Comparative Assessment of Low-Cost SLAM-Based Scanners for Indoor Surveying Applications

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Abstract

The rapid diffusion of low-cost Simultaneous Localization and Mapping (SLAM), based mobile laser scanners is reshaping indoor surveying by enabling fast kinematic acquisitions with limited operational constraints, while raising critical questions regarding metric reliability and geometric fidelity. This paper presents a comparative assessment of four commercial SLAM-based scanners spanning different market segments, from entry-level to professional-grade solutions. The analysis focuses on point cloud quality, geometric noise, registration stability, and the preservation of planar surfaces and sharp edges under controlled indoor conditions.
For objective validation, SLAM-derived point clouds were compared with reference datasets acquired using a high-precision terrestrial laser scanner and a multi-station instrument certified to international metrological standards. All datasets were collected following a standardized experimental protocol and processed using proprietary software without additional filtering to isolate intrinsic system performance. Quantitative evaluation relied on target-based registration accuracy and planar section analysis, complemented by a qualitative assessment of noise patterns and edge preservation. The results reveal a clear stratification among systems. Mid-range devices demonstrate strong geometric performance, in some cases comparable to professional solutions, largely due to advanced processing algorithms, whereas the entry-level system exhibits significant limitations in noise control and geometric stability. The findings highlight a non-linear relationship between cost and performance and highlight the relevance of standardized validation protocols to support informed adoption of SLAM technologies in professional surveying workflows.

1. Introduction

1.1 Context and technological evolution in geomatics

In modern geomatics and topographic surveying, the last decade has witnessed an unprecedented technological revolution, marked by an exponential increase in the adoption of innovative solutions for measurement, documentation, and three-dimensional modelling. This transformation began with the large-scale commercial introduction of consumer-grade Unmanned Aerial Vehicles (UAVs), a phenomenon that broadened access to photogrammetric techniques previously considered the exclusive domain of specialists. As noted by Alathamneh et al. (2024), this democratization of advanced spatial data acquisition has made sophisticated tools accessible to a broader professional audience, introducing new opportunities for efficiency while raising questions about operational consistency and quality control.
At present, the geomatics sector is experiencing a similar evolutionary dynamic in laser-scanning systems. This technology represents the conceptual and operational evolution of motorized total stations, redefining consolidated paradigms in territorial surveying and architectural documentation. Unlike traditional Total Stations (TS), which estimate coordinates for targeted points relatively slowly, laser scanners estimate azimuth and zenith angles at extremely high speeds via the rapid rotation of the instrument's moving parts. By measuring distances in microseconds, these systems enable the massive acquisition of millions of points. This wealth of data enables metric analyses and 3D modeling at previously inaccessible levels of detail, though it introduces additional complexity in the post-processing phase to recognize specific objects of interest that, in traditional surveying, were defined during the measurement phase.

1.2 The Advent of SLAM Systems and Operational Challenges

The focus of current research is an emerging technology that is driving the widespread adoption of surveys in complex and operationally challenging environments: laser-scanning based on Simultaneous Localization and Mapping (SLAM) algorithms. These systems represent a significant qualitative leap compared to traditional static laser scanners. By integrating multidirectional laser emission with sophisticated real-time self-localization algorithms, SLAM systems enable dynamic, real-time modeling of complex geometries (Urban et al., 2024).
The distinctive feature of SLAM-based scanners is their ability to operate in kinematic mode, eliminating the need for multiple tripod setups and enabling continuous acquisition as the operator moves through the environment. This approach effectively minimizes "shadow zones" that would otherwise require additional setups and complex registration phases. However, maintaining global geometric consistency requires continuous, precise reconstruction of the sensor's trajectory. Simultaneous localization algorithms must process geometric information in real time, solving nonlinear systems of equations to optimize both the sensor's path and the environment's mapped geometry.
Despite the breakthrough efficiency of these systems, their widespread use raises critical quality-control issues. The simplified interfaces of modern SLAM devices may reduce the perceived need for rigorous validation procedures, potentially affecting survey accuracy if not properly addressed (Ingles et al., 2024). Previous comparative studies have already highlighted that the metric reliability of SLAM outputs is heavily dependent on trajectory characteristics, environmental geometry, and the inherent robustness of the underlying algorithms (Chrbolková et

al., 2025; Biström, 2018). Different commercial solutions employ distinct algorithmic approaches to address these computational challenges, resulting in significant variations in final performance and the qualitative characteristics of the generated point clouds. Within this framework, the present study compares the quality and accuracy of four SLAM-based solutions across different price points to establish best practices and guide professional use. The objective is not to benchmark SLAM algorithms per se, but to characterize the geometric behavior of commercially available systems under controlled conditions.

2. Materials and methods

2.1 Instrument Characterization and Hardware Consistency

The study presents a comparative evaluation of four SLAM-based mobile scanning systems that exemplify different technological tiers and design approaches currently available on the commercial market. This configuration represents a methodological advantage, as it allows the acquisition hardware to be treated as a controlled variable and highlights the role of SLAM processing strategies. The selected instruments span a wide range of implementation strategies, from entry-level devices to professional-grade platforms, with particular emphasis on integrating sensor fusion, trajectory estimation, and mapping algorithms across market segments. In SLAM-based workflows, point cloud quality emerges from the combined influence of sensing geometry, measurement noise, and the performance of trajectory estimation and optimization procedures (e.g., scan matching, loop closure, graph refinement). This interplay justifies a comparative framework that considers both hardware configuration and algorithmic design (Carlone et al., 2025; Mostafa et al., 2023).

(a) (b) (c) (d)

Figure 1. The SLAM devices: Eagle Max RTK (a), SHARE S20 (b), Lixel Kity K1 (c), and Leica BLK2GO (d)

The Eagle Max RTK system (Figure 1a) represents the entry-level tier and incorporates the Livox Mid-360 LiDAR sensor (Figure 2), the same acquisition unit used by the Share S20 and Lixel Kity K1 systems (Figures 1b and 1c). Such sensor homogeneity constitutes a methodological advantage, as it enables the acquisition hardware to be treated as a controlled variable. Consequently, observed differences in point cloud quality can be attributed primarily to the respective SLAM pipelines, specifically, the registration framework, pose-estimation strategy, and global optimization routines, rather than to disparities in raw measurement performance. This is consistent with the premise that, once sensor characteristics are fixed, algorithmic design becomes the main determinant of drift mitigation and reconstruction consistency (Carlone et al., 2025; Chen et al., 2019). The Mid-360 itself provides omnidirectional horizontal coverage, a wide vertical field of view, and nominal performance specifications compatible with continuous frame-to-frame registration in mobile mapping.

(a) (b)

Figure 2. Livox Mid 360 LiDAR sensor (a), and its acquisition angle (b)

Despite the advantages of controlled sensor conditions, the Eagle Max RTK reveals limitations in its GNSS implementation under the tested conditions. Although marketed under “RTK” terminology, the system does not support real-time kinematic correction during acquisition; instead, it records standard GNSS observations for subsequent post-processed correction, effectively corresponding to PPK operation (Lauer, n.d.). The device is also constrained to the WGS84 reference frame, hindering straightforward integration with national or local geodetic realizations. Furthermore, the lack of diagnostic tools to monitor satellite geometry and solution robustness prevents operators from identifying and mitigating problematic GNSS segments (e.g., occlusions, multipath, poor satellite geometry). In professional surveying contexts, real-time quality indicators, including satellite count and dilution-of-precision metrics, play an essential role in assuring the reliability of GNSS-derived positions; GDOP, in particular, is recognized as a key geometry-based index of positional uncertainty (Teng & Wang, 2015). These constraints limit the system’s applicability in workflows requiring verifiable geodetic accuracy.

The mid-range tier comprises the Share S20 (Figure 1b) and the Lixel Kity K1 (Figure 1c), both of which use the Livox Mid-360 sensor but differ significantly in their auxiliary subsystems and software ecosystems. Each integrates a fully operational RTK module that receives differential corrections via NTRIP-based data streams, enabling real-time georeferencing when network conditions permit. NTRIP, widely used for GNSS correction delivery, provides standardized dissemination of RTCM and other correction formats over IP networks. Both systems also offer interfaces for configuring correction parameters and monitoring solution quality during acquisition and post-processing, including visualizations of indicators such as satellite availability, GDOP, and estimated accuracy, which are essential for maintaining systematic quality control in professional surveying environments (Teng & Wang, 2015).

Differences within this tier are primarily associated with the breadth and integration of proprietary software toolchains. The Share S20 environment offers a workflow aligned with that of Leica’s BLK2GO system (Figure 1d), including trajectory recalculation, control-point registration, interoperability with external point clouds, and in-cloud measurement capabilities. These functionalities address common SLAM post-processing needs, particularly those relating to trajectory refinement and drift compensation (Chen et al., 2019; Mostafa et al., 2023). The Lixel Kity K1 software extends this baseline with advanced restitution and analysis tools, including quality checks on control measurements, direct volume computation, and sectioning utilities for generating two-dimensional deliverables. Comparable advanced functions typically require external specialized software when working with BLK2GO or Share S20 datasets.

Although differences in SLAM strategy may yield distinct behaviors in drift accumulation, loop-closure management, and

trajectory refinement, the present analysis concentrates primarily on the resulting point cloud characteristics, particularly quality and noise. Accordingly, specific implementation details of individual SLAM pipelines are treated as secondary, consistent with the broader understanding that point cloud properties reflect both sensor noise and the cumulative effects of registration and trajectory estimation (Carlone et al., 2025; Chen et al., 2019).
Finally, the Leica BLK2GO (Figure 1d), representing the professional tier, adopts a markedly different design philosophy. The instrument does not include GNSS positioning; instead, it prioritizes high-precision laser sensing and robust inertial integration, aligning with use cases such as indoor mapping and architectural documentation where internal consistency and relative accuracy take precedence over absolute georeferencing. Marketed as a handheld imaging laser scanner operating under the “GrandSLAM” framework, the BLK2GO provides stated accuracy levels under controlled indoor conditions and supports an end-to-end workflow optimized for rapid, detailed 3D capture in GNSS-denied environments. The performance advantages of this system stem from certified precision components, tightly integrated inertial sensing, and proprietary technologies designed to ensure metric reliability in demanding operational contexts (Mostafa et al., 2023).

2.2 Reference Systems for Validation and Quality Control

To ensure an objective comparison of the tested SLAM systems, two reference surveys were conducted using instruments certified to international metrological standards. The combined use of these high-precision platforms provided a robust, traceable dataset for validating the point clouds generated by the mobile systems, in line with established best practices in accuracy assessment for terrestrial laser scanning (e.g., Lichti, 2013; Schneider et al., 2018).
The first reference dataset was acquired with the Riegl VZ-600i terrestrial laser scanner (Figure 3a), a state-of-the-art instrument widely adopted for topographic and architectural documentation. The device delivers high-fidelity point clouds, enabled by a nominal range accuracy of ±5 mm at 100 m and an angular resolution of 0.0024°, characteristics that make it a recognized benchmark in scientific applications.

(a) (b)

Figure 3. The devices used for validation: Riegl VZ-600i (a), and Leica MS60 MultiStation (b)

A second independent reference was produced using the Leica MS60 MultiStation (Figure 3b), which integrates the functions of a precision total station and a terrestrial scanner. Its angular accuracy of ±1″ and distance accuracy of ±1 mm + 1.5 ppm provide a solid geometric control framework, particularly suitable for verifying the absolute accuracy of SLAM-derived point clouds.
Together, the VZ-600i and MS60 surveys established a rigorous metric reference, enabling a reliable evaluation of geometric deviations and ensuring traceability throughout the validation process.

2.3 Design and Implementation of the Experimental Protocol

The experimental protocol was designed in accordance with principles of scientific rigor to enable an objective, quantitative assessment of geometric noise and dimensional accuracy in SLAM-generated point clouds. Proprietary processing environments were used without applying any additional denoising or optimization algorithms, thereby isolating the intrinsic performance of each system—an approach commonly adopted in validation studies of SLAM-based mapping (Mostafa et al., 2023; Chen et al., 2019).
A controlled indoor environment was selected to ensure repeatability of the experiments. The room featured smooth, planar surfaces and uniform reflectance, minimizing surface-related variability and enabling a clear characterization of instrumental noise. Wall planarity was verified using topographic instrumentation to confirm compliance with the experimental requirements.
The reference framework was materialized by placing six high-reflectance artificial targets along the perimeter walls, arranged to optimize geometric redundancy during registration. Each target was measured with the Leica MS60 using redundant observation schemes to enhance coordinate reliability. All reference data were expressed in a local coordinate system optimized to minimize transformation uncertainties during alignment.
The geometric model of the environment was obtained from three static scans acquired with the Riegl VZ-600i. The scanner positions were selected to guarantee complete coverage and sufficient redundancy. Registration of the scans was performed in RiSCAN PRO using bundle-adjustment algorithms to ensure globally optimized geometry, an established method for high-precision TLS datasets.

2.4 Acquisition Protocol and Software-Specific Considerations

Acquisition using the four SLAM systems followed a standardized internal protocol designed to ensure comparable results and minimize uncontrolled experimental variables. A fixed trajectory was defined within the laboratory test room to ensure full coverage of the surfaces of interest while maintaining operational distances consistent with typical professional indoor surveying practices. Representative examples of these trajectories are shown in Figure 4 for the four systems. Each acquisition was constrained to a maximum duration of 60 seconds to limit the accumulation of temporal drift, an effect particularly pronounced in low-cost systems equipped with less accurate inertial sensors. Although this constraint reduces the temporal scope of the tests, it enables the evaluation to focus on the intrinsic performance of the SLAM algorithms while minimizing time-dependent degradation mechanisms, in accordance with established experimental practices for SLAM validation.
During the analysis, some software-related constraints were observed in the Eagle Max RTK system, likely attributable to its low-cost design approach, potentially affecting overall performance and future scalability. The proprietary software processes geometric reconstruction and RGB-based coloring as two independent operations, resulting in two separate outputs: (i) a geometrically more accurate but uncolored point cloud, and (ii) a colored point cloud with higher noise and reduced metric quality. This architectural choice has direct implications for

registration on reference targets. The monochrome geometric cloud lacks sufficient definition for reliable identification of target centers, even when relying on laser reflectance values; despite the high contrast of the artificial targets, the Eagle Max RTK pipeline fails to preserve this contrast adequately in the point cloud to support precise detection. Consequently, the colored point cloud was adopted for all registration and analysis stages, accepting a necessary compromise in geometric accuracy that mirrors the operational constraints users would encounter in real-world applications. Higher-tier systems do not exhibit such issues, as their integrated processing architectures allow color information to be applied directly to the optimized geometric cloud, ensuring full alignment between geometric, radiometric, and reflectance attributes. This difference reflects varying levels of software integration and processing maturity across the analyzed systems.

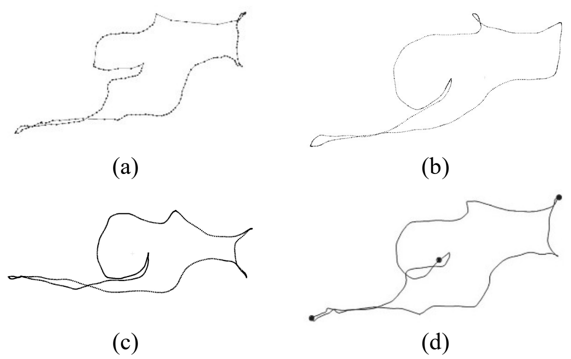

Figure 4. The SLAM trajectories: Eagle Max RTK (a), SHARE S20 (b), Lixel Kity K1 (c), and Leica BLK2GO (d)

3. Results

3.1 Registration Performance and System Stability Under Controlled Conditions

The registration of point clouds onto the reference targets yielded quantitatively satisfactory results for all analyzed systems, as indicated by the residual discrepancies at the control points. The RMS (Root Mean Square) errors remained within acceptable thresholds relative to the nominal specifications of each instrument, as summarized in Table 1. RMS values range from 6–8 mm for mid-range and professional systems, increasing to approximately 18 mm for the entry-level solution. It is important to note, however, that these performance levels were obtained under highly controlled experimental conditions, characterized by a compact test environment and acquisition durations limited to 60 seconds.

Setting	RMS [m]
Riegl VZ-600i	0.002
Leica BLK2GO	0.007
Xgrids Lixel K1	0.006
Share S20	0.008
3DMakerpro Eagle Max RTK	0.018

Table 1. RMS registration errors of all tested systems with respect to the Leica MS60 control targets

The primary objective of this phase was to ensure the most accurate possible alignment between the SLAM-derived point clouds and the reference targets, thereby establishing a reliable basis for the subsequent analysis of intrinsic noise characteristics. Even under conditions specifically designed to enhance global geometric consistency, namely a small indoor environment and minimal temporal drift, preliminary differences among the systems were already detectable. These discrepancies suggest that broader performance variability may emerge under more demanding acquisition scenarios.

The favorable results observed in this controlled environment must therefore be contextualized. The low residual variance and the high level of geometric consistency achieved during registration, demonstrated by the alignment with the targets measured using the Leica MS60 and located within the limited spatial extent of the test room, are directly linked to the spatial constraints of the environment and, crucially, to the 60-second limit imposed on each acquisition.

Additional tests, not included in the present analysis, indicated different system behaviors in larger and more complex environments. revealed markedly different behaviors among the systems. The Eagle Max RTK, in particular, exhibited recurrent algorithmic instabilities, including geometric misalignment, progressive trajectory drift, and loss of global mapping coherence. These issues reduce the system’s reliability in applications involving extended trajectories or complex geometries that require longer acquisition times or navigation within articulated spaces. Importantly, the observed instabilities occurred consistently across multiple trials, confirming that they do not represent isolated anomalies.

By contrast, the Share S20, Lixel Kity K1, and Leica BLK2GO demonstrated substantially more stable and robust SLAM performance. Although an exhaustive assessment under complex operational conditions was not conducted in this study, preliminary tests, combined with evidence from the literature, indicate that these systems exhibit dependable behavior in standard surveying scenarios. Among them, the Leica BLK2GO represents the benchmark for algorithmic robustness, though under the controlled conditions adopted here, its performance showed only marginal qualitative advantages over the mid-range systems.

These findings reflect the intrinsic computational complexity of SLAM, which requires the simultaneous resolution of sensor self-localization and geometric reconstruction of the environment. Overall, the results reveal a clear stratification among systems: the mid-range and professional-grade instruments implement sufficiently mature and robust algorithms to ensure reliable performance across varied contexts, whereas the entry-level solution exhibits inherent limitations that constrain its suitability for applications demanding high reliability or extended operational continuity.

3.2 Geometric Noise Analysis of Planar Sections

The geometric noise assessment was performed using planar sections extracted from the point clouds. This approach enables an objective quantification of section thickness and reveals characteristic noise patterns that function as a technological “digital signature” for each system, reflecting the underlying design philosophy and implementation choices of the respective manufacturers.

The reference dataset acquired with the Riegl VZ-600i (Figure 5) exhibits the highest point density among all analyzed systems, with planar section thicknesses typically ranging between 8 and 10 mm. The point distribution shows a sharp decay beyond the nominal noise threshold, generating crisp, well-defined linear profiles that accurately represent the true geometry of the surveyed surfaces. This behavior constitutes the qualitative benchmark against which the other systems were evaluated.

The Leica BLK2GO (Figure 6) displays a markedly different pattern, generating point clouds characterized by a discontinuous, dotted distribution rather than a continuous line. The average thickness is approximately 15 mm, higher than the reference, accompanied by local jitter expressed as irregular micro-variations along the section. Despite its distinctive signature, the overall geometric consistency remains within acceptable limits. This behavior is attributable to the engineering priorities of the BLK2GO, which emphasize geometric fidelity over point density.

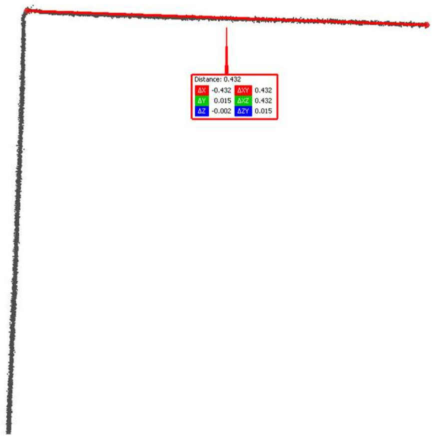

Figure 5. Riegl VZ600i laser acquisition with measurement parameter (shorter side approx. 43 cm)

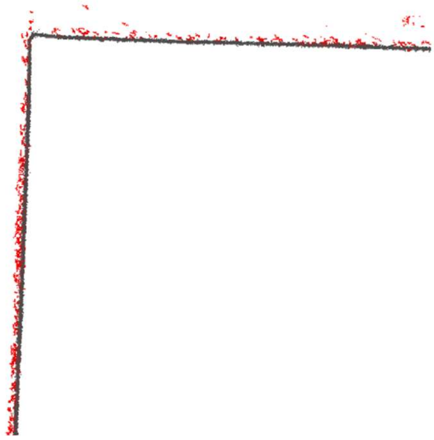

Figure 6. Comparison of BLK2GO (red) against Riegl VZ600i (black)

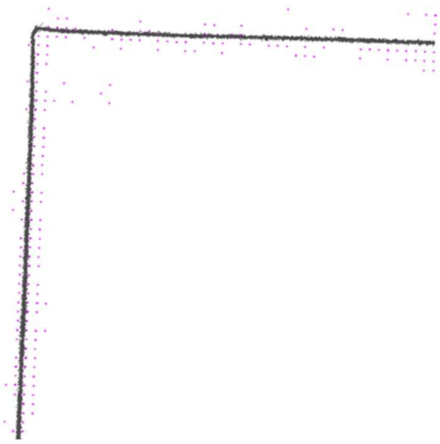

Figure 7. Comparison of Eagle Max RTK (magenta) against Riegl VZ600i (black)

The Eagle Max RTK (Figure 7) shows the most evident limitations, with planar section thicknesses of 40–50 mm, substantially higher than those of all other systems. The point cloud exhibits a regular grid-like pattern, likely resulting from simplified sampling strategies adopted to reduce computational load. The presence of systematic noise beyond the nominal thickness threshold suggests deficiencies in sensor calibration or in the implementation of error-correction routines typical of entry-level devices.

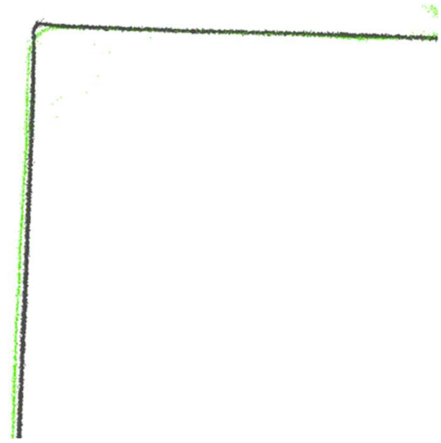

Figure 8. Comparison of Share S20 (green) against Riegl VZ600i (black)

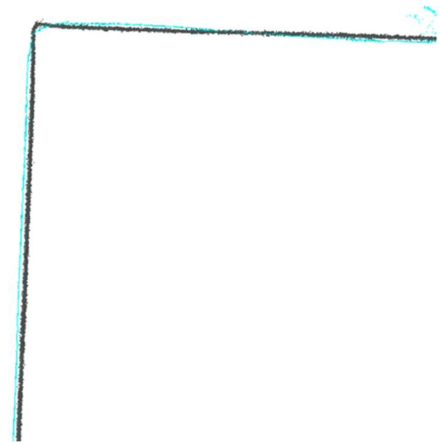

Figure 9. Comparison of Lixel Kity K1 (cyan) against Riegl VZ600i (black)

The mid-range systems, Share S20 and Lixel Kity K1 (Figures 8 and 9), deliver unexpectedly strong performance, with noise levels on planar surfaces lower than those of the Riegl VZ-600i, a result of aggressive filtering strategies rather than intrinsic sensor precision. The Share S20 achieves section thicknesses of approximately 6–8 mm using automatic cleaning and thinning filters, though occasional outliers remain. The Lixel Kity K1 reaches even thinner profiles, around 5–7 mm, likely due to more advanced smoothing procedures.

These algorithmic strategies, however, introduce a trade-off: a slight tendency to soften sharp geometric transitions, resulting in minimal edge rounding. While negligible in many operational contexts, this effect may become critical in applications requiring strict preservation of fine geometric details, such as architectural restoration or structural diagnostics, where centimeter-level precision is mandatory.

In such scenarios, the Riegl VZ-600i remains the most reliable solution. Although it exhibits slightly higher planar noise than aggressively filtered mid-range systems, it preserves geometric detail with greater fidelity, ensuring superior overall metrological accuracy.

3.3 Analysis of Geometric Fidelity in Edge and Angle Preservation

The ability of a SLAM system to preserve the original geometric characteristics of the surveyed environment is a fundamental parameter for assessing its suitability for professional applications. The adopted methodology focused on a portion of the test room characterized by perfectly smooth surfaces intersecting at well-defined right angles, a configuration that enables an objective assessment of representation fidelity.
The reference dataset acquired with the Riegl VZ-600i (Figure 5) demonstrates excellent adherence to geometric reality. The system accurately reconstructs sharp angular transitions and produces well-defined edges, confirming its role as the qualitative benchmark for comparison.
The Leica BLK2GO (Figure 6), despite the previously noted discontinuous point distribution, maintains strong performance in preserving geometric edges. The system successfully retains the original angular characteristics, indicating the use of advanced feature-preservation procedures that compensate for lower point density and local jitter. The Share S20 (Figure 8) exhibits generally positive behavior, with only a slight tendency to smooth the most pronounced edges. Although this effect introduces a minimal deviation from the true geometry, it remains within acceptable thresholds for most operational contexts. The behavior reflects the application of smoothing filters calibrated to balance noise reduction and detail preservation. The Lixel Kity K1 (Figure 9) exhibits a more pronounced smoothing effect, resulting in visible rounding of sharp corners and partial transformation of right angles into curved profiles. This characteristic, also observed, though to a lesser extent, in the Share S20, constitutes a limitation for applications requiring strict preservation of geometric detail. The Eagle Max RTK (Figure 7) confirms the limitations observed in the previous analyses. The point cloud is affected by high geometric uncertainty and significant noise, and the grid-like distribution pattern introduces artifacts that compromise edge and angular transition representation. These deficiencies substantially reduce the system’s suitability for tasks requiring high metrological accuracy.

3.4 Grid-Based Approach in Point Cloud Processing

The grid-based methodology represents a structured strategy for organizing raw point cloud data, yet its implications extend beyond simple discretization. By partitioning the three-dimensional space into a regular lattice of voxels, the approach enables efficient indexing and uniform data handling. In the analyzed case, the point cloud is mapped onto a Cartesian grid, where each voxel aggregates all points within its volume and may store occupancy information, descriptive statistics, or additional metadata. This structure facilitates downstream processing steps such as filtering, classification, or local surface analysis, offering a computationally tractable framework for managing dense datasets.
Nevertheless, the comparative system assessment indicates that such discretization carries methodological consequences that must be critically acknowledged. A fixed voxel size imposes an intrinsic scale on the data, effectively acting as a low-pass filter that may attenuate or eliminate fine geometric features. When the voxel dimension is large relative to the characteristic size of the surveyed elements, small details risk being blurred or entirely suppressed, altering the interpretability of the reconstructed geometry. Furthermore, quantization effects inherent to voxelization may introduce stepped morphologies or artificial discontinuities on smooth surfaces, thereby reducing geometric fidelity and potentially biasing subsequent analyses.
These observations suggest that the grid-based approach, while computationally efficient, inherently trades spatial detail for regularity and speed. Its performance is therefore highly dependent on the chosen voxel resolution and on the specific objectives of the survey. When implemented without explicit consideration of these methodological implications, voxelization may shift the balance away from metrological accuracy toward simplified geometric representation. In this sense, the identified limitations are not merely technical; they also affect the broader interpretability and reliability of the resulting point cloud products, particularly in applications that rely on subtle geometric cues.

3.5 Considerations on Cost–Performance Ratios

The comparative evaluation reveals a non-linear relationship between system cost and performance quality, emphasizing the need for a multifaceted perspective when assessing cost-effectiveness. Mid-range systems demonstrate geometric performance that, in specific scenarios such as the present controlled experiment, is comparable to or even exceeds that of substantially more expensive solutions. This observation underscores the decisive role of proprietary processing algorithms in determining the overall quality of the final point cloud.
The phenomenon likely reflects different commercial and engineering strategies. Manufacturers of premium systems tend to invest heavily in high-precision hardware components, extended calibration procedures, and certification processes. Conversely, producers of mid-range systems often prioritize developing optimized software algorithms that extract maximum performance from standard hardware configurations. These divergent philosophies open interesting opportunities for users seeking high-quality outputs without the financial investment typically associated with top-tier instruments.

3.6 Analysis of Implemented Algorithmic Approaches

The experimental results reveal substantial differences in data-processing strategies among the analyzed systems, each reflecting distinct design philosophies and intended application domains. The conservative approach, adopted by the Riegl VZ-600i and partially by the BLK2GO (Figures 5 and 6), aims to preserve the raw data as faithfully as possible, minimizing algorithmic interventions that could introduce distortions or eliminate meaningful information. This strategy is particularly suitable for metrological applications and scientific documentation requiring maximum representational fidelity. The selective filtering approach, typical of the Share S20 (Figure 8), applies noise-reduction algorithms that eliminate random artifacts while preserving the integrity of salient geometric features. This methodology seeks a balanced compromise between visual quality and geometric accuracy, making it especially suitable for architectural modeling and three-dimensional visualization. The systematic smoothing approach used for the Lixel Kity K1 (Figure 9) employs algorithms that prioritize continuous, homogeneous surface reconstruction over the preservation of sharp geometric details. While this strategy can be advantageous for applications requiring surfaces optimized for CAD workflows or automated generation of simplified models, it may compromise high-fidelity

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representation in more demanding contexts. The grid-based approach observed in the Eagle Max RTK system (Figure 7) appears to stem from computational and software limitations rather than intentional design. The resulting degradation in geometric detail and the introduction of quantization artifacts lead to significantly inferior performance when compared with other systems, limiting its applicability in workflows requiring professional architectural or topographic surveying.

4. Discussion and conclusion

The increasing availability of SLAM-based mapping systems at affordable cost levels is reshaping current surveying practices and expanding their adoption within the geomatics and architectural documentation communities. While this technological diffusion offers clear operational benefits, it also raises methodological considerations that extend beyond instrument performance alone. As acquisition workflows become more accessible and user-centred, the responsibility for ensuring data reliability progressively shifts from specialized operators to the robustness of procedures, documentation practices, and validation frameworks. This shift highlights a critical methodological implication: the absence of harmonized protocols and explicit quality-control strategies can compromise the traceability and reproducibility of results, particularly when systems are used by non-expert operators.

Within this context, the study reinforces the need for dedicated, standardized procedures to characterize and evaluate commercial SLAM systems. The current lack of harmonized testing methodologies complicates cross-system comparisons and limits the ability to objectively assess suitability for specific operational scenarios. However, it is equally important to acknowledge the inherent limitations of controlled experiments. While controlled conditions ensure repeatability and enable systematic parameter isolation, they inevitably simplify the complexity of real-world environments, where SLAM performance is influenced by scene geometry, lighting conditions, environmental dynamics, trajectory design, and acquisition duration. As a result, performance indicators obtained under constrained settings should be interpreted as conditional outcomes rather than universal benchmarks. Their generalization requires caution and must be accompanied by explicit reporting of the assumptions, constraints, and operational simplifications adopted during testing.

These considerations point to the necessity of broader, more diverse validation scenarios. Future assessment frameworks should combine controlled benchmarks with structured field experiments that reflect the full variability of real-world operating conditions. High-priority scenarios include extended indoor–outdoor transitions, feature-poor or repetitive environments, long acquisition sequences that amplify drift, dynamic scenes with moving elements, and geometrically challenging spaces where loop-closure reliability becomes critical. Inter-laboratory initiatives, the creation of shared benchmark datasets, and the use of transparent performance metrics would further support reproducibility and facilitate cross-study comparison. Moreover, incorporating stress tests that explicitly target known SLAM failure modes would provide a more comprehensive understanding of system robustness and operational boundaries.

The technological trends observed in the comparative analysis also suggest key directions for future improvements. Enhancing the quality of inertial subsystems in low-cost solutions, implementing automatic calibration routines, and introducing real-time diagnostic and correction strategies would considerably strengthen operational reliability, particularly for non-specialist users. At the same time, the relationship between cost and performance remains non-linear: under the controlled conditions examined, mid-range systems can approximate the geometric behaviour of higher-end instruments, largely driven by increasingly sophisticated proprietary processing algorithms. This finding underscores that no system emerges as universally optimal; rather, suitability is strongly scenario-dependent and must account for the maturity of the software ecosystem, workflow integration, technical support, and expected technological evolution.

Ultimately, the growing accessibility of SLAM technologies represents both an opportunity and a methodological challenge. To ensure that their diffusion translates into reliable and meaningful surveying outcomes, technical development must be accompanied by investments in training, the definition of rigorous operational standards, and the establishment of shared quality-assurance frameworks. Only through the integration of technological innovation and robust methodological practices can the potential of SLAM systems be fully and responsibly realized within the geomatics community.

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