborations to create a long-term and homogeneous GNSS climate dataset.
- Enhance the performance of near real-time and real-time processing of multi-GNSS products suitable for rapid-update NWP and weather nowcasting.
- Assess the qualitative and quantitative contributions of multi-GNSS products to climate modeling; develop robust methods for the monitoring of climate change fingerprints, atmospheric circulation, e.g., atmospheric river, and the detection of climate extremes, e.g., ENSO and drought.
- Evaluate the qualitative and quantitative contributions of multi-GNSS products to NWP systems; enrich the data assimilation techniques to improve weather forecasts and the acquisition of atmospheric parameters and background fields; investigate miscellaneous statistical methods, e.g., AI-empowered models, for the nowcasting of weather extremes using multi-GNSS atmospheric products.
- Encourage the transfer of knowledge and expertise, the dissemination of data, software, and techniques regarding the aforementioned issues; stimulate cross-sectional collaboration for articulating climate action plans, facilitating risk-informed decision-making, and supporting sustainable development goals.

Members

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Li Li (China)
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SC 4.3: Atmosphere Remote Sensing

Chair: Ningbo Wang (China)
Vice-Chair: Mainul Hoque (Germany)

Terms of Reference

The Earth's atmosphere can be structured into various layers depending on physical parameters such as temperature or charge state. From the geodetic point of view the atmosphere is nowadays not only a disturbing quantity which has to be corrected but also a target quantity, since almost all geodetic measurement techniques, such as GNSS, satellite altimetry, VLBI, SLR, DORIS and radio occultations, provide valuable information about the state and the dynamics within the atmosphere. One up-to-date challenge is to combine all these data efficiently to extract as much information as possible. Space weather events, gravity waves, natural hazards, climate change and autonomous driving are a few modern catchwords in this context.

For decades the International GNSS Service (IGS) is delivering high-precision tropospheric and ionospheric, i.e. atmospheric products. The Ionosphere Associated Analysis Centers (IAAC), for instance, provide routinely maps of the Vertical Total Electron Content (VTEC), i.e. the integral of the electron density along the height to correct measurements for ionospheric influences, usually disseminated to the user with latencies of days to weeks and based on post-processed observations and final orbits. Precise GNSS applications, however, such as autonomous driving or precision farming, require the use of high-precision and high-resolution atmospheric correction models in real-time. Thus, real-time modeling of the atmosphere is one of the key tasks of the SC 4.3.

Space weather and especially its impacts and risk are gaining more and more importance in politics and sciences, since our modern society is highly depending on space-borne techniques, e.g., for communication, navigation and positioning. Besides sounding the atmosphere and studying space weather effects by modern evaluation methods, the promising GNSS reflectometry technique (GNSS-R) is another research topic within the SC 4.3.

Objectives

- Studying and solving problems of atmosphere research for up-to-date applications such as autonomous driving.
- Bridging the gaps between modern geodetic observation techniques such as radio occultations or GNSS reflectometry, measurements from other scientific branches such as astrophysics and geophysics with the geodetic community.
- Exploring the synergies between geodesy and other scientific branches such as astrophysics and geophysics.
- Investigating ionosphere phenomena such as disturbances and scintillations.
- Supporting atmospheric prediction models based on the combination of data from different observation techniques and, sophisticated estimation procedures, e.g. machine learning.

- Improving precise positioning and navigation on the basis of new atmosphere models.
- Developing real- and near real-time techniques for atmosphere monitoring.

Program of Activities

- To promote research collaboration among geodetic groups and other branches worldwide dealing with atmosphere research and applications.
- To organize and/or participate in scientific and professional meetings (workshops, conference sessions, etc.).
- To maintain a web page concatenating the Sub-Commission's activities and reports.
- To encourage journal special issues on research, applications, and activities related to the topics of this Sub-Commission.
- Close cooperations with other entities of the IAG and GGOS.

JWG 4.3.1: Real-time ionosphere monitoring and modeling

(joint with IGS and GGOS)
Chair: Zishen Li (China)
Vice-Chair: Heng Yang (China)

Terms of Reference

This WG focuses on the methodology development for real-time ionosphere monitoring and modeling with the use of multiple space-geodetic observations during the upcoming maximum activity of solar cycle 25. This involves integrating ground-based ionospheric data from the multi-GNSS systems (e.g. GPS, Galileo and BeiDou), ionosonde measurements, as well as the spaceborne observations from altimetry, DORIS, GNSS Precise Orbit Determination (POD) and Radio Occultations (RO). Additionally, the in-situ observations, such as Langmuir Probe (LP), are also taken into account. The approaches for the retrieval of precise ionospheric parameters (e.g. Total Electron Content, electron density), generation of two-and/or three-dimensional ionosphere maps on regional and global scales, independent validation and combination of ionospheric information from different providers in real-time will be developed and analyzed. The dissemination of real-time ionospheric information following RTCM, 5G, satellite internet access or other standards will be discussed in support of both scientific researches and technological applications. Connections to IGS, iGMAS, IDS, IRI, NeQuick and other communities will also be involved for the possible establishment of sub-groups or experimental campaigns on real-time ionosphere monitoring.

Objectives

- Close connections to different scientific communities (e.g. IGS, iGMAS and IDS) for the coordination of RT/NRT ground-based, spaceborne, and in-situ measurements in support of real-time ionosphere monitoring.

- Assessment campaigns, e.g. every 6 months, of the performance of real-time ionosphere models/services subjected to different solar activity intensities, such as accuracy, availability and latency. This will allow to compare different approaches for real-time ionosphere modeling by considering the combination of multi-constellation observations with distinct characteristics (e.g. biases and time latencies).
- Development of methods for the NRT/RT independent assessment, utilizing direct ionospheric measurements from altimetry satellites like JASON-3, and alternative methods such as in-situ ionospheric measurements and DORIS observations.
- Share the IGS methods for combination of real-time global/regional real-time ionospheric information from different RT-IGS providers. The ionospheric analysis centers are welcome to consider the possibility of joining RT-IGS service.
- Discussions on the distribution of real-time ionospheric information within scientific and technological communities (e.g. target parameter, data format and time latency).
- Generation and dissemination of experimental two-and/or three-dimensional ionospheric information in support of real-time ionosphere monitoring and associated scientific applications.
- Possible joint sub-groups or experimental campaigns on real-time ionosphere monitoring in close scientific collaboration with IGS and IDS WGs, COSPAR, URSI, IRI and NeQuick WGs, among others.

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WG 4.3.2: Ionospheric state predictions and early warnings for space weather services

Chair: Murat Durmaz (Türkiye)
Vice-Chair: Marjolijn Adolfs (Germany)

Terms of Reference

Disturbances in the state of upper atmosphere especially in ionosphere may adversely affect power grids, navigation, information and communication infrastructures. As the technology advances space-based communication and internet services are becoming ubiquitous covering the entire civilization around the world. Even some natural processes on Earth such as earthquakes may have signatures in the ionospheric state. Providing timely predictions and early warnings on ionospheric state and dynamics can help protecting critical infrastructures. Thus, developing solutions for accurate and timely predictions of ionospheric state and generating early warnings is still an extremely important and challenging issue.

Remote sensing of ionospheric state utilizing GNSS during the last decades has resulted in an invaluable legacy of long-term ionospheric state estimates provided by different analysis centers. Ensemble model (IGS final maps) with a weighted average of each analysis center resulted in a realistic representation of daily ionosphere in terms of Total Electron Content (TEC). Besides, radio occultation (RO) technique using GNSS receivers on board of LEO satellites is another space-based method for sounding the atmosphere. In addition, radio beacon measurements from DORIS receivers onboard LEO satellites may also be used. Vertical sounding of atmosphere is possible with satellite altimetry (e.g., TOPEX-Poseidon, Jason 2 & 3 missions). On the other hand, various ground-based techniques such as vertical sounding (VS), Incoherent Scatter Radar (ISR), Very Low Frequency (VLF) or Radio Beacon (RB) provide additional remote sensing capabilities for different parts of the global ionosphere. Although the availability of these observations has enormously increased during the last decades, the global coverage is still not enough, especially over the oceans. Recent studies try to overcome the issue by filling the gaps in the observations/products with the help of machine learning (ML) and especially in deep learning (DL) techniques. In the meantime, various applications of ML and DL for space weather prediction have been reported in the literature.

In the development of successful ML and DL models applied in different disciplines maybe the most important driver is to establish challenging test cases and provide the necessary reference datasets. At the same time, metrics on the effectiveness of the models need to be well established and reflect the operational capability of the predictions and early warnings. Establishing reference test cases and metrics results in a fair comparison on different models and drives the improvement of each model. In the previous four years a study has been conducted to compare various global vertical TEC (VTEC) predictions in an established test case. The initial findings suggest that ML and DL may provide better results for ionospheric state predictions both for short and long-term horizons. In addition, ensembles of these models may provide even more realistic results in terms of accuracy. With the developments in end-to-end DL methods and also hybrid methods real-time or near real-time raw data may be used directly in the prediction process, which may provide better accuracy and shorten response times.

Objectives

- Analyzing operational requirements for early warning and prediction of ionospheric state and establish metrics on accuracy assessment. Compile reference datasets on space weather parameters and electron density/content of ionosphere.
- Developing end-to-end and hybrid ML and DL models for timely and improved ionospheric state predictions as well as early warnings on ionospheric disturbances (including e.g., electron content, gradients, TID, density variations).
- Developing techniques utilizing ML and DL tools to improve the accuracy of existing historical archive of global and regional ionospheric products (Global Ionosphere Maps) by combining all existing unused space and ground-based measurements.
- Develop ML and DL techniques to distinguish space weather induced ionospheric anomalies from ionospheric signatures of Earth system processes such as earthquakes.

Members

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WG 4.3.3: Analysis and prediction of ionospheric scintillations

Chair: Dmytro Vasylyev (Germany)
Vice-Chair: Rafał Sieradzki (Poland)

Terms of Reference

Trans-ionospheric radio signals of GNSS (GPS, GLONASS, GALILEO and BeiDou) may suffer from rapid and intensive fluctuations of their amplitude and phase caused by small-scale irregularities of the ionospheric plasma. Such disturbances occur frequently in the equatorial region during the evening hours due to plasma flow inversion or during geomagnetic storms in the polar region. This phenomenon is called radio scintillation and can strongly disturb or even disrupt the signal transmission. The main effects of scintillation on trans-ionospheric radio system are signal loss and phase cycle slips, causing difficulties in the signal lock of receivers. All GNSS signals are affected, but the influence of the small-scale irregularities is expected to differ since the signals are transmitted by different carrier frequencies and are constructed in different ways. Furthermore, the sensitivity of receivers to scintillation events differs between various GNSS receiver types and an advanced analysis using “bitgrabber” systems is needed to rate their vulnerability. In spite of the importance of irregular density variations for the science of the ionosphere and for space weather operations, no fully sufficient global model for such disturbances is available.

Objectives

- Understanding the climatology of ionospheric scintillations, namely, its variation with latitude, season, local time, magnetic activity and solar cycle.
- Investigation of the GNSS signal frequency and receiver impact on signal loss and phase cycle slips during scintillation events.
- Global modeling and forecasting of scintillations taking into account temporal and regional (polar and equatorial region) differences.
- Establishing parametric statistical models for scintillation occurrence on a global scale aiming at improvements in scintillation models and forecasting capabilities.

Members

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Suvorova Alla (China-Taipei)
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Yoshihiro Kakinami (Japan)

WG 4.3.4: Indices for characterizing ionospheric perturbations

Chair: Grzegorz Nykiel (Poland)
Vice-Chair: Andres Cahuasqui (Germany)

Terms of Reference

Perturbations in the ionosphere have different physical background and thus different nature and temporal-spatial extent. Their occurrence significantly impacts radio signal propagation, such as in communications and GNSS. Therefore, the detection and characterization of ionospheric disturbances are of interest for scientific research and applications. One way to monitor perturbations is to use ionospheric indices, which provide a clear and consistently simple representation of the state of the ionosphere (usually in the form of a single value). Their use can be essential for maintaining the safety of systems and making appropriate decisions for customers. Despite much research in recent years, there are still numerous issues to be resolved. Within this WG, we want to focus on investigation of options how measurable ionospheric variables can effectively be utilized to get condensed information on the spatial and temporal behavior of the electron density distribution at local, regional, and global scales. Recommendations should be given how the perturbation degree of the ionosphere can be quantified by indices considering different geophysical conditions. This includes the development of corresponding scales and thresholds usable in space weather services.

Objectives

- Select suitable ionospheric variables in relation to the available database.
- Develop and standardize algorithms for calculating ionospheric indices. Define thresholds for separating regular ionosphere conditions from perturbed conditions.
- Develop index-related scale(s).
- Study and demonstrate the relevance of these indices for research and for mitigating ionospheric errors in modern radio systems.
- Validate the results by independent measurements.
- Demonstrate the utilization of indices by impact studies on applications like GNSS and remote sensing radars.
- Compare the applicability of different ionospheric indices (e.g., ROTI, GIX, SIDX) and determine which indices perform better in which geographic regions and geophysical conditions.

Members

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Norbert Jakowski (Germany)
Ningbo Wang (China)
Qi Liu (China)
Zhihao Fu (China)

WG 4.3.5: Ionosphere and space weather monitoring using ground and spaceborne GNSS

Chair: Zhe (Jenny) Yang (China)
Vice-Chair: Yang Wang (USA)

Terms of Reference

This WG focuses on advancing the use of ground and spaceborne GNSS observations for the ionosphere and space weather monitoring. Our current observation and study of the ionosphere relies significantly on the total electron content (TEC) and scintillation measurements from ground GNSS networks. There are large data voids over the ocean and polar areas, where it is not feasible to deploy a (dense) network of GNSS receivers. Spaceborne GNSS measurements, such as from radio occultation and reflectometry, show good promise in filling the data gaps. Our major goals are to bridge the gaps between ground and spaceborne GNSS observation techniques and in the utilization of their measurements, to improve our capabilities of monitoring, nowcasting, and forecasting of ionospheric states and space weather impacts, and to obtain a more comprehensive understanding of the space environment and the physical processes by continuously observing and analyzing the ionospheric conditions and disturbances.

Objectives

- Developing data processing techniques and algorithms to enable the utilization of combined ground-based and satellite-based observations to obtain high-resolution monitoring of the ionospheric states.
- Assembling a comprehensive collection of historical data, spanning a substantial duration, for quantitative characterizations of space weather impacts on GNSS services with respect to variable ionospheric states (such as TEC or electron density gradients) and to support scientific studies of ionospheric responses to space weather activities.
- Assessing and quantifying the cascading impacts of space weather events, such as geomagnetic storms and radio blackouts, on the disruptions of GNSS signals and the degradation of positioning accuracy, for an enhanced understanding of the lead time in space weather forecasting.
- Developing algorithms to improve the nowcasting and forecasting capabilities for ionospheric disturbances at regional scales across the entire globe in response to geomagnetic storms, acknowledging their significant influence on the availability and accuracy of GNSS systems.

Members

Zhe (Jenny)Yang (China); Chair
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Fabricio S. Prol (Finland)
Irina Zakharenkova (USA)

Jade Morton (USA)
Lucilla Alfonsi (Italy)
Mengjie Wu (China)
Nicholas Ssessanga (Norway)
Wojciech J. Miloch (Norway)
Zheng Wang (China)

JWG 4.3.6: Validation of ionospheric models for positioning applications

(joint with IGS)
Chair: Anna Krypiak-Gregorczyk (Poland)
Vice-Chair: Xiaodong Ren (China)

Terms of Reference

Global and regional ionospheric models are routinely used in Space Weather studies, but also in high-precision applications like e.g. GNSS positioning. There are currently many analysis centers and research groups providing operational and test ionospheric maps. The global ionospheric maps (GIMs) provided as an official product by the IGS Ionosphere Working Group (IIWG) are developed by performing a weighted mean of the various Analysis Centers (AC) VTEC maps. There are also important empirical models like the International Reference Ionosphere (IRI) or NeQuick that are based on statistical analysis of the results of measurements.

Reliable modeling of the ionospheric propagation errors is still one of the most challenging aspects of precise GNSS positioning and GNSS-based geodetic and geodynamic studies. However, IGS ACs and other groups use different mathematical models and estimation techniques resulting in different resolutions, accuracies and time delays of their products. Therefore, there is a need to compare and validate existing ionospheric models in order to better understand their performance and quality, and to foster the usage of ionospheric models in geosciences community.

Objectives

- Comparison of GNSS-derived ionospheric maps and empirical models;
- Validation of ionospheric models in precise GNSS positioning;
- Validation of existing and new ionospheric models for different geomagnetic activity levels;
- Development of new validation techniques.

Members

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Ang Liu (China)
Attila Komjathy (USA)
Beata Milanowska (Poland)

Grzegorz Nykiel (Poland)
Haixia Lyu (China)
Mainul Hoque (Germany)
Manuel Hernández-Pajares (Spain)
Michael Schmidt (Germany)
Peng Chen (China)
Qi Liu (Spain)
Reza Ghoddousi-Fard (Canada)
Shengfeng Gu (China)
Wojciech Jarmołowski (Poland)

JWG 4.3.7: Machine learning for the atmosphere

(joint with GGOS)
Chair: Yury Yasyukevich (Russia)
Vice-Chair: Venkata Ratnam D (India)

Terms of Reference

Machine learning (ML) techniques are becoming more and more popular in different fields of research. ML is used for different tasks: forecasting, classification, clustering, anomaly detection and others. Scientists use different ML algorithms to create models of the ionosphere and atmosphere, to reveal effects from different sources, and to cluster or classify the data. Today new ML-based ionospheric models appear regularly. However, there are almost no rules (in contrast to other ML fields) on how to compare the models, and how to describe a model and its code. That often prevents reproducing the results and undermines the ML reliability. Open science would assist significantly in overcoming some of such problems. Within this WG, we will focus on how to provide reproducable ML-based results and to benefit more from ML, and especially to find out which new fields of atmospheric physics could involve ML. Today, the atmospheric community does not reveal trends, benefits and shortcomings of different ML approaches for particular tasks. We suppose that ML (as quite a new technique) could assist in involving young scientists in the problems of atmosphere and ionosphere physics – promoting ML within the atmospheric and ionospheric community can also be a task of the WG.

Objectives

- Review the current state of ML applications for the ionosphere.
- Identify areas within atmospheric and ionospheric research which could benefit from ML algorithms.
- Initiate discussions to uncover potential pitfalls associated with the application of ML techniques in the above contexts.
- Develop and establish guidelines for the publication of source code and datasets in articles utilizing ML for atmospheric and ionospheric science. Demonstrate these guidelines through practical application in our articles.

- Formulate recommendations and prepare a dataset for the ionospheric ML-based model testing.
- Promote the adoption of ML approaches among young scientists through seminars, lectures, and dedicated conference sections.
- Perform experiments showing tangible benefits from ML for atmospheric and ionospheric studies.
- Organizing special issues dedicated to ML application in the ionosphere or atmosphere and actively reviewing corresponding papers to encourage dissemination of valuable research in this field.

Members

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Elvira Astafyeva (France)
Aleksei Zhukov (Igdore)
Seyyed Reza Ghaffari-Razin (Iran)
Yuval Reuveni (Israel)
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Daniel Okoh (Nigeria)
John Bosco Habarulema (South Africa)
Erman Şentürk (Türkiye)
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WG 4.3.8: Troposphere Modeling and Monitoring

Chair: Cuixian Lu (China)
Vice-Chair: Jonathan Jones (UK)

Terms of Reference

Advanced GNSS tropospheric products will contribute to resolving and understanding extreme weather, mitigating the negative impact of natural disasters. The main objective of this WG is to develop, optimize, and assess advanced GNSS tropospheric products, and exploit their full potential in troposphere monitoring, modeling, precise positioning, and numerical and non-numerical weather forecasting. The action aims to produce a variety of reliable real-time/post-processed GNSS tropospheric products by using the precise point positioning (PPP) method. It will foster a better understanding of the influence of atmospheric water vapor in different weather processes and systems and reduce uncertainties in weather predictions. Besides, multi-source water vapor information will be taken into account to enrich the tropospheric modeling and monitoring. Furthermore, the action will seek to leverage the power of data-driven methods to enhance the accuracy and reliability of the tropospheric delay models. Last, but not least, investigating the contribution of applying the a priori tropospheric information to improving the GNSS precise positioning is also one of the focuses.

Objectives

- Develop and optimize advanced GNSS tropospheric products, such as zenith total delays, tropospheric horizontal gradients, slant total delays, water vapor maps, and other parameters.
- Assess the benefit of GNSS tropospheric products in monitoring and forecasting different weather processes and systems (extreme precipitation, convective storms, drought…) and exploit their full potential in initializing rapid-update NWP and nowcasting applications.
- Make full use of the current water vapor sensing systems to establish advanced tropospheric models for applications in both meteorology and geoscience.
- Develop enhanced global/regional/local tropospheric delay models by using machine learning or deep learning methods to fuse multi-source and multi-scale information.
- Explore the full potential of tropospheric delay models in enhancing GNSS precise positioning.
- Stimulate the development of application software for routine production.
- Setup a link to the potential users, review product format and requirements.

Members

Cuixian Lu (China); Chair
Jonathan Jones (UK); Vice-Chair
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Eric Pottiaux (Belgium)
Thaleia Nikolaidou (Canada)
Junping Chen (China)
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WG 4.3.9: Observing convective and volcanic clouds with geodetic remote sensing techniques

Chair: Hugues Brenot (Belgium)
Vice-Chair: Riccardo Biondi (Italy)

Terms of Reference

All the regions of the neutral atmosphere of the Earth, from the equator to the pole, passing through temperate zones, show climate changes. The anthropogenic activity and the volcanic eruption are the two main identified sources that trigger such changes. Severe weather clouds (deep convection, intensive storms, severe precipitation, ice clouds, wet, cold and heat wave) are continuously increasing, causing destructive flooding, fatalities, material damages or drought situation. The occurrence of hazardous clouds (from volcanic eruption or from accidental or provoked industrial explosion) is also a consequent threat for the health of neighboring populations. Both convective and volcanic clouds represent a risk for the safety of aviation air traffic.

The main objective of this WG is to improve the detection and awareness of hazardous structures of the neutral atmosphere by looking at disruption or attenuation in the radio wave signals propagated by GNSS satellites and received by ground-based stations or by LEO satellites (radio-occultation). Case studies to better characterize the composition of convective and volcanic clouds but also nowcasting applications are required to detect, warn and mitigate the risk of extreme clouds.

To reach this objective, the synergy with other remote sensing techniques can bring consequent improvement in severe and hazardous clouds detection (case studies of extreme events but also near real-time situation). Measurements of the ground-deformation and the seismicity bring substantial information for understanding the mechanisms of an eruption and analyzing the composition of gas emissions and the structure of the volcanic plume. The detection and the awareness of extreme clouds requires a quantification of the atmospheric refractivity (benefits of the improvement in real-time troposphere monitoring conducted by WG 4.3.8) with the aim of 1) generating anomaly detection with respect to reference data; 2) using nowcasting system or potential assimilation in numerical meteorological models. The development of tropospheric parameters from multi-GNSS is critical to retrieve 3D-structure from tomography technique or to develop diagnostic tool from slant delays observations. Long-term time-series are essential for making references and anomaly detections of extreme clouds.

Objectives

Within the next four years, this WG on the detection of extreme clouds in the neutral atmosphere intends to develop nowcasting tools in synergy with other remote sensing techniques and to address current challenges in 3D-monitoring by focusing on GNSS tomography principles and synergic approach. Hereby, the main objectives are:

- Setting-up benchmark campaigns (convective and volcanic clouds) for studying the combination of ground-based multi-GNSS with radio-occultation and other observation techniques (e.g., InSAR);
- Synergic approach by using LEO hyperspectral sensors, GEO multispectral imagers and weather radar, combined with GNSS radio-occultations and measurements from GNSS ground-based network to characterize the 3D-structure of convective and volcanic clouds: retrievals of the composition, cloud height, thickness, and density;
- Improvement of GNSS tomography by decreasing the ill-conditioned and ill-posed system (e.g., novel iterative approach, machine learning technique);
- Development of nowcasting tool to detect convective and volcanic clouds;
- Investigation on ray-tracing approaches for the reconstruction of space-based observations using radiative transfer model.

Members

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Chi. O. Ao (USA)
George Hajj (USA)
Kuo-Nung (Eric) Wang (USA)
Soyoung Ha (USA)
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WG 4.3.10: Remote sensing using GNSS reflected signals

Chair: Milad Asgarimehr (Germany)
Vice-Chair: Maximilian Semmling (Germany)

Terms of Reference

GNSS Reflectometry represents an innovative remote sensing method using GNSS signals reflected off the Earth's surface to gain new insights into our environment and Earth system. This initiative aims to foster collaboration and propel research about diverse potential applications of reflectometry across atmosphere, ionosphere, land surfaces, and oceanic properties.

This WG seeks to facilitate joint endeavors focused on leveraging reflectometry data obtained from various platforms, including airborne, ground-based, and space-based systems. An emphasis will be placed on using information from recently deployed satellites like the ESA PRETTY mission and upcoming missions such as ESA HydroGNSS. The investigations have a broad spectrum, encompassing the physics behind observations, methodological advancements, and the steps to the geophysical application. These efforts aim to enhance the quality of observations and retrievals while broadening the spectrum of applications, leading to better understanding of the Earth system and climate change impacts.

Objectives

- Explore novel applications of reflectometry, particularly focusing on recent missions and new instruments. This includes estimation of sea surface height, total electron content, studying ionospheric disturbances, soil and vegetation moisture content and land climate parameters and hydrological processes, aligning with the objectives of missions like PRETTY and HydroGNSS.

- Enhance the quality of reflectometry products by advancing physical understanding or proposing innovative methodologies. This maintains synergy with the JSG "AI for GNSS Remote Sensing" of the GGOS focus area "AI for Geodesy".
- Identifying the potential of reflectometry for Earth system modeling such as properties like soil moisture, vegetation characteristics, ocean winds, sea surface height, ionospheric, and atmospheric conditions. This integration can occur through conventional methods like data assimilation or modern methods such as AI-driven approaches.
- Identify common objectives and synergies with related societies (e.g., IEEE Geoscience and Remote Sensing Society, GRSS) and collaborate with technological, engineering, and operational entities linked to GNSS (e.g., IGS).
- Host workshops, seminars, and training sessions to disseminate knowledge and raise awareness about reflectometry techniques among the scientific community and stakeholders.
- Foster international cooperation and the exchange of visiting scientists.

Members

Milad Asgarimehr (Germany); Chair
Maximilian Semmling (Germany); Vice-Chair
Adriano Camps (Spain)
Clara Chew (USA)
Andreas Dielacher (Austria)
Yusof Ghiasi (Canada)
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Weiqiang Li (Spain)
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Mario Moreno (Germany)
Jade Morton (USA)
Hossein Nahavandchi (Norway)
Serge Reboul (France)
Minfeng Song (China)
Georges Stienne (France)
Jens Wickert (Germany)
Tianqi Xiao, (Germany)
Daixin Zhao (Germany)
Florian Zus (Germany)
Dongliang Guan (China)
Fan Gao (China)

SC 4.4: Engineering Geodesy

Chair: Janis Kaminskis (Latvia)
Vice-Chair: Eimuntas Parseliunas (Lithuania)

Terms of Reference

Engineering geodesy focuses on the capture, setting-out, and monitoring of local and regional geometry-related phenomena, emphasizing quality assessment, sensor systems, and reference frames. An engineering geodesist must possess advanced technical skills and be well-versed in the terminology of adjacent disciplines and related industries.

As an application-oriented science, engineering geodesy employs its own conceptual and methodological approaches. Initially defined by its applications in civil engineering, it is increasingly recognized as a discipline within an interdisciplinary field. The development and optimization of measurement concepts, setups, and data analysis strategies, considering both technical and non-technical criteria and employing theoretical-methodological as well as numerical simulation and optimization techniques, are among the core competencies of engineering geodesy.

This Sub-Commission intends to unite scientists, researchers, and professionals under the theme: “Engineering geodesy - continuous innovation in modern space and time”. Looking forward, we anticipate that engineering geodesy will continue to evolve technically and creatively, leading to innovative developments and next-level technical achievements.

Objectives

- Surveying and field measurements.
- Setting-out is defined as the transfer of predetermined geometric dimensions from a planning model to the construction site.
- Monitoring based on data acquisition, observation, and supervision of natural and artificial systems.
- Geometry-related phenomena (to determine and model further spatial parameters).
- Quality assessment and management (quality of the measurements and analysis of results).
- Sensor technology and geodetic metrology.
- Reference systems (observation domain and coordinate domain).

Program of Activities

- To promote research collaboration among geodetic groups and other branches worldwide dealing with engineering geodesy.
- To organize and/or participate in scientific and professional meetings (workshops, conference sessions, etc.).
- To maintain a web page concatenating the Sub-Commission’s activities and reports.

- To encourage journal special issues on research, applications, and activities related to the topics of this Sub-Commission.
- Close cooperations with other entities of the IAG and GGOS.

WG 4.4.1: Novel GNSS applications in engineering geodesy

Chair: Junbo Shi (China)
Vice-Chair: Li Zhang (Germany)

Terms of Reference

This WG focuses on the methodology development for novel GNSS applications in engineering geodesy. We intend to establish the theoretical framework of local engineering coordinate reference frame. We are also dedicated to exploring the maximum concurrency user volume of GNSS CORS network. We will optimize GNSS positioning methods to meet the demands of complex engineering projects, which are large in horizontal size and in height difference. Finally, we intend to provide a multi-modal, multi-scale, high-quality engineering geodetic dataset and support it by AI methods. Through our efforts, we aim to drive innovation and advancement in the field.

Objectives

- Establishing the theoretical framework for the transition from global ITRF coordinate reference frame to local engineering coordinate reference frame, as well as methods for the maintenance and updating of the local coordinate reference frame.
- Exploring the optimal division scheme for GNSS CORS virtual grids in engineering application scenarios with high-concurrency users.
- Optimizing GNSS high-precision positioning and projection methods for complex engineering projects with large height difference and long horizontal distance.
- Developing fine-grained signal separation methods for GNSS positioning coordinate sequences in ultra-large and ultra-high engineering projects.
- Constructing the multi-modal, multi-scale high-quality engineering geodetic dataset, and developing corresponding AI-enabled data mining and prediction methods.

Members

Junbo Shi (China); Chair
Li Zhang (Germany); Vice-Chair
Hongzhou Yang (Canada)
Chenhao Ouyang (China)

WG 4.4.2: InSAR engineering geodesy for infrastructure health monitoring

Chair: Liming Jiang (China)

Terms of Reference

Due to various geological issues and human activities, structural deformation is a serious threat to large-scale infrastructure safety, typically including bridges, airports, buildings, highways, railways, subways, dams, and heritage sites. As an imaging geodesy, Interferometric Synthetic Aperture Radar (InSAR) techniques have distinct advantages over other engineering methods for infrastructure deformation monitoring, with large-scale and noncontact monitoring capabilities, high spatial resolution and acceptable measurement accuracy. This WG focuses on InSAR theoretical methods, cut-edge algorithms, and new ground-based/UAV SAR instrument towards novel applications in engineering geodesy for infrastructure health monitoring.

Objectives

- To promote algorithms and technologies of InSAR geodesy for improving accuracy and robustness in monitoring surface deformation and infrastructure health.
- To develop new ground-based/UAV SAR instruments to be integrated with spaceborne InSAR measurements for performances and resilience in InSAR engineering geodetic applications and monitoring.
- To combine multidisciplinary knowledge (such as hydrology, geology, geotechniques, and meteorology), numerical models and emerging cutting-edge technologies (e.g. deep learning, 5G communication services) to develop early-warming decision-making systems to assist in the maintenance of urban infrastructures.
- To establish links with other WGs of SC 4.4 addressing the infrastructure health monitoring problem with other engineering geodetic sensors, such as GNSS, TLS.

Members

Liming Jiang (China); Chair
Peifeng Ma (China-Hong Kong)

WG 4.4.3: Multisensor Displacement and Deformation Monitoring

Chair: Maya Ilieva (Bulgaria)
Vice-Chair: Jan Kapłon (Poland)

Terms of Reference

This WG is dedicated to advancing the field of displacement and deformation monitoring by integrating various observation and computation techniques, exploiting new technologies, and developing effective strategies for monitoring the changes of Earth's surface, infrastructure and objects. On one hand, the challenges imposed in the integration of data from different sensors and measuring techniques are mostly related with the difference in the temporal and spatial resolution of the data coverage, format and coordinate frames. While, on the other hand, the combination of data acquired by satellite, aerial and terrestrial measurements also adds the scale variable for the monitoring objects. Another still open question is the presentation of a proper weight frame for the data in the integrated models. This WG focusses on providing a scientific platform for discussion and seeking for solutions to the above-mentioned arguments. The WG is also adopting the fastly developing ML algorithms in multisensor data integration and 3D spatial analyses. The knowledge gained from the synthesis of distinctive data will strengthen the possibility of building comprehensive deformation monitoring systems and developing early-warning systems for strategic infrastructure and territories.

Objectives

- Propose strategy for integrated deformation monitoring systems.
- Evaluation of the mathematical modeling of multisensory observations.
- Explore the integration of measurement techniques for monitoring of non-linear deformation.
- Explore the new generation of space-borne radar and terrestrial sensors.
- Developing scenarios for displacement and deformation monitoring utilising the real-time and non real-time sources of multisensor data.
- Promote real-time and near-real time deformation monitoring using geodetic observation techniques, e.g. satellite, aerial and terrestrial.
- Study the displacement and deformation information for early warning systems.
- Explore new ML methods in displacement and deformation detection.

Members

Maya Ilieva (Bulgaria); Chair
Jan Kapłon (Poland); Vice-Chair
Jacek Paziewski (Poland)
Jacek Rapiński (Poland)

WG 4.4.4: TLS and LiDAR Scanning for Building Information Modelling (BIM) Services

Chair: Janina Zaczek-Peplinska (Poland)
Vice-Chair: Ales Marjetic (Slovenia)

Terms of Reference

In the construction investment process, there are several stages in which geodetic surveying and inventory measurements are necessary. They are necessary during the execution of construction works, installation of machinery and equipment, commissioning and trial operation of facilities, and inventory of the completed stage of work. Routine, cyclic observations related to the monitoring and analyzing of their geometry and technical condition are required for many construction, industrial, and technical infrastructure elements put into operation. For this purpose, satellite, aerial, and ground measurement technologies are used. Currently, LiDAR (Light Detection And Ranging) laser scanning techniques are gaining popularity. Laser scanners provide precise and detailed data on measured objects. Thanks to their universal applicability, terrestrial laser scanners (TLS) are increasingly replacing and displacing other equipment and classical surveying techniques. Laser scanning is a measurement method in which the measured object's surface is sampled with a laser beam. Information about the position of points representing the object is collected during spatial measurement. In addition, data on the color and intensity of the reflection of the laser beam from the measured elements are recorded. The collected information can be used in many industries. Most often, the products of this technology are used to create digital documentation in the form of 2D drawings or 3D spatial models, to build databases about objects, BIM (Building Information Modeling) technology, or spatial information systems.

The goal of the WG will be to study and develop laser scanning techniques in the broad field of engineering surveying. The experience gathered will be aimed at, among other things: verifying the precision and accuracy of measurement of building structures, optimizing laser scanning techniques, building algorithms for conducting measurements, and processing data. The research will contribute to increasing efficiency in applying laser scanning techniques for BIM.

Objectives

- Development of BIM technology in rail transport;
- Development of BIM technology in the construction and monitoring of concrete dams;
- Application of TLS technology and LiDAR scanning in surveying engineering;
- Application of TLS technology for monitoring natural objects and engineering structures;
- Develop algorithms that optimize laser scanning techniques for higher accuracy in determining the geometry of building objects;
- Assessment of the possibility of using laser scanning techniques for diagnostic tests of building objects.

Members

Janina Zaczek-Peplinska (Poland); Chair
Ales Marjetic (Slovenia); Vice-Chair
Zbigniew Muszyński (Poland)
Michał Strach (Poland)
Maria Kowalska (Poland)

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