

# Editorial:

## Advancing the Maturity of Seamless Indoor–Outdoor Navigation: Breakthrough Research in GNSS Resilience, AI-Driven Positioning, and Sensor Fusion

**T**HE IEEE JOURNAL OF INDOOR AND SEAMLESS POSITIONING AND NAVIGATION (J-ISPIN) is now in the third year as a gold open-access publication of the IEEE Sensors Council (SC), the IEEE Signal Processing Society (SPS), and the Instrumentation and Measurement Society (IMS).

2025 brings 21 original articles, seven of which are expanded versions of the best papers from the ICL-GNSS 2024 conference and two are extended versions of the best papers at the Indoor Positioning and Indoor Navigation Conference. This volume shows a vibrant and expanding field driven by technological advancements, global challenges and increasing demand for resilient positioning solutions. It reflects the journal's unique scope that bridges indoor, outdoor and seamless navigation technologies, with a strong emphasis on experimental validation, machine learning, and robustness in GNSS-denied environments.

An important theme in this volume is the growing urgency to design resilient positioning systems facing GNSS vulnerabilities. Several articles address threats like jamming, spoofing, and environmental interference by exploring alternatives, such as synthetic aperture radar, magnetometer arrays, ambient light sensors, and other non-GNSS signals. Enhancements to authentication mechanisms, notably through statistical analysis of spreading code authentication and improvements to the Galileo OSNMA service, are proposed. The article on GNSS Positioning Under Threat shows how traditionally indoor technologies have become pivotal in outdoor scenarios, including conflict zones, where signal security is critical. The takeaway is clear: indoor and hybrid positioning systems are no longer niche solutions. They are foundational technologies for global navigation resilience.

Artificial intelligence continues to transform the landscape of seamless positioning, playing a role at nearly every level of the system. This volume presents advancements in triplet and quadruplet-loss learning for GNSS interference classification, machine-learning-driven fingerprinting in NB-IoT/ultra-wide

band (UWB) systems and few-shot learning to distinguish jammers with limited data. Others use data-driven methods to calibrate sensors (barometers and ultrasonic microphones). These contributions are practical because they consider low-latency inference, energy constraints, and uncertainty estimation, making them suitable for real-world use in embedded or mobile contexts.

From smartphone ambient light sensors fused with inertial-based dead reckoning, to radar channel impulse responses derived from UWB radios, to audio-based positioning using a single loudspeaker's reflections, this volume contains highly creative yet feasible sensor strategies leveraging existing hardware, aligning with the community's interest in scalable and low-cost deployment. A noteworthy trend is the use of neuromorphic computing for real-time edge processing.

Fusing heterogeneous sensing technologies, often across both measurement and algorithmic levels, is also essential in the field. Contributions demonstrate tightly integrated systems combining barometric, light, RF, and audio data via Kalman filters, pose graphs, two-filter smoothers, and particle filters. The range of sensors used is notably wide. There are traditional ones such as inertial, light, GNSS, lidar, acoustics, UWB and barometer, used in innovative ways and more recent ones such as synthetic aperture radar for robots, passive-mode Wi-Fi sniffing for pedestrian detection, narrowband IoT networks for the Internet of Things, device tracking with the new 5G noncellular DECT-2000 standard, and magnetic arrays for robotic odometry. The community is clearly moving beyond siloed sensor systems to cross-modality fusion architectures that bridge indoor and outdoor environments seamlessly.

Finally, the community is steadily embracing open science practices, reflecting a growing commitment to transparency and collaboration. Five articles contribute open datasets for reuse and further research, supporting reproducibility and fostering innovation. One article offers a comprehensive meta-analysis of open science practices within the IPIN community from 2019 to 2024. It highlights a gradual but clear trend toward greater adoption of open data, code sharing, and reproducibility standards. Beyond benchmarking progress, this article provides practical guidance on improving transparency, replicability, and reliability, values deeply aligned with J-ISPIN's open access mission.

Collectively, these contributions mark a significant cultural shift and a call to action for broader adoption of open science in the field.

We warmly thank all authors whose high-quality contributions shape this third volume of J-ISPIN and demonstrate the vitality and depth of the indoor and seamless indoor/outdoor positioning community. We are equally grateful to the Editorial Board members for their sustained commitment to guiding the review process with rigor, fairness, and scientific vision, as well as to the reviewers whose expertise and dedication remain essential to the journal's standards of excellence.

As J-ISPIN reaches a new stage of maturity, with increasing visibility, international recognition, and the forthcoming attribution of its first impact factors, this volume illustrates both the scientific strength of the field and the journal's role as a trusted

forum for cutting-edge research. We hope readers will find in this collection not only technical advances but also a reflection of a community progressing toward resilient, transparent, and impactful navigation solutions.

VALÉRIE RENAUDIN, *Editor-in-Chief*  
AME-GEOLOC, Univ. Gustave Eiffel Bouguenais  
F-44344 Bouguenais Cedex, France

FRANCESCO POTORTÌ, *Associate Editor-in-Chief*  
Institute of Information Science and Technologies (ISTI)  
National Research Council of Italy (CNR)  
56127 Pisa PI, Italy