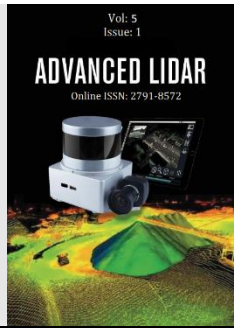
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Research Article /Review Article:

Handheld Laser Scanners in Industrial Applications: A Review of Metrology-Grade and SLAM-Based Systems

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Abstract

Handheld laser scanners have become established tools for measurement and reality capture in industry, yet the single label conceals two technologically distinct families whose accuracies differ by about three orders of magnitude. The first family gathers metrology-grade optical handhelds based on laser triangulation and structured-light projection; these reach volumetric accuracies of roughly 0.02 to 0.1 mm and are used for reverse engineering, dimensional inspection, and geometric dimensioning and tolerancing (GD&T) verification of manufactured parts. The second family gathers simultaneous localisation and mapping (SLAM) based mobile handhelds, which fuse time-of-flight light detection and ranging (LiDAR) with inertial and visual sensing to reach centimetre-level accuracy, typically 5 to 60 mm, for as-built documentation, plant mapping, and digital-twin creation. This review is organised around that division and confines its scope to industrial and production settings, leaving aside construction, mining, and tunnelling. Drawing on peer-reviewed benchmarks, it describes the working principles of each family, tabulates independently measured accuracy, and reviews representative applications in manufacturing quality control, automotive and aerospace inspection, weld and casting evaluation, and plant documentation. Handheld systems are then positioned against coordinate measuring machines, articulated arms, terrestrial laser scanners, and photogrammetry. The evidence indicates that the two families are complementary rather than competing, that field accuracy is consistently poorer than manufacturer specification, and that a synthesis confined to industrial metrology addresses a real gap, since wearable and mobile handhelds have so far been studied mainly for documentation and cadastre rather than production measurement.

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Contribution to the field statement:
This review distinguishes two families of handheld laser scanners by their measurement principles, accuracy, and industrial applications. By synthesizing independent accuracy benchmarks and comparing scanners with established measurement technologies, it clarifies their complementary roles, highlights the gap between manufacturer specifications and field performance, and identifies the need for further validation in operating industrial environments.

Highlights:

- Two scanner families are distinguished by accuracy and measurement purpose.
- Independent studies are reviewed to assess real-world scanning accuracy.
- Industrial applications are matched to the appropriate scanner type.
- Further testing of mobile scanners in operating factories is recommended.

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1. Introduction

Three-dimensional laser scanning has moved from a specialised surveying method to a mainstream measurement technology that supports quality assurance, reverse engineering, and asset documentation throughout manufacturing and heavy industry. Among the available instruments, handheld laser scanners hold a distinctive place, because they pair dense non-contact surface capture with an operator-guided mobility that fixed devices such as coordinate measuring machines (CMMs) and tripod-mounted terrestrial laser scanners (TLS) cannot offer. Being able to bring the sensor to the part, or to the installed equipment, rather than the other way round is often decisive for large assemblies and for components whose geometry is difficult to reach [1], [2].

A persistent source of confusion is that the phrase handheld laser scanner is applied to two families of instruments whose accuracies are separated by about three orders of magnitude. Metrology-grade optical handhelds, built around laser triangulation or structured-light projection, reach volumetric accuracies of roughly 0.02 to 0.1 mm and are used for part inspection, GD&T verification, and reverse engineering [3], [4]. Mobile handhelds based on simultaneous localisation and mapping (SLAM) fuse time-of-flight LiDAR with inertial and visual sensing and map whole rooms, plants, and structures at centimetre-level accuracy, typically between 5 and 60 mm [5], [6]. Treating the two families as interchangeable invites unrealistic expectations, since a metrology handheld cannot cover a factory hall efficiently and a SLAM handheld cannot certify a machined tolerance.

Mobile and wearable handheld scanning has spread quickly in geomatics practice, and Turkish research groups have been particularly active in applying it. Wearable mobile LiDAR has been tested for cadastral surveying and for the rapid three-dimensional modelling of buildings [7], [8], while terrestrial laser scanning continues to underpin national documentation workflows for architectural and cultural assets [9], [10]. Integrated pipelines that merge terrestrial scanning with photogrammetry have likewise become common [11]. These applications are, however, overwhelmingly oriented towards documentation and cadastre rather than production metrology, which is precisely the emphasis of the present review.

The review is therefore organised around the two-family taxonomy and restricted to industrial and production use, leaving construction, mining, and tunnelling aside, since those domains follow different accuracy budgets and are already well served elsewhere [12]. Four questions structure the discussion: how each family works, what accuracy it delivers under independent testing, where it is applied in practice, and how it compares with the established alternatives of CMM, articulated arm, TLS, and photogrammetry. Consolidating peer-reviewed benchmarks for both families under a single industrial lens is the main contribution, because existing surveys tend to treat shop-floor metrology and facility mapping in isolation. Throughout, technical terms and abbreviations are defined at first use and sources are numbered in order of first appearance, following the IEEE style.

2. Review method

This article is a narrative review rather than a systematic one, and its evidence base was assembled through a structured search rather than a formal meta-analytic protocol. Candidate studies were identified with the Consensus academic search service together with the Web of Science and Scopus indexing records, using combinations of the terms handheld laser scanner, structured-light scanner, SLAM scanner, dimensional metrology, reverse engineering, and industrial inspection. Priority was given to peer-reviewed journal and conference papers published between 2020 and 2025, while a small number of earlier works were retained where they remain the standard reference for a principle or a benchmark.

Sources were then screened against three criteria: relevance to an industrial or production measurement task; a quantified accuracy result obtained against a stated reference system; and sufficient bibliographic completeness for citation. Accuracy claims taken solely from manufacturer marketing material were excluded from the benchmark synthesis, although nominal datasheet values are reported separately and labelled as such. In keeping with the scope defined above, studies confined to construction, mining, or tunnelling were not included, except where a controlled tunnel or bridge experiment provides the only independent measure available for a SLAM device that is also marketed for industrial use.

3. Fundamentals of handheld laser scanning

The two families rest on different physical principles, and their accuracy follows directly from those principles. Metrology-grade handhelds recover geometry optically. In laser triangulation, one or more laser lines are projected onto the surface and imaged by a camera set at a known baseline; the position of the reflected line on the sensor fixes the depth of every illuminated point. Self-referencing against retro-reflective targets, or against the part geometry itself, keeps the result stable despite shop-floor vibration and movement of the part during scanning [13]. Structured-light scanning instead projects coded and sinusoidal fringe patterns over an area, so that the deformation of those patterns encodes the shape of the whole field in a single exposure. Fringe projection captures dense data quickly and usually gives the best form accuracy, though it is more sensitive to ambient light and to surface reflectivity [14].

SLAM-based handhelds recover geometry and motion at the same time. A compact multi-beam LiDAR measures ranges by time of flight as the operator walks, while an inertial measurement unit and, in most current

devices, one or more cameras supply odometry. A SLAM algorithm fuses these streams to estimate the six-degree-of-freedom trajectory of the device and to assemble a consistent point cloud [15]. Accuracy is limited not by any single range measurement but by the gradual accumulation of trajectory error, or drift; revisiting a known location closes a loop and redistributes that error, and external control points bound it further. Fusing many overlapping observations also suppresses random noise and removes transient objects from the final cloud [16]. The same operating principle underlies the wearable mobile systems that have been used for rapid building capture in recent Turkish studies [8].

4. Classification of handheld scanning systems

Figure 1 sets out the taxonomy adopted here. The metrology branch covers laser-triangulation and structured-light devices aimed at individual parts and tooling, verified against a CMM or an articulated arm. The mobile branch covers SLAM devices aimed at rooms, plants, and structures, verified against a TLS or a total station. The two branches share a name and a non-contact optical nature, but almost nothing else: they differ in scale, in accuracy, in the reference instruments used to test them, and in the industrial questions they answer. Table 1 summarises the distinction.

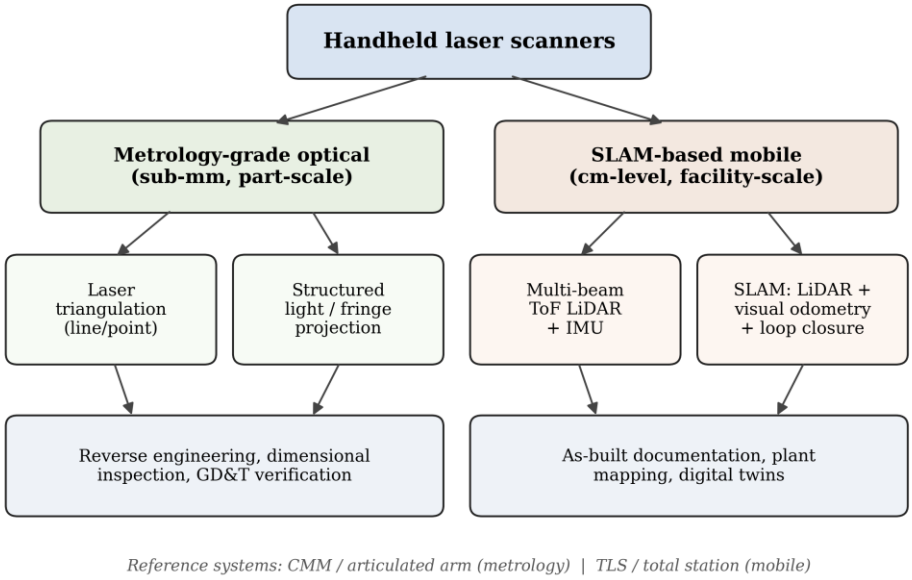


Figure 1. Taxonomy of handheld laser scanners, showing the two families, their underlying measurement principles, and their principal industrial outputs.

Table 1. Overview of the two handheld laser scanner families.

Attribute	Metrology-grade optical handheld	SLAM-based mobile handheld
Primary principle	Laser triangulation / structured light	ToF LiDAR + IMU + visual SLAM
Typical accuracy	0.02–0.1 mm (volumetric)	5–60 mm (position)
Measurement scale	Individual parts and tooling	Rooms, plants, structures
Reference system	CMM / articulated arm	TLS / total station
Representative use	Inspection, GD&T, reverse engineering	As-built, digital twin, asset mgmt.

N/A: not applicable. Ranges are indicative and compiled from the studies cited in the following sections.

5. Accuracy and performance

5.1. Metrology-grade handhelds

The most rigorous published benchmark of metrology handhelds was reported by Cuesta and colleagues [3], who compared four optical sensors against a coordinate measuring machine using a purpose-built ceramic artefact designed for GD&T evaluation. Structured light matched the CMM most closely on form and on feature diameters, with most planar form errors below 10 micrometres and diameter deviations of a few tens of micrometres, whereas the laser-triangulation devices showed diameter deviations of one to two tenths of a millimetre. Across

all four sensors the largest deviations appeared on shiny spherical features rather than on matte surfaces, which confirms surface reflectivity as the dominant error source. Studies conducted under the VDI/VDE 2634 protocols reach a similar conclusion, namely that fixed and arm-mounted configurations outperform freehand operation while handhelds remain accurate enough for demanding reconstruction tasks [4]. Table 2 lists representative devices and their nominal specifications.

Table 2. Representative metrology-grade handheld scanners and their nominal (manufacturer-stated) specifications.

Device	Principle	Nominal accuracy	Note
Creaform HandySCAN BLACK	Laser triangulation	0.035 mm	Volumetric 0.020 + 0.040 mm/m
Creaform HandySCAN BLACK|Elite	Laser triangulation	0.025 mm	ISO 17025 accredited
Artec Leo	Structured light	0.1 mm	On-board processing
Zeiss T-Scan hawk 2	Laser triangulation	0.02 mm + 0.015 mm/m	ISO 10360 acceptance
Shining3D / ScanTech line	Laser triangulation	~0.02 mm	Marker-based tracking

Source: manufacturer datasheets. Values are best-case laboratory figures and are not independently verified.

5.2. SLAM-based handhelds

Independent testing of SLAM handhelds has settled on centimetre-level accuracy that improves noticeably with each device generation. Chrbolková and colleagues [5] compared two static scanners and three SLAM scanners in a controlled indoor environment against a high-accuracy reference cloud; the static Leica RTC360 gave the best absolute accuracy at 1.2 mm, while the new-generation SLAM devices reached post-smoothing noise of about 2.1 to 2.2 mm, close to the static systems and well ahead of an older SLAM unit. In a 120 m curved tunnel, Štroner and colleagues [17] recorded SLAM deviations of 12 to 24 mm after georeferencing, comparable to the 22 to 27 mm obtained with static scanners in the same setting. El Yamani and colleagues [6] benchmarked the NavVis VLX and the Leica BLK2GO against a total station and a high-end static scanner, obtaining roughly 5 mm indoors and 10 to 60 mm outdoors depending on trajectory length, and a bridge case study using the GeoSLAM ZEB Horizon reported deviations near 20 mm after denoising [18]. Table 3 collects these results, and Figure 2 places both families on a common logarithmic axis alongside their reference systems.

Table 3. Independently reported accuracy of SLAM-based handheld scanners against reference systems.

Study	Device(s)	Reference	Reported accuracy
Chrbolková et al.	ZEB Horizon RT, Hovermap ST-X, FARO Orbis	Static ref. cloud	~2.1–2.2 mm noise (new gen.)
Štroner et al.	SLAM vs static (tunnel)	Control network	12–24 mm deviation
El Yamani et al.	NavVis VLX, Leica BLK2GO	Total station / TLS	~5 mm indoor; 10–60 mm outdoor
Bridge case study	GeoSLAM ZEB Horizon	Static TLS	~20 mm after denoising

Values are independently measured field results; see the cited studies for full test conditions.

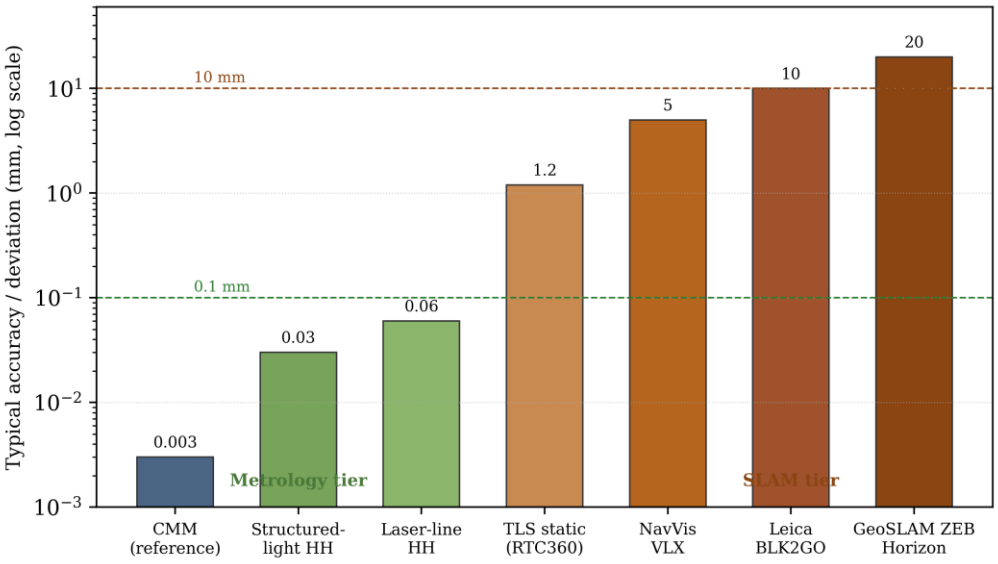


Figure 2. Typical accuracy of metrology-grade and SLAM-based handhelds compared with their reference systems, on a logarithmic scale. Values are indicative and drawn from the studies discussed in this section.

6. Industrial applications

Metrology handhelds are now embedded across the manufacturing quality cycle. The prevailing pattern is to scan first and verify second: a handheld captures the full surface as a part-to-CAD deviation map that localises problem areas, and a CMM then confirms the traceable magnitude of the few critical features that carry a contractual tolerance. The same devices feed reverse-engineering pipelines that reconstruct legacy parts, tooling, and damaged components for remanufacture [1]. In the automotive sector, handheld and tracked laser scanners inspect body-in-white assemblies, stampings, and castings, and early comparative testing already established their suitability for such parts [19]. In aerospace, portable handhelds measure brackets, panels, and turbine components both in the laboratory and on installed hardware during maintenance, where disassembly is undesirable. Weld and casting inspection is a further growth area: Hegedűs-Kuti and colleagues [20] showed a scanner-based method that clusters point-cloud deviations against standardised weld-fault classes and detected most of the evaluated defect types automatically.

SLAM handhelds address the complementary facility scale. They capture industrial plants, refineries, and factory halls quickly for scan-to-BIM and digital-twin creation, and they are at their best in the confined, occluded spaces such as tanks and engine rooms where tripod-based scanning is slow or impossible. A representative industrial study combined a terrestrial laser scanner with a handheld scanner to model piping instrumentation at an oil-and-gas facility, achieving a cloud-to-cloud registration error below 3 mm and a mean absolute geometric deviation of 1.6 mm, with a largest absolute difference of 3.4 mm [2]. Hybrid workflows of this kind, in which the static scanner supplies the accurate skeleton and the handheld fills occluded detail, are typical of heavy industry. Figure 3 shows a handheld scanner in such an industrial setting, and Table 4 maps the principal application domains to the appropriate family.



Figure 3. A handheld laser scanner in operation on an industrial component placed on a marker-referenced scanning table. The second author performs the scan in a manufacturing workshop. Photograph by the authors (original).

Table 4. Industrial application domains, the appropriate handheld family, and representative studies.

Application domain	Family	Representative evidence
Dimensional inspection / GD&T	Metrology	Cuesta et al. [3]
Reverse engineering / tooling	Metrology	Helle and Solheim [1]
Weld and casting inspection	Metrology	Hegedűs-Kuti et al. [20]
Plant / piping as-built	SLAM (+ TLS)	Gumilar et al. [2]
Facility digital twin	SLAM	El Yamani et al. [6]

Families follow the taxonomy of Table 1; construction, mining, and tunnelling are outside the scope of this review.

7. Comparison with alternative measurement technologies

Handheld scanning does not so much displace the established measurement technologies as redistribute the tasks among them. Set against the CMM, a metrology handheld is faster, portable, and able to reach complex free-form and installed geometry without fixturing, yet the CMM keeps its traceable micrometre-level accuracy for the critical features that define a contractual tolerance and remains the reference against which scanners are calibrated [3]. Articulated measuring arms sit between the two, offering stable repeatability at the cost of limited reach. Compared with static TLS, a SLAM handheld is roughly an order of magnitude faster in the field and suffers fewer occlusions, but it is noisier and less accurate, so TLS stays preferable where survey-grade detail is needed [5], [17]. Photogrammetry complements both families, providing scale control over large volumes and filling the gaps that line-of-sight scanning leaves behind; integrated scanning-and-photogrammetry pipelines of this kind are already widely used [11]. Figure 3 earlier illustrated a field deployment; Figure 4 and Figure 5 position the technologies against one another, and Table 5 summarises their trade-offs.

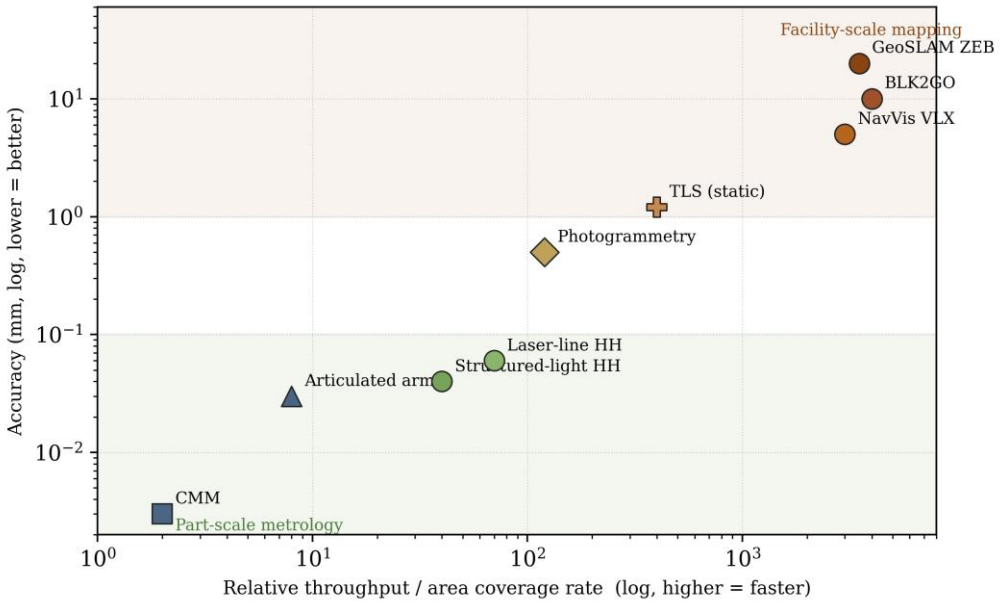


Figure 4. Positioning of measurement technologies by accuracy against relative area-coverage rate. The upper region denotes facility-scale mapping and the lower region part-scale metrology.

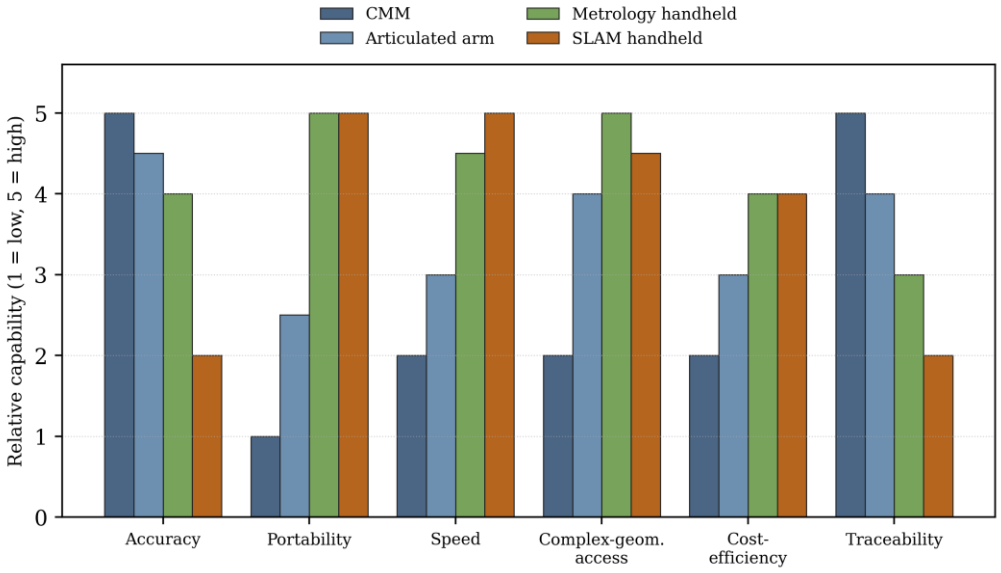


Figure 5. Relative capability of CMM, articulated arm, metrology handheld, and SLAM handheld across six selection criteria (1 = low, 5 = high).

Table 5. Comparative trade-offs of handheld scanning and alternative measurement technologies.

Technology	Typical accuracy	Key strength	Key limitation
CMM	0.001–0.005 mm	Traceable, certifiable	Fixed, slow, fixturing
Articulated arm	0.02–0.05 mm	Stable, repeatable	Limited reach
Metrology handheld	0.02–0.1 mm	Portable, complex geometry	Below CMM traceability
SLAM handheld	5–60 mm	Fast facility capture	Drift, cm-level only
TLS (static)	1–3 mm	Survey-grade detail	Occlusions, slower
Photogrammetry	0.1–1 mm	Scale control, low cost	Texture-dependent

Accuracy figures are indicative and context-dependent; see the preceding sections for the underlying studies.

8. Discussion

Taken together, the evidence points to a straightforward practical picture. The two handheld families are complementary rather than rival technologies, and their very different accuracy regimes exist because they answer different questions: whether a manufactured part conforms to tolerance, or whether a facility has been documented faithfully. Instrument choice thus follows the scale of the task, and the hybrid workflows seen in practice, scanning combined with CMM verification on the shop floor and terrestrial scanning combined with handheld infill in the plant, reflect a sensible division of labour rather than duplication [2], [3].

A second observation is that manufacturer specifications tend to overstate the accuracy achieved in the field, and the gap is systematic. Nominal figures such as 0.025 mm for a metrology handheld, or a few millimetres for a SLAM device, are best-case laboratory values; independent studies report larger deviations, especially outdoors and over long trajectories where drift accumulates [5], [17], [6]. It is therefore wiser to budget accuracy from independent benchmarks than from datasheets, and to treat the nominal values of Table 2 as ceilings that are rarely reached in production.

The direction of travel is nonetheless one of convergence towards the reference systems. New-generation SLAM scanners now approach static-scanner noise levels after smoothing, and learning-based methods for registration and denoising are increasingly built into both families, alongside real-time feedback that lets an operator close coverage gaps before leaving site [5], [15]. These capabilities feed naturally into digital-twin and Industry 4.0 workflows, in which the handheld becomes the capture front end for a continuously updated model of a plant or product. The rapid uptake of wearable and mobile handhelds in Turkish documentation and cadastral practice [7], [8], [9] is a further sign of this diffusion, and it suggests an obvious next step towards industrial deployment.

The review has limits worth stating plainly. It is a narrative synthesis rather than a systematic one, so the selection of sources reflects judgement rather than an exhaustive protocol. A good deal of the independent SLAM accuracy evidence collected in Table 3 was in fact obtained in tunnels, on bridges, and in heritage buildings rather than on a factory floor; carrying those figures across to a working plant, where vibration, complex metallic reflections, and abrupt temperature changes can all degrade a scan, is therefore a transferability assumption that still awaits direct validation. Controlled testing of SLAM inside operating factories remains comparatively thin, and it is the clearest opening for future work. Finally, the deliberate exclusion of construction, mining, and tunnelling keeps the scope coherent but means the conclusions should not be carried over to those domains without re-examining their distinct accuracy budgets [12].

9. Conclusion

Handheld laser scanning in industry is best understood not as one technology but as two complementary families. Metrology-grade optical handhelds deliver sub-0.1 mm accuracy for part inspection, GD&T verification, and reverse engineering, whereas SLAM-based mobile handhelds deliver centimetre-level accuracy for facility documentation and digital twins. Peer-reviewed benchmarks confirm that each family now approaches its own reference system, that the two are chosen by the scale of the task rather than in competition, and that field accuracy is reliably poorer than manufacturer specification. A synthesis confined to industrial and production metrology, as offered here, helps clarify a literature that has otherwise treated shop-floor and facility scanning separately, and that has so far applied wearable and mobile handhelds mainly to documentation and cadastre. The priority for further research is controlled validation of SLAM handhelds inside operating industrial environments, together with the continued integration of learning-based processing and real-time feedback into both families.

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Conflicts of Interest

The authors report no conflicts of interest.

Data Availability Statement

No new data were created or analysed in this study. Data sharing is not applicable.

Institutional Review Board Statement

Not applicable; this study did not involve humans or animals.

CRediT Author Statement

Shah Wali Nazari: Conceptualisation, Methodology, Investigation, Writing, original draft.
Veli Akarsu: Supervision, Validation, Writing, review and editing. Both authors have read and approved the final manuscript.

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