Report to the 47th General Assembly
FIG Working Week 2024, Accra, Ghana

Commission 5 – Positioning and Measurement

Report of Activities 2023-2024

1. General

FIG Commission 5 focusses on meeting the highest level of 'fit-for-purpose' performance for Positioning and Measurement. It provides the tools, techniques and procedures to inform, educate and train surveying professionals everywhere. The appropriate methodologies for data collection, processing and analysis are necessary to be successful in this era of global, integrated geospatial data."

2. Members of the Commission

The members of Commission 5 are listed as follows:

- Ryan Keenan (Chair), Australia
- Kevin Ahlgren (Deputy Chair), United States
- David Martin, (Chair - Working Group 1), France
- Nic Donnelly, (Co-chair - Working Group 2), New Zealand
- Chris Pearson, (Co-chair - Working Group 2), New Zealand
- David Alvarez, (Chair - Working Group 3), Mexico
- Eldar Rubinov, (Co-chair - Working Group 4), Australia
- Safoora Zarminpardaz, (Co-chair - Working Group 4), Australia
- Amir Khodabandeh, (Chair - Working Group 5), Australia
- Li Zhang, (Co-chair - Working Group 6), Uganda
- David Mulindwa, (Co-chair - Working Group 6), Uganda
- Allison Kealy, (Co-chair - Working Group 7), Australia
- Jelena Gabela, (Co-chair - Working Group 7), Austria

The Commission and its members meet regularly in person at different events, and online for Commission and other events.

Figure 1 – Commission 5 holding a video call (March 2024) to discuss preparations for Working Week 2024

3. Work Plan and Activities

In its Mission and Work Plan, Commission 5 endeavours to:

- Focus on modern technologies, and technical developments and assist individual surveyors, engineers and GIS/LIS professionals through guidelines and recommendations, to choose and utilise those methods, technologies and instruments that are most appropriate to different applications;
- Follow technical developments through collaboration with other FIG Commissions, Networks and Task Forces; participation in appropriate meetings and the preparation or appropriate publications;
- Support research and development and stimulate new ideas in the fields of expertise represented within the commission;
- Collaborate with manufacturers on the improvement of instrumentation and associated software;

- Present and promote the work of the Commission and its working groups on an on-going basis at FIG Congresses, FIG Working Weeks, FIG Regional Conferences and other relevant technical meetings and in appropriate FIG and other media.

Significant accomplishments during the period were the contributions of the 2023 FIG Working Week in Orlando, a forthcoming publication update for the Reference Frames in Practice Manual, and internal discussions around upcoming activities for expanding the commission's member base.

Engagement with UN-GGIM's UN-SCoG continued, particularly with the WG on Capacity Development around geodetic reference frames, and the ongoing needs for knowledge transfer into developing regions. Collaborating with the FIG Capacity Development Networks and Commission 2, particular focus was made on assessing these geospatial needs globally.

There is an ongoing collaboration with United Nations Agencies to address global problems such as sustainable development and humanitarian needs. The disciplines covered by Commission 5 help to deliver solutions for the spatial aspects of these important global problems. Specific activities aimed at developing countries include examination of Low-Cost Surveying Technologies, assistance with implementation of modern Geodetic and Vertical Reference Frames and associated infrastructure and contribution to appropriate Continuing Professional Development programs.

Additionally, Commission 5 continued to work closely with the International Association of Geodesy (IAG) and the United Nations Global Geospatial Information Management (UN GGIM) on the development of new models, standards and tools for implementing a Global Geodetic Reference Frame (GGRF) that includes aspects of the International Terrestrial Reference Frame (ITRF) and the International Height Reference Frame (IHRF). The GGRF will serve as a global standard for all Nations to implement their respective national datums. As such, this directly impacts FIG Members who must implement these new datums and the requirements to access them. Likewise, FIG has engaged with ISO TC211 to ensure that internationally recognized GIS standards are consistent with those for national reference frames utilized by FIG Member organizations.

In terms of the African region, Commission 5 is significantly involved with its partners IGS, UN-GGIM Africa and UN-GGCE, in engaging the African member states to gain insights on their current geodetic infrastructure capabilities and future needs, and thus help identify opportunities for education, training and in-region collaboration. Having the 2024 WW and 2026 Congress events in Africa will greatly support this initiative and updates can be expected in the coming months.

The next in-person RFIP seminars remain planned for the FIG Working Week in Ghana 2024, Working Week Brisbane 2025 and the FIG Congress 2026 in Cape Town.

Commission 5 continued support to FIG Task Forces, the Standards Network, and regional Capacity Development Networks (including Asia Pacific (AP CDN) and the new Americas network). The Commission will also respond to the FIG Council to address new issues as they emerge.

In March 2024, Commission 5 provided the FIG Office with insights for a GIM International article covering the topic of FIG's ongoing contribution to resilient and impactful surveying, due for publication in Spring 2024.

A summary of the Commission's working group activities in the period 2023-2024 follows. As always, we are happy to accept new members and volunteers within any of the working groups, and are grateful for insights and experiences coming from across the globe.

4. Working Groups

WG 5.1 – Standards, Quality Assurance and Calibration

Chaired by David Martin

Standards provide a framework that supports the accurate and reliable functioning of surveying instruments. Additionally, they contribute to the professionalism, consistency, and quality of surveying practices, ultimately benefiting both practitioners and the broader community that relies on surveying data.

Working Group 5.1 actively participates in technical sessions, technical seminars and presentations for FIG Working Weeks and Congresses. Working Group 5.1 is also very closely linked to the FIG Standards Network. Importantly Working Group 5.1 is the contact for FIG liaison to the ISO Technical Commission (TC) 211 (http://www.isotc211.org/) and Technical Committee ISO/TC 172/SC 6.

ISO TC 211 focuses on standardisation within the realm of digital geographic information. The committee's objective is to establish a systematic set of standards for information related to objects or phenomena directly or indirectly tied to a location on Earth. These standards delineate methods, tools, and services for the comprehensive management of geographic information. This encompasses aspects such as definition and description, data acquisition, processing, analysis, access, presentation, and transfer in digital/electronic formats across diverse users, systems, and locations. The committee aligns its work with relevant standards in information technology and data wherever feasible, offering a framework for developing sector-specific applications utilizing geographic data.

At present, Michael Dennis of NOAA/NOS/National Geodetic Survey, and Nic Donnelly, from Land Information New Zealand, are the FIG liaisons to TC211.

Key projects in TC211 are the work on ISO 19127 (Geographic information — Geodetic register standard) to conform to ISO 19111 (Geographic information — Referencing by coordinates) and a revised version of ISO 19135 (Geographic information — Procedures for item registration — Part 1: Fundamentals) currently under development.

ISO/TC 172/SC 6 addresses the practical aspects associated in the utilisation of classical surveying instruments. These standards specifically focus on field procedures for testing geodetic and surveying instruments, encompassing tools such as theodolites, total stations, levels, and GNSS in real-time kinematic (RTK). Current work items for ISO/TC 172/SC 6 include: ISO/WD 9849 Geodetic and surveying instruments — Vocabulary; ISO/CD 17123-6 — Part 6: Rotating lasers; and, ISO/CD 17123-11 — Part 11: GNSS instruments. Currently, Werner Lienhart is the FIG representative to ISO/TC 172/SC 6, and is also Chair of FIG Commission 6.

In Orlando, two highly successful sessions were devoted to exploring the establishment of a standard for drone-based surveying. The participants in these sessions demonstrated extensive knowledge and posed highly specific and relevant questions. The outcome of these sessions indicated widespread support for this initiative in FIG, notably from Commissions 4, 5, 6, and 7.

Since Orlando, a new standard, ISO 17123-10 UAV Photo measurement systems is under development and a first draft version has been edited. It specifies field procedures to be adopted when determining and evaluating the accuracy (closeness to true values) and additionally in the full test procedure also the precision (repeatability) of UAV photo measurement systems (Unmanned Aerial Vehicles with cameras – or also known as drone systems), when used in specific surveying tasks, such as determining land surfaces, monitoring earthworks, monitoring and measuring all kind of structural designs and civil construction sites, calculating volumes and many other similar surveying applications.

We will follow this standard closely because it may address many of the questions raised in the Orlando sessions. Alternatively, or possibly with the ISO 17123-10 standard, FIG may work on short documents addressing drone operation and good practice.

Finally, Working Group 5.1 has a lasting goal of endorsing the guidelines outlined in the ISO Guide to Uncertainty in Measurement (GUM) and its dedicated supplements. These guidelines aim to ensure measurement traceability, which is a process that guarantees a measurement considers all uncertainties, providing an accurate representation of the object being measured.

WG 5.2 – 3D Reference Frames

Chaired by Nic Donnelly and Chris Pearson

The main activities for Working Group 5.2 were updating the RFIP manual and organizing the RFIP Workshop as a pre-event of the Working Week 2024 in Accra. The RFIP Manual is essentially finished and will be presented at the RFIP Workshop on Saturday 18 May. For this Workshop, another strong program is forming and we are pleased to have received confirmation of the UN ICG's continued sponsorship for a number of attendees from the developing world.

It was clear from the presentations that there is excellent progress on reference frame development being made in many countries. Ongoing challenges include capacity and capability development, the incorporation

of deformation into reference frames, implementing vertical reference frames based on geoids and helping decision-makers understand the crucial role of the reference frame underpinning accurate positioning and data management.

Working group members continue to be active in a number of relevant international groups. These include the OGC project teams working on the standardisation of a deformation model functional model and format as well as the IAG's Working Group 1.3.1 on Time-dependent transformations between reference frames in deforming regions.

WG 5.3 – Vertical Reference Frames
Chaired by David Avalos-Naranjo

WG5.3 collaborates in the organization of the Reference Frames in Practice workshop (RFIP) for its version at the FIG Working Week 2024, providing up to date material regarding the International Height Reference Frame (IHRF) and sharing experiences on the transition from the classical approach. In collaboration with the International Association of Geodesy, WG5.3 continues to promote the creation of a special publication with recommendations and descriptions of best practice in the use of modern vertical reference frames.

The focus of this working group remains on creating opportunities to learn about the importance of maintaining or advancing the vertical control in positioning for official purposes. The new generation of vertical reference frames allows access to higher precision, stability and connection with neighbouring or even non-neighbouring countries. Such capability is considered essential for projects aiming to contribute in the achievement of local and global sustainable development goals.

WG 5.4 – GNSS
Co-chaired by Eldar Rubinov and Safoora Zarmindarpaz

The GNSS Working Group continues to support multi-constellation GNSS activities through the UN International Committee on GNSS (UN ICG) with collaboration from the International GNSS Services (IGS), International Association of Geodesy (IAG) and Multi-GNSS Asia (MGA).

In 2023-2024, FIG WG 5.4 is contributing and participating in the ION GNSS+ and IGNSS conferences as well as various online webinar series on GNSS.

In terms of capacity building activities, FIG WG 5.4 has been actively involved in the ongoing efforts of the UN GGIM's Subcommittee on Geodesy (SCoG)'s Education, Training and Capacity Building (ETCB) working group. At the FIG Working Week Orlando in 2023, the WG presented the new open-source analysis centre software Ginan from Geoscience Australia, which gives developing nations a new means to compute and monitor their reference frames.

The WG is continuously monitoring the new state-of-the-art technologies that enhance the resilience of GNSS, as well as provide new methods of augmenting GNSS, such as the Low Earth Orbit Positioning

Navigation and Timing (LEO PNT) constellations as well as new telecommunications standards such as the 5G 3rd Generation Partnership Project (3GPP) that have the potential to bring high-precision positioning to mass market devices, including mobile phones.

In summary, FIG WG 5.4 is actively involved with those groups responsible for helping to define the future of GNSS positioning into the next decade, and beyond. WG 5.4 chairs welcome ideas and contributions from members of the FIG on ways to better engage and support our community on all aspects of satellite positioning.

WG 5.5 – Multi-Sensor-Systems

Chaired by Amir Khodabandeh [Email: akhodabandeh@unimelb.edu.au]

The objective of this Working Group is to develop theory and algorithms that can extend our understanding of the tools and technologies with which one can combine sensory data from multiple devices and/or measuring systems, providing high-precision and trustworthy Positioning, Navigation and Timing (PNT) services. It has a major focus on:

- Performance characterization of positioning sensors and technologies that can play a role in augmenting core GNSS capabilities.
- Theoretical and practical evaluation of current algorithms for measurement integration within multi-sensor systems.
- The development of new measurement integration algorithms based around innovative modeling techniques in other research domains such as machine learning and genetic algorithms, spatial cognition.
- Establishing links between the outcomes of this WG and other FIG WGs and the International Association of Geodesy (IAG).
- Generating formal parameters that describe the performance of current and emerging positioning technologies that can inform FIG and IAG members.

Activities in the past 12 months [2023-2024]

Publications in geodetic and GNSS journals: Aligned with the objectives of this WG, members have developed novel positioning algorithms for fusing GNSS observations and Light Detection and Ranging (LIDAR) measurements. The developed algorithms have been verified through several globally distributed real-world datasets as well as synthetic data. The corresponding results have been presented in the following recent publications:

1) Zhang J., Khodabandeh A., Khoshelham K. (2023). On the role of lidar measurements in speeding up precise point positioning convergence. GPS Solutions, doi:10.1007/s10291-023-01497-3.

2) Khodabandeh A., Teunissen P.J.G., Psychas D. (2023). A Multi-Epoch Processing Strategy for PPP-RTK Users, International Association of Geodesy Symposia, doi: 10.1007/1345_2023_228.
3) Khodabandeh A., and Teunissen P.J.G. (2023). Ambiguity-Fixing in Frequency-Varying Carrier Phase Measurements: Global Navigation Satellite System and Terrestrial Examples, NAVIGATION, doi:10.33012/navi.580.
4) Trainotti C., Dassié M., Giorgi G., Khodabandeh A., Günther C. (2023). Autonomous Synchronization of Satellite Constellations via Optical Inter-Satellite Links. Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS), Toyama, Japan, doi: 10.1109/EFTF/IFCS57587.2023.1027217.
5) Sadegh Nojehdeh P., Khodabandeh A., Khoshelham K., Amiri-Simkooei (2024). Estimating process noise variance of PPP-RTK corrections: a means for sensing the ionospheric time-variability. GPS Solutions, doi:10.1007/s10291-023-01577-4.

Attending international conference proceedings: WG members participated in various capacities in the following conferences:

- ISPRS 2023, Cairo, Egypt, 2-7 September 2023
- ION GNSS+ 2023, Denver, USA, 11 - 15 September 2023 (virtual)
- IGNSS 2024, Sydney, Australia, 7 - 9 February 2024

Inviting new members from early-career scientists, engineers, and specialists: This WG welcomes new and active members. Existing members of this WG are inviting emerging leaders in the fields of geospatial and PNT to join this group.

Activities planned for the next 12 months [2024-2025]

Organizing workshops addressing the objective of the group: This WG plans to organize in-person and online workshops across the members. Before each workshop, the topic of discussion as well as the corresponding research questions will be shared with members. The expected outcomes of these workshops are to showcase state-of-the-art algorithms, tools, and technologies of multi-sensor PNT and to address existing challenges ahead of multi-sensor integration, thereby providing a broad outlook on such topics.

Inviting new members from early-career scientists, engineers, and specialists: Existing members of this WG will continue to attract new members mainly from enthusiastic early-career scientists, engineers, and specialists in the fields of geospatial and PNT to join this group.

Continuing publishing journal papers and attending international conference proceedings: Existing members of the WG will continue to develop and assess new algorithms and methods concerning multi-sensor systems, presenting outcomes in relevant journals and conferences.

WG 5.6 – Cost Effective Positioning
Co-chaired by Li Zhang and David Mulindwa

Throughout the year, WG 5.6 remained committed to its mission of promoting education and collaboration in the field of surveying. Our efforts focused on providing valuable guidance to associations and individual surveyors regarding the optimal use of surveying instruments and software, with a keen eye on economic considerations. By offering insights into the most cost-effective solutions, we aimed to empower decision makers in establishing positioning strategies that are both effective and budget friendly.

Furthermore, our team dedicated considerable efforts to designing fit-for-purpose surveying systems that prioritize cost-effectiveness without compromising on quality. We firmly believe that tailored solutions can significantly enhance project outcomes while minimizing expenses.

In addition to our educational endeavours, WG members actively participated in several conferences:

- Scientific Workshop on Uncertainty and Quality of Multi-Sensor Systems, 27-28 May 2023 in Orlando, USA
- FIG Working Week 2023 and the Scientific Workshop on Uncertainty and Quality of Multi-Sensor Systems, 28 May – 01 June 2023 in Orlando, USA
- Intergeo Conference 10-12 October 2023 in Berlin, Germany
- Chintergeo Conference 27-29 November 2023 in Guangzhou, China

These events provided valuable opportunities for knowledge exchange and networking, further enriching our collective expertise.

Moreover, WG 5.6 is pleased to report that we embarked on several exciting research and development projects in 2023. Notable among them are initiatives such as the development of Low-Cost GNSS Equipment for Monitoring and the creation of cost-effective multi-sensor systems for fault localization on railway tracks. We also initiated projects aimed at providing cost-efficient scalable solutions for the agricultural and construction industries, reflecting our commitment to innovation and practical problem-solving.

Looking ahead, we are excited to announce plans for the 3rd Edition of FIG Report 74, titled "Cost-Effective Precise Positioning with GNSS". With the support of WG 5.4, we aim to deliver a comprehensive resource that addresses the evolving needs and challenges in the field of precise positioning.

New Working Group 5.7 Emerging Technologies for Positioning, Navigation and Timing (PNT)
Co-chaired by Allison Kealy and Jelena Gabela, partnering with IAG.

The primary mission of the Emerging Technologies for PNT Working Group is to identify, assess and integrate innovative technologies which have the potential to revolutionise precision navigation and timing systems. By fostering collaboration and experimentation, the group aims to shape the future landscape of PNT with the infusion of emerging and disruptive technologies.

Activities planned for the next 12 months [2024-2025]

- White paper on current status of quantum sensors for PNT applications
- Conferences: IGNSS (Australia) ION PNT Pacific, ION GNSS+, IAG Symposium, ISPRS, Mobile Mapping
- Webinar on Quantum PNT and AI
- Collaborations IAG special study groups on Quantum Geodesy and Quantum PNT
- Journal publication on performance assessment of integrated GNSS and Quantum Magnetometry
- Joint membership through FIG/IAG/ION

5. Collaboration, Seminars and Workshops

The Commission is involved with myriad partners, both inside of FIG, and beyond.

5.1 Collaboration with Other FIG Groups

Other areas of collaboration include:

- Commission 4 regarding Hydrographic Surveying on the Ellipsoid
- Commission 6 and ISPRS on GNSS-based Deformation Monitoring
- Commission 6 on UAV Usage for Surveying
- Commission 7 and 3 on Cost-Effective Positioning
- Regional Capacity Development efforts in Asia-Pacific, Africa, and the Americas
- Task Force: International Trends and Future Geospatial Information Ecosystem
- Task Force: Diversity and Inclusion
- Task Force: Climate Compass
- Task Force: FIG and the Sustainable Development Goals (SDGs)

5.2 Collaboration with Sister Organisations

Commission 5 continued to maintain a successful working relationship with the International Association of Geodesy (IAG), PGSC (with AP CDN) and SIRGAS. This was achieved by convening joint Technical Seminars on Reference Frames in Practice, technical sessions and holding joint administrative meetings on significant issues.

Based on feedback from our members, and insights into current trends, Commission 5 is creating a new Working Group, in partnership with the IAG, around Emerging Technologies for PNT.

5.3 Cooperation with UN

FIG and IAG are both supporting the UN International Committee on GNSS (UN ICG) as well as the UN Global Geospatial Information Management (UN GGIM) Committee. The UN GGIM has implemented the Global Geodetic Reference Frame (UN GGRF) that is being implemented by the UN GGIM SubCommittee on Geodesy (UN SCoG). In 2023, FIG Commission 5 was formally invited to become a Partner of the UN SCoG. The UN SCoG has several working groups including one on Capacity Development WG CD (formerly WG Education, Training and Capacity Building (ETCB)). FIG Leadership as well as Commissions 2 and 5 are

working closely with WG CD ~~ETCB~~ to evaluate the geodetic and surveying capabilities of Nations and to catalog available training resources for surveyors around the world. Ryan Keenan is the key liaison for these connections with UN and is actively involved with the UN SCoG and a number of its WG, as well as being an individual member of the International Advisory Committee (IAC) of the UN GGCE.

5.4 Cooperation with ISO

There has been ongoing interaction with ISO/TC211, the geographic information technical committee of ISO. Nic Donnelly continues as the Special Liaison from FIG to ISO/TC211. ISO TC211 has focused on maintaining and expanding the ISO Geodetic Registry to ensure all national and international reference frames and vertical datums are listed officially. This enables GIS and other programmers to accurately transform positions and measurements for FIG Members.

6. Events and other activities

2023

In 2023, Commission 5 supported:

- UN-GGCE Inaugural Event, and 3rd Plenary Meeting of the UN SCoG in Bonn, Germany in March 2023
- UN-GGIM 13th Session, Plenary of Experts on Geodesy - in New York, United States in July/August 2023
- UN ICG 17th Meeting in Madrid, Spain, in October 2023
- UN-GGCE Consultation in Bonn, Germany in November 2023.

2024

In 2024, Commission 5 plans to participate in:

- UN-GGCE – Listening Tour Webinar series with FIG/IHO/ISO, online in February 2024
- UN-GGCE – 2nd Meeting of the IAC of the United Nations Global Geodetic Centre of Excellence & 4th Plenary Meeting of SCoG in Bonn, Germany in March 2024
- FIG Africa Mentoring Program 2024
- The FIG Working Week hosted by Ghana in May 2024
    - RFIP Workshop as a pre-event
    - Five Commission specific technical sessions
    - One joint technical session with Commission 6
    - Supporting the UN-GGIM specific meetings
- UN-GGIM Plenary of Experts on Geodesy - in New York, United States in August 2024
- UN ICG 18th Meeting in Wellington, New Zealand in October 2024
- FIG Regional Technical Seminar hosted by Nepal in November 2024
- Active involvements in preparations for the FIG Working Week 2025 in Brisbane, through membership of the Local Organising Committee (LOC).

7. Communication and Publications

Commission 5 has issued numerous reports and periodic newsletters to our delegates. These information can also be found on websites:

- http://www.fig.net/organisation/comm/5/index.asp
- New LinkedIn Group Page
  https://www.linkedin.com/showcase/fig-commission-5-positioning-and-measurement/?viewAsMember=true
- GIM International article on FIG's Ongoing Contribution to Resilient and Impactful Surveying (planned for Spring 2024)

Ryan Keenan
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March 2024

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