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DIGITIZATION ACCURACY IN FOCUS: A COMPARATIVE ANALYSIS OF CMM AND 3D STRUCTURED-LIGHT SCANNING TECHNOLOGIES

Stefan BODI, Claudiu-Ioan RUSAN, Radu COMES,
Zsolt-Levente BUNA, Raul-Silviu ROZSOS, Emilia-Maria CÂMPEAN

Abstract: In the context of increasingly digitized and data-driven manufacturing environments, accurate and efficient workpiece digitization plays a pivotal role in quality assurance processes. This study presents a comparative analysis of two widely used digitization methods – with Coordinate Measuring Machine (CMM) and with structured-light 3D scanning – applied to a workpiece composed of basic geometric features. A CAD model with identical nominal geometry was developed as a reference. The investigation includes a deviation analysis between the CMM-generated surfaces / shapes and the CAD model, as well as between the 3D scan point-cloud and the same model. Key metrics such as dimensional deviation, acquisition time, and point density are evaluated to determine the strengths and limitations of each method. The results provide critical insights into the trade-offs between measurement accuracy, time efficiency, and data richness, contributing to informed decision-making in the selection of digitization technologies for industrial applications.

Key words: Coordinate Measuring Machine; 3D Structured-Light Scanning; Geometric Deviation Analysis.

1. INTRODUCTION

Data-driven approaches are increasingly present in the manufacturing industry, as there is a rising need for achieving high standards of dimensional accuracy and quality control, that in turn assure long-term competitiveness and process reliability for companies. The adoption of digital metrology solutions enabled faster and more comprehensive inspection processes, supporting both in-line and offline quality assurance strategies. Within this context, digitization of manufactured workpieces serves as a foundational step for evaluating geometric conformity, enabling downstream analysis such as deviation assessment, defect detection, and reverse engineering.

In this paper, the focus is put on two prominent technologies used for workpiece digitization, Coordinate Measuring Machines (CMMs) and 3D structured-light scanners (3D SLS). In the first case, CMMs are known for their precision and repeatability, but at the same time, their data acquisition process is typically slower and limited to discrete point sampling.

On the other hand, 3D SLS offer rapid, non-contact digitization, resulting in high-density point clouds, making them well-suited for complex surface geometries and large data capture. Despite their advantages in speed and versatility, 3D scanning accuracy may be limited by environmental conditions, surface properties, and calibration inconsistencies.

This study presents a comparative evaluation of these two digitization technologies by applying both to a 3D reference model (with nominal dimensions), designed with simple geometric features. Deviation analysis is performed between the CMM-acquired data and the CAD model, as well as between the 3D scan data and the same CAD reference. Key performance indicators such as dimensional deviation, point cloud density, surface fidelity, and inspection time are considered in the analysis.

By focusing on a workpiece with basic geometries, this paper aims to provide a controlled and clear understanding of the strengths and limitations inherent to each digitization method. The findings will be

relevant for quality engineers, metrology specialists, and decision-makers evaluating trade-offs between accuracy, efficiency, and data quality in industrial inspection processes.

2. LITERATURE REVIEW

The evolution of digitization technologies has led to extensive research comparing the efficacy of CMMs and 3D SLS. These studies provide insights into their respective accuracies, operational efficiencies, and applicability in various industrial contexts.

A recent study [1] conducted a comprehensive analysis of these two technologies, accurately pinpointing, in both cases, advantages and limitations. Finally, it concluded with improvement suggestions for controlling the quality of products and prototypes even faster.

In another article [2], the authors assessed the geometric measurement capabilities of structured-light 3D scanners against CMMs when inspecting 3D printed plastic components. Their findings indicated that while 3D scanners are more suitable for real-time inspections, CMMs are preferable for final quality assurance due to their superior accuracy levels.

Kenan V. et al. conducted a study [3] that compare measurements obtained from a Carl Zeiss Contura G2 CMM and a RangeVision PRO 3D scanner. Their research focused on various geometric features, concluding that while both systems are effective, CMMs provide more consistent results for features requiring high precision.

An investigation by the authors of [4] explored the use of optical 3D scanners for measuring the macro-geometry of cutting tools. The study demonstrated that, although 3D scanners are suitable for general measurements, they may fall short in capturing intricate details compared to CMMs.

Further research presented in [5] examined the reliability of handheld structured-light scanners in capturing facial geometries. The study emphasized the importance of scanner calibration and environmental conditions in achieving accurate results, factors that are less critical in CMM operations.

In the context of industrial applications, in [6] it's highlighted the integration of AI in 3D scanning processes, enhancing the accuracy and efficiency of measurements. However, the study also acknowledged that CMMs remain the reference standard for tasks requiring the highest precision.

A comprehensive comparison of various 3D scanning sensors, including structured-blue-light systems, presented in [7], revealed that while advancements have improved scanner accuracy, CMMs still outperform in terms of repeatability and measurement uncertainty.

Collectively, the above-mentioned studies highlight the trade-offs between the two technologies: 3D scanners offer speed and flexibility, while CMMs continue to be the benchmark for precision, especially in applications where measurement accuracy is paramount.

Although the cited references capture the respective advantages and limitations of each technology, a direct comparative analysis using an identical reference baseline remains limited in the current literature. In the following section, the authors present their own methodology, which addresses this gap by employing the deviation analysis approach.

3. METHODOLOGY

The methodology of this paper included 5 main steps to reach the preset objective. An overview of the entire approach is synthesized in the following figure.

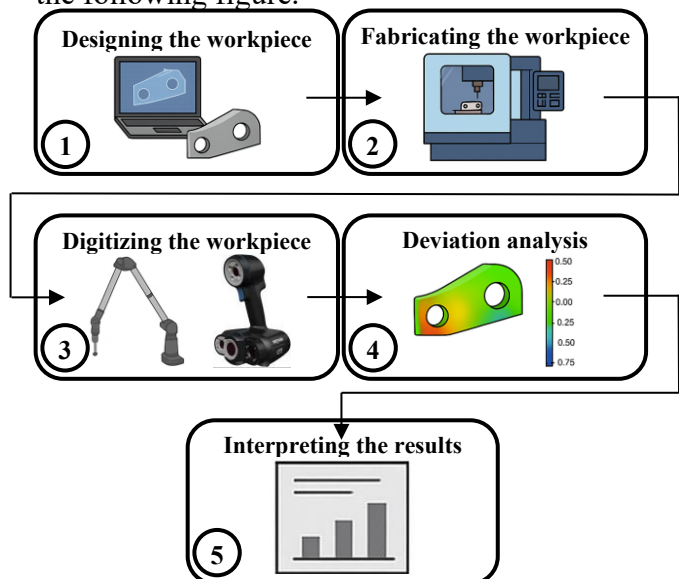


Fig. 1. Overview of the methodology

First, a proper workpiece was designed that contains mainly simple geometrical shapes, that can be easily digitized using both CMMs and 3D scanners. For this purpose, the authors used CATIA V5 to model the workpiece and create the technical documentation to fabricate the workpiece.

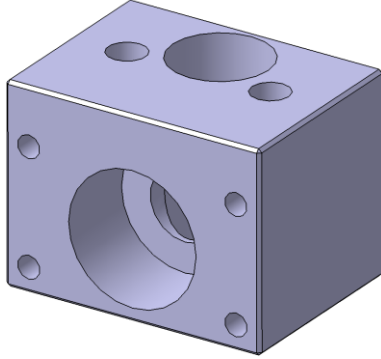


Fig. 2. The final model of the workpiece

In the second step, the workpiece was manufactured on a Microcut Challenger MCV-2418 CNC machine out of a C45 material (medium carbon steel) stock. The milling parameters, drill type, etc. are not detailed as they are outside the scope of this paper.

The third phase involved the deployment of two digitization equipment: regarding the CMM, a CimCore Stinger II mobile measuring arm was used to probe points on the surface of the workpiece and to generate the simple geometrical shapes that make it up (planes, cylinders, circles, etc.); the scanning, on the other hand, was performed using a Creaform GoSCAN 50 structured-light scanner. It should be noted that, prior to scanning, the surface of the workpiece was coated with a thin layer of white powder to minimize reflectivity and ensure accurate data acquisition.

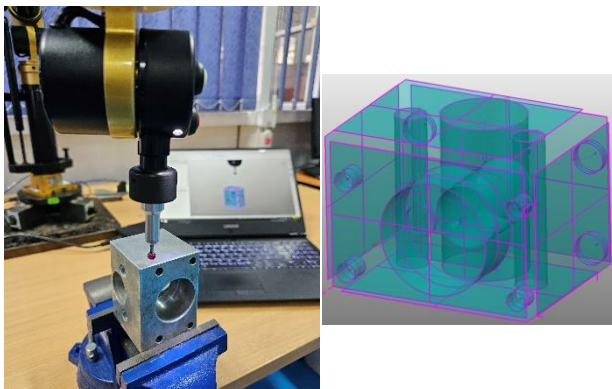


Fig. 3. Measuring the workpiece (left); Digitized features of the workpiece (right)

These were chosen as they both have a declared precision of 50 microns, according to their technical specifications. By employing equipment with equivalent precision, the comparability of results is ensured, as the differences can be attributed to the intrinsic characteristics of the digitization technologies rather than potential biases arising from variations in measurement and/or scanning accuracy.

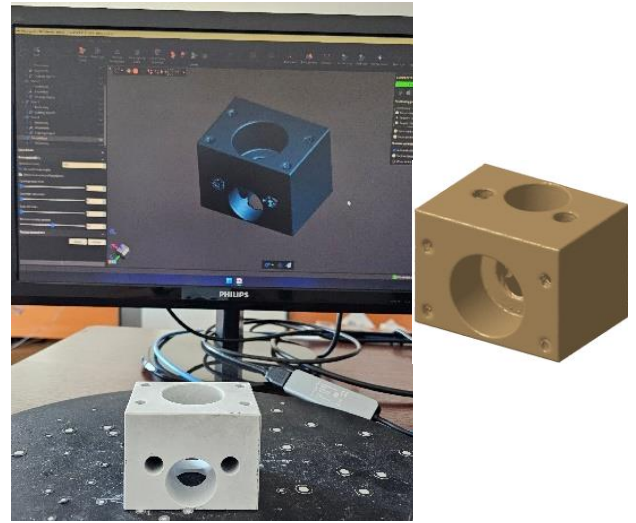


Fig. 4. Scanning the workpiece (left)
Workpiece mesh (right)

In the fourth step, two deviation analyses were performed by comparing the results obtained from the CMM and the 3D structured-light scanner against the nominal CAD model of the workpiece. In the first case, an IGES (.igs) file was imported, containing reference planes and probed geometric entities that define the nominal workpiece. In the second case, a STEP (.stp) file representing the polygonal mesh of the scanned workpiece was analyzed.

The fifth and final step was reserved for interpreting the results and drawing discussions based on the outcomes.

4. RESULTS AND DISCUSSION

The deviation analyses were performed using the “best-fit” method, in which the software automatically computed the alignment between the geometric dataset (for the CMM measurement) or point cloud (for the scanned mesh) and the position of the origin of the nominal workpiece.

As the two figures illustrate (Fig. 5 & Fig. 6), the results revealed notable differences between the two digitization methods.

The deviation maps are accompanied by color-coded scales displayed on the right side of each figure, which provide a visual interpretation of the magnitude and distribution of dimensional differences across the workpiece surface. Colors close to green indicate minimal deviation from the nominal CAD model, representing areas that closely conform to the intended geometry. Warmer tones (yellow to red) highlight positive deviations, where the measured surface lies above the nominal reference, while cooler tones (blue to dark blue) represent negative deviations, indicating material deficits or recessed areas. This color-coded representation enables an intuitive assessment of both the magnitude and spatial localization of deviations, complementing the numerical results obtained from the analysis.

The CMM results, obtained by probing discrete geometric entities, showed high accuracy relative to the nominal CAD model, with dimensional deviations generally remaining within ± 0.5 mm and with 91.89% of points within the ± 1 mm limits. This confirms the role of CMMs as the benchmark in precision metrology, especially for planar and cylindrical surfaces where direct probing provides robust dimensional validation. However, the discrete nature of the probed data limited the overall surface representation, leading to a less detailed model of the workpiece. It should be noted that a general deviation of ± 0.5 mm is quite acceptable for such deviation analyses as this range accounts for machining capabilities, measurement uncertainty and potential alignment errors.

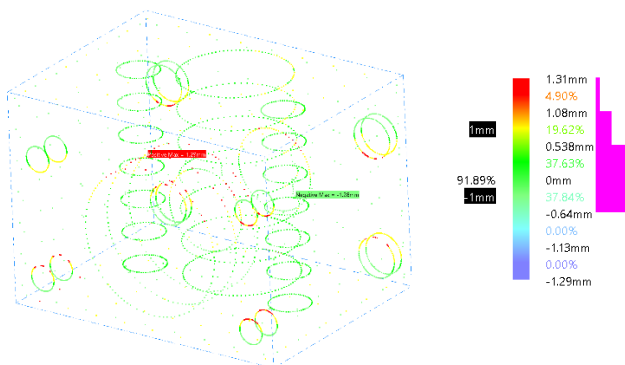


Fig. 5. Deviation analysis between the measured geometrical dataset and the nominal workpiece

In contrast, the 3D structured-light scanner produced a dense point cloud with good coverage of the workpiece surface, being limited in scanning deep and narrow indentations, like holes and grooves (due to its physical construction). This enabled a detailed reconstruction of the geometry, which is valuable for reverse engineering and visual inspection. Nevertheless, the deviation analysis in this case indicated local variations and lesser accuracy compared to the results from the CMM, with only 87.95% of points located within the ± 1 mm limits. These deviations can also be attributed to environmental influences, surface preparation quality, and scanner calibration.

When comparing time efficiency, the 3D scanner significantly outperformed the CMM, requiring only a fraction of the time to complete full surface digitization. This highlights its suitability for applications where speed and visualization are prioritized over absolute dimensional accuracy. However, additional time may be required in case the mesh needs further processing and refinement, e.g. removing isolated triangles; filling holes; “healing” the mesh, but these actions may or may not be undertaken and depend on the skill of the operator and the quality of final mesh. Also, the authors recognize that newer scanning solutions include lesser noise in the scanning process and the meshes are more reliable, as in the case of structured-light scanners with volumetric accuracy of 50 microns.

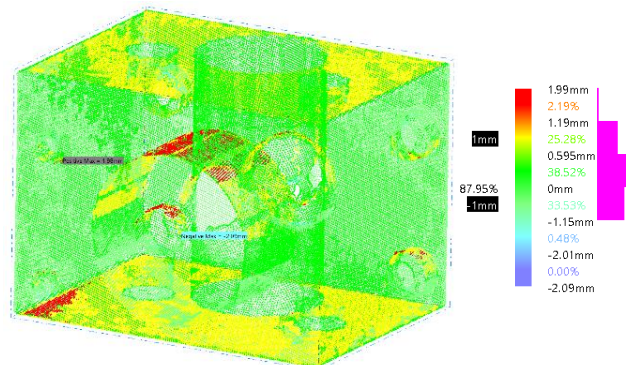


Fig. 6. Deviation analysis between the scanned mesh and the nominal workpiece

The CMM, although slower, remains more reliable for tasks where dimensional tolerances are critical and higher precision is required.

Overall, the results confirm the complementary nature of the two technologies. The CMM ensures high accuracy for critical measurements, while the 3D scanner provides fast and comprehensive surface data. For industrial practice, the choice between the two methods should therefore be guided by the specific requirements of accuracy, speed, and data richness.

Table 1 summarizes the key quantitative and qualitative differences observed between the two digitization technologies. This comparative overview highlights the complementary strengths of the two approaches and supports the interpretation of the deviation maps discussed above.

Table 1

Comparative results between CMM and 3D structured-light scanning

Metric	CMM CimCore Stinger II	3D SLS Creaform Go!SCAN 50
Declared precision	±0.05 mm	±0.05 mm
Observed deviation range	generally ±0.5 mm	generally ±0.75 mm
% of points within ±1 mm	91.89%	87.95%
Data density	Low (discrete points, probed geometries)	High (dense point cloud)
Surface fidelity	Limited, geometric entities only	Detailed reconstruction of full surface
Time efficiency	High measurement time	Rapid digitization (fraction of CMM time)
Sensitivity	Low sensitivity to environment	Higher sensitivity to surface prep, lighting, calibration
Best suited for	Dimensional verification with high accuracy	Reverse engineering, visualization, rapid inspection

5. CONCLUSIONS

This study presented a comparative analysis of workpiece digitization using a Coordinate Measuring Machine (CMM) – CimCore Stinger II and a 3D structured-light scanner (3D SLS) – Creaform GoSCAN 50. By employing equipment with similar declared precision, the

results highlighted differences that are attributable primarily to the inherent characteristics of each technology rather than disparities in nominal accuracy.

The findings can be summarized and presented as follows:

- CMM measurements demonstrated superior dimensional accuracy and repeatability, particularly for simple geometric features, though at the cost of longer measurement times and limited data density.
- 3D SLS provided rapid acquisition of high-density point clouds and detailed surface representations, but with larger deviations in certain areas and greater sensitivity to surface preparation, scanner calibration, environmental conditions and was limited to scanning certain type of geometry.
- The deviation analysis confirmed that CMM is more suitable for final dimensional verification, while 3D scanning is advantageous for rapid digitization, reverse engineering, and visualization tasks.

In conclusion, neither technology can be considered universally superior. Instead, their use should be complementary, depending on whether the application requires maximum accuracy (favoring CMM) or high-speed comprehensive surface capture (favoring 3D scanning).

Future work will focus on extending this comparative framework to more complex geometries, different material types, and hybrid approaches combining the strengths of both technologies.

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ACURATEȚEA DIGITIZĂRII ÎN PRIM-PLAN: O ANALIZĂ COMPARATIVĂ A TEHNOLOGIILOR MMC ȘI SCANARE 3D CU LUMINĂ STRUCTURATĂ

În contextul unor medii de producție tot mai digitalizate și orientate spre date, digitizarea precisă și eficientă a pieselor joacă un rol esențial în procesele de asigurare a calității. Studiul de față prezintă o analiză comparativă a două metode larg utilizate de digitizare – prin intermediul unei mașini de măsurat în coordonate (MMC) și al scanării 3D cu lumină structurată – aplicate unei piese compuse din forme geometrice de bază. Un model CAD cu o geometrie nominală identică a fost realizat ca referință. Investigația include o analiză a abaterilor între suprafețele și formele generate cu MMC și modelul CAD, precum și între norul de puncte obținut prin scanare 3D și același model. Se evaluează indicatori cheie precum abaterea dimensională, timpul de achiziție și densitatea punctelor, pentru a evidenția punctele forte și limitările fiecărei metode. Rezultatele oferă perspective critice asupra compromisurilor dintre acuratețea măsurărilor, eficiența temporală și bogăția datelor, contribuind astfel la luarea unor decizii informate privind selecția tehnologiilor de digitizare în aplicații industriale.

Stefan Bodi, Ph.D., Eng., Associate professor, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, stefan.bodi@muri.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.

Claudiu-Ioan Rusan, Ph.D., Eng., Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, claudiu.rusan@ipr.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.

Radu Comes, Ph.D., Eng., Associate professor, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, radu.comes@muri.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.

Zsolt-Levente Buna, Ph.D., Eng., Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, zsolt.buna@muri.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.

Raul-Silviu Rozsos, Ph.D. Candidate, Eng., Assistant Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, raul.rozsos@muri.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.

Emilia-Maria Câmpean, Ph.D., Eng., Associate professor, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, emilia.campean@muri.utcluj.ro, 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj County, Romania.