

EVALUATING THE PERFORMANCE OF GNSS RTK AND UAV (DRONE) TECHNOLOGIES UNDER VRS MODE IN CHALLENGING ENVIRONMENTS

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Abstract

Reliable geospatial data acquisition in obstructed environments is important for engineering surveying, but buildings, vegetation, multipath, and operational restrictions can reduce positioning reliability. This field study compared Global Navigation Satellite System Real-Time Kinematic (GNSS RTK), an RTK-enabled unmanned aerial vehicle (UAV) using Virtual Reference Station (VRS) corrections, and handheld Simultaneous Localisation and Mapping (SLAM) across urban, forested, mixed-use, and semi-urban sites in Sri Lanka. Static GNSS and closed Total Station traverses established the reference coordinates. GNSS RTK was tested at all four sites, UAV RTK only in the urban corridor, and SLAM in the forested and mixed-use sites. Horizontal performance was assessed using root mean square error (RMSE), median, 95th percentile, maximum error, and availability. GNSS RTK RMSE values ranged from 0.064 to 0.121 m, UAV RTK recorded 0.106 m in the urban corridor, and SLAM recorded 0.160 m in the forest and 0.299 m in the mixed-use site. GNSS RTK gave the lowest errors where a stable FIX was available; UAV RTK provided rapid coverage, while SLAM maintained continuous mapping with higher drift-related error. Technology selection should therefore reflect required accuracy, coverage, access, and operating constraints.

Keywords: Surveying, LiDAR mapping, SLAM, Positional accuracy, Infrastructure monitoring

1. Introduction

GNSS RTK can provide centimetre-level positioning in favourable conditions, while RTK-enabled UAVs and LiDAR-based mobile mapping support rapid spatial data acquisition. Urban canyons, dense vegetation, and terrain masking reduce satellite visibility and introduce multipath and non-line-of-sight signals [1]. Network RTK and VRS reduce distance-dependent atmospheric errors but cannot remove local obstruction effects [2].

Previous studies commonly evaluate GNSS RTK, UAV mapping, or alternative positioning methods separately [3,4]. This study provides a field-based comparison of current GNSS RTK, UAV LiDAR, and handheld SLAM applications in engineering surveying using a common reference framework. The objectives were to compare horizontal accuracy and availability, examine environmental effects, and provide task-specific technology-selection guidance.

2. Materials and Methods

Four environments were studied: the Sarasavi Mawatha urban corridor at the University of Kelaniya, Kaju Kale forest and a mixed-use campus area at the University of Moratuwa, and a semi-urban preliminary site at Pita Kotte.

Reference coordinates were established from approximately one-hour static GNSS observations and post-processed closed Total Station traverses. All traverse networks satisfied a closing linear fractional error of 1/10,000 or better. Point-level covariance for the adjusted reference coordinates was not retained, so formal uncertainty propagation was not possible;

reported errors are therefore discrepancies relative to the adjusted reference network. GNSS RTK was collected at all four sites; DJI Matrice 350 RTK/Zenmuse L2 data were collected only in the urban corridor; and a GoSLAM M40 was used in the forested and mixed-use sites because UAV approval was unavailable near Ratmalana Airport. The semi-urban site used GNSS RTK only.

UAV and SLAM point clouds were processed in 3Dsurvey and compared with reference checkpoints. Easting and Northing differences were used to calculate horizontal error, RMSE, median, 95th percentile, maximum error, and availability. N denotes common checkpoints used in each statistical comparison; availability denotes usable observations relative to planned checkpoints.

3. Results and Discussion

Table 1 reports the requested sample size, error-distribution statistics, and field availability for each dataset.

Table 1: Comparative horizontal positioning performance.

Site	Tech.	N	Median (m)	RMSE (m)	95th pct. (m)	Max (m)	Avail. (%)
Urban	GNSS RTK	15	0.044	0.064	0.110	0.115	100
Urban	UAV RTK	15	0.091	0.106	0.170	0.252	83.3
Forest	GNSS RTK	16	0.075	0.079	0.103	0.107	84.3
Forest	SLAM	16	0.139	0.160	0.257	0.358	100
Mixed-use	GNSS RTK	19	0.068	0.074	0.099	0.113	100
Mixed-use	SLAM	19	0.287	0.299	0.486	0.489	100
Semi-urban	GNSS RTK	35	0.106	0.121	0.186	0.216	100

GNSS RTK showed lower central and tail errors than UAV RTK in the urban corridor, while UAV availability fell to 83.3% because three of 18 planned points were unavailable. Forest GNSS RTK retained lower errors at valid FIX stations but availability fell to 84.3%; SLAM maintained full route coverage with higher error. Mixed-use SLAM showed the largest tail error (95th percentile 0.486 m; maximum 0.489 m). Figure 1 shows the median, 95th percentile, and maximum error for each dataset rather than repeating the RMSE-only comparison.

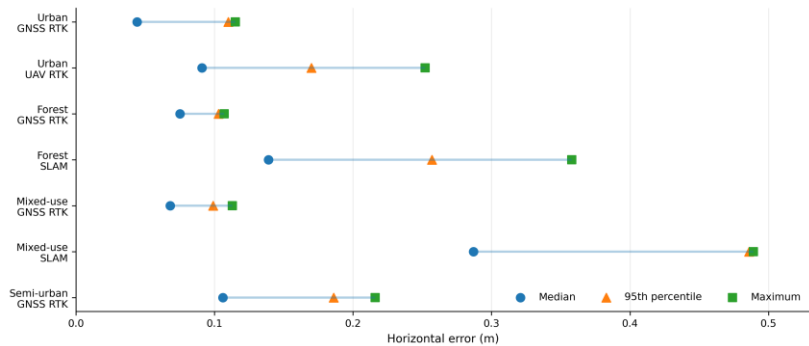


Figure 1: Horizontal error distribution summary by technology and environment.

4. Practical Implications

GNSS RTK is appropriate for accuracy-critical control where a stable FIX is available. UAV RTK can support rapid corridor or area mapping when its approximately 0.1 m RMSE and flight conditions meet project tolerances. SLAM preserved continuity in the forested and mixed-use sites, but its 0.160-0.299 m RMSE limits use for precision control; UAV and SLAM outputs should be verified against independent GNSS or Total Station control for engineering decisions.

5. Conclusions

GNSS RTK produced the lowest horizontal errors but lost availability beneath dense canopy. UAV RTK provided rapid urban coverage but showed greater variability and missing observations under severe obstruction. SLAM maintained continuous coverage where UAV operation was not feasible, although drift reduced accuracy. Technology should therefore be selected by task and tolerance rather than treated as interchangeable. Future work should retain reference-network covariance for formal uncertainty propagation and examine mountainous terrain and tighter GNSS-inertial-LiDAR-SLAM integration.

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References

- [1] M. Aldibaja, N. Sukanuma, K. Yoneda, and R. Yanase, "Challenging environments for precise mapping using GNSS/INS-RTK systems: Reasons and analysis," *Remote Sens.*, vol. 14, no. 16, p. 4058, 2022.
- [2] T.-S. Bae and M. Kim, "Performance analysis of network-RTK techniques for drone navigation considering ionospheric conditions," *J. Sens.*, vol. 2018, Art. no. 5154697, 2018.
- [3] L. Tavasci, F. Nex, and S. Gandolfi, "Reliability of real-time kinematic positioning for low-cost drones navigation across global navigation satellite system critical environments," *Sensors*, vol. 24, no. 18, p. 6096, 2024.
- [4] X. Liu, W. Wen, F. Huang, H. Gao, Y. Wang, and L.-T. Hsu, "3D LiDAR aided GNSS NLOS mitigation for reliable GNSS-RTK positioning in urban canyons," *arXiv:2212.05477*, 2022.

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Graphical Abstract

1 Study environments and technology coverage



Environmental complexity affects both positioning accuracy and operational feasibility.

2 Reference framework and workflow



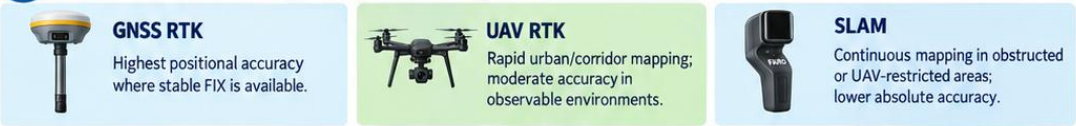
UAV approval unavailable at University of Moratuwa sites near Ratmalana Airport.

3 Key quantitative results

Environment	Technology	RMSE (m)	Availability (%)	RMSE (m) – visual	Availability (%) – visual
Urban	GNSS RTK	0.064	100	0.064	100
	UAV RTK	0.106	83.3	0.106	83.3
Forest	GNSS RTK	0.079	84.3	0.079	84.3
	SLAM	0.160	100	0.160	100
Mixed-use	GNSS RTK	0.074	100	0.074	100
	SLAM	0.299	100	0.299	100
Semi-urban	GNSS RTK	0.121	100	0.121	100

Forest GNSS RTK values are based on valid FIX observations. Lower RMSE indicates higher accuracy.

4 Main findings and practical guidance



No single technology is optimal in every setting. Select the method according to required accuracy, spatial coverage, site access, and operating constraints.