Dresden University of Technology

Bridging the Indoor–Outdoor Gap

Cross-Technology Ranging for Seamless Robot Navigation

Motivation

Mobile robots in logistics, inspection, and search-and-rescue routinely cross the building wall, and the ranging infrastructure changes underneath them. Outdoors, Global Navigation Satellite Systems (GNSS) dominate. Indoors, terrestrial systems such as Ultra-Wideband (UWB), WiFi Fine Time Measurement (FTM), and Bluetooth Low Energy (BLE) take over. A unified measurement-level view of how these technologies behave across the transition is still missing.

Figure 1 shows the available observations per technology across the three zones. Visible satellites drop toward the indoor zone while coverage shifts to the terrestrial systems, so no single technology spans the full trajectory.

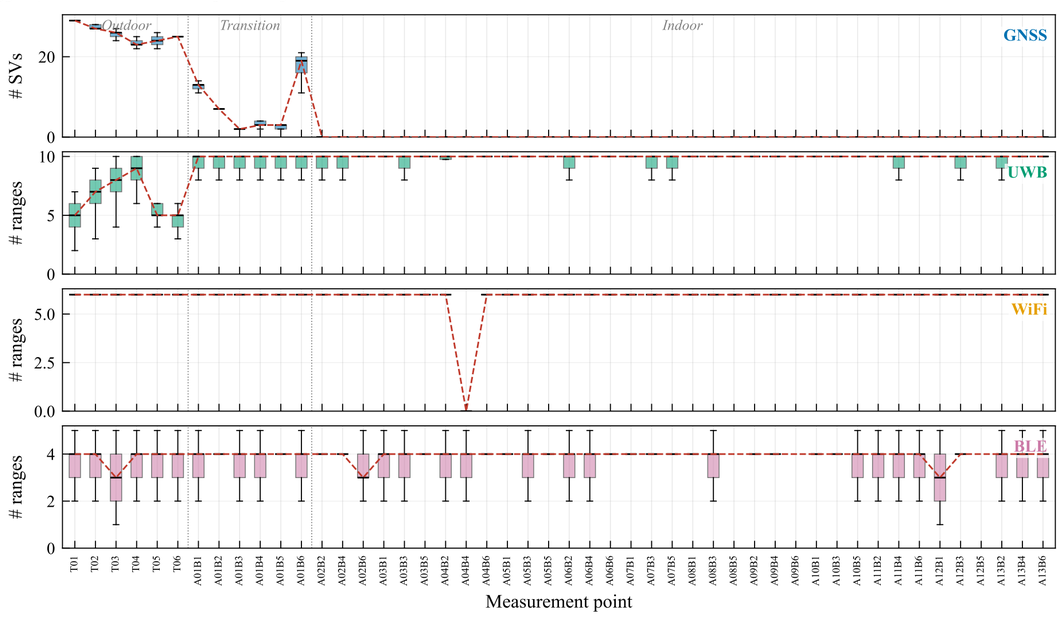


Figure 1: Per-point observation counts: valid ranges (UWB, WiFi, BLE) and visible satellites (GNSS).

HYMN Dataset

The HYbrid Multi-technology Navigation (HYMN) dataset [1, 2] records four ranging technologies side-by-side in a 44 m × 18 m industrial hall in Torgau, Germany, whose wide driveway gate forms a natural indoor–outdoor transition. GNSS (NovAtel PwrPak7), UWB (ZigPos RTLS), WiFi FTM (HPE Aruba 630), and BLE (Metirionic DMK-215) run simultaneously, with a Leica TS16 total station giving millimetre ground truth across 48 points (6 outdoor, 6 transition, 36 indoor) on a shared timescale, so all four can be compared epoch-by-epoch.

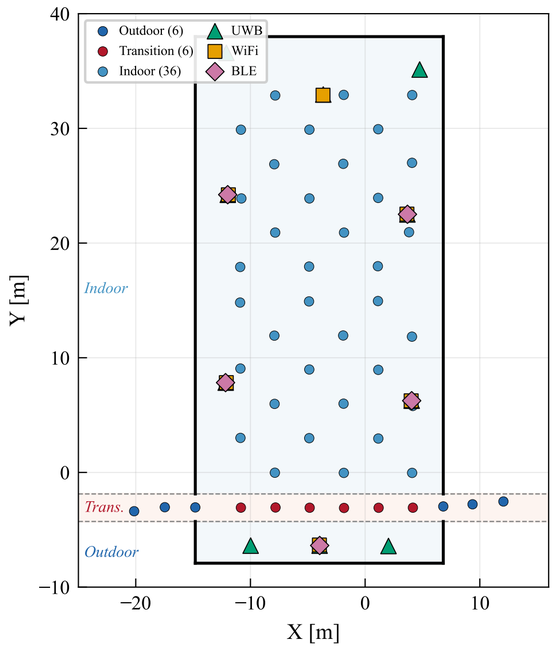


Figure 2: Torgau hall: driveway, zones, anchor positions, and measurement grid.

[1] HYMN Descriptor
doi:10.1109/IEEEDATA.2026.3691044

[2] HYMN Dataset (Zenodo)
doi:10.5281/zenodo.17979434

Cross-Technology Ranging Analysis

The technologies use different measurement protocols, yet each produces a range between a mobile device and a transmitter of known position (a satellite for GNSS, a fixed anchor otherwise):

- **GNSS**: one-way pseudoranges, single-differenced against the highest-elevation satellite
- **UWB**: double-sided two-way ranging
- **WiFi FTM**: 802.11mc round-trip timing
- **BLE**: phase-based ranging across the 2.4 GHz band

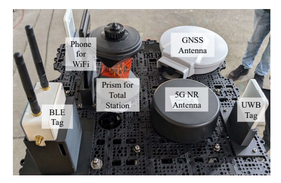


Figure 3: Sensor platform

Despite these differences, every observation fits one shared structure: the raw range is the true geometric distance plus three error terms,

$$\rho = \underbrace{d}_{\text{geometry}} + \underbrace{b}_{\text{bias}} + \underbrace{\eta}_{\text{NLOS / multipath}} + \underbrace{\epsilon}_{\text{noise}}.$$

Bias b is handled per technology: UWB and WiFi FTM cancel the clock offset within their two-way exchange, while GNSS removes it by between-satellite single-differencing. The environment term η is positive in mean, heavy-tailed, and unevenly weighted across technologies, so no single Gaussian model fits all four. Deriving the noise covariance, outlier thresholds, and fusion weights a state estimator needs is the open challenge.

Ranging accuracy splits sharply by technology and zone (Figures 4 and 5). UWB is centimetre-level indoors (median 0.05 m) but adds heavy-tailed outliers, while GNSS carries a 9–13 m bias and only survives outdoors and at the gate. WiFi FTM and BLE sit in between, so the four systems are complementary rather than interchangeable across the transition.

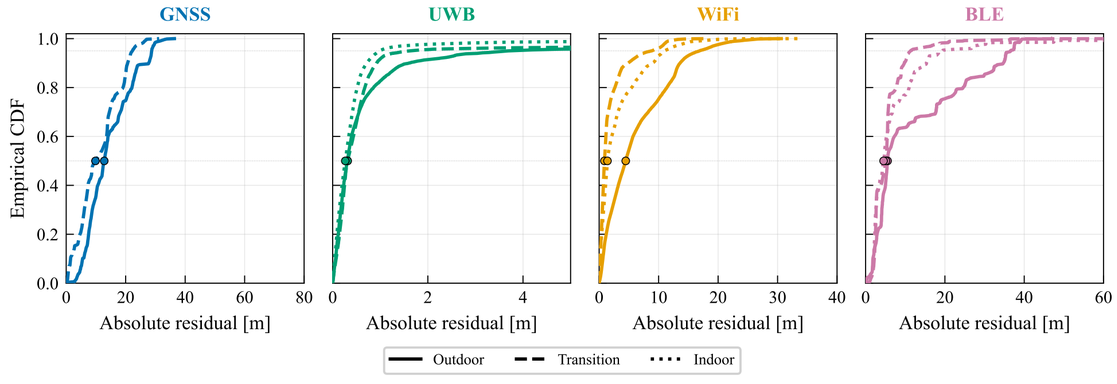


Figure 4: Empirical CDFs of absolute ranging residuals per zone. Linestyles encode zones; dots mark medians. Independent x-axes per technology.

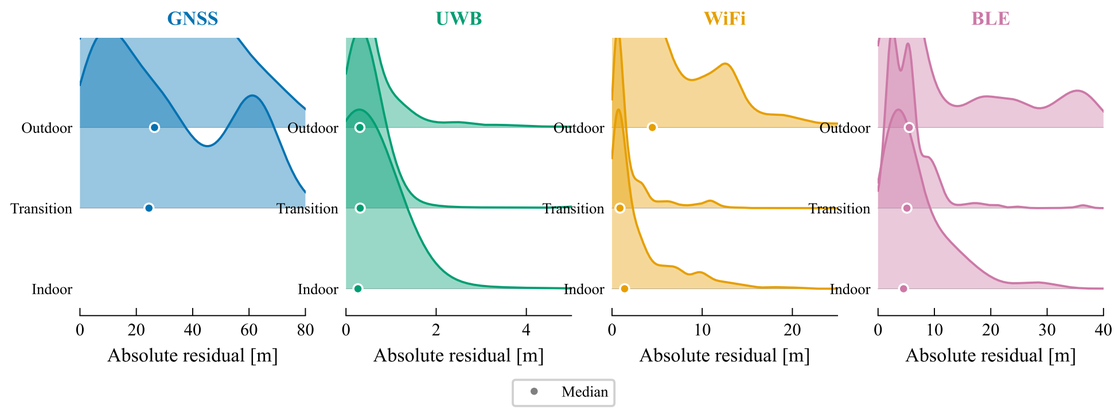


Figure 5: Kernel-density of ranging residuals per technology and zone. Dots mark medians.

Conclusion

Implications. The transition zone is critical: satellite and terrestrial ranging degrade together at the gate, so an estimator weighting all measurements equally fails where it matters most. Heavy-tailed, per-technology residuals rule out a single Gaussian model and call for robust handling, while per-anchor bias motivates self-calibrating infrastructure.

Bridging communities. GNSS contributes rigorous error budgets and integrity monitoring, while indoor positioning brings heterogeneous modalities, empirical error models, and self-calibration. Robust factor graphs already handle urban-canyon GNSS, and integrity concepts are entering ·obotics. The barrier that remains is mismatched terminology.

Full Paper

ITVS Informationstechnik für Verkehrssysteme

DRESDEN concept