

Comparative analysis of crack information extraction using structured light and SfM techniques

Análise comparativa da extração de informações de fissuras utilizando luz estruturada e técnicas de SfM

Iane Silva Pereira¹; Samir de Souza Oliveira Alves²; Luis Augusto Koenig Veiga³

¹ Federal University of Paraná, Geomatics Department, Curitiba/PR, Brazil. Email: ianepereira@ufpr.br
ORCID: <https://orcid.org/0000-0001-9935-4746>

² State University of Rio de Janeiro, Department of Cartographic Engineering,
Rio de Janeiro/RJ, Brazil. Email: samir.alves@eng.uerj.br
ORCID: <https://orcid.org/0000-0003-3083-0681>

³ Federal University of Paraná, Geomatics Department, Curitiba/PR, Brazil. Email: kngveiga@ufpr.br
ORCID: <https://orcid.org/0000-0003-4026-5372>

Abstract: Structural safety is a critical concern in civil engineering, making the monitoring of pathological manifestations essential, particularly cracks, which are among the most frequent defects in concrete structures. Accurate crack characterization is fundamental to ensuring structural integrity and preventing potential failures. Traditional assessment methods often rely on destructive testing or visual inspection, which may either damage the structure or depend heavily on operator expertise. In contrast, non-destructive techniques enable more reliable and repeatable data acquisition. This study presents a comparative analysis of crack characterization using structured light and Structure from Motion (SfM) techniques. Both approaches generate point clouds from which geometric features, such as crack width, can be extracted. The case study was conducted on a crack located at the Botanic University Restaurant in Curitiba, Paraná, Brazil. Data acquisition was performed using a portable infrared structured light scanner and a smartphone for the SfM approach. Calibrated targets, referenced by a total station, were used as control points. The results demonstrate that both techniques are suitable for geometric characterization, although they present distinct performance in terms of accuracy and consistency. Structured light provided more stable local measurements, while SfM showed better agreement with reference distances for global geometry.

Keywords: Point Cloud 1; Non-destructive testing 2; Structural Integrity 3; Pathological Manifestation 4.

Resumo: A segurança estrutural é uma preocupação fundamental na engenharia civil, tornando essencial o monitoramento de manifestações patológicas, especialmente fissuras, que estão entre os defeitos mais frequentes em estruturas de concreto. A caracterização precisa dessas fissuras é crucial para garantir a integridade estrutural e prevenir falhas. Métodos tradicionais frequentemente dependem de ensaios destrutivos ou inspeções visuais, que podem danificar a estrutura ou depender da experiência do operador. Em contraste, técnicas não destrutivas permitem uma aquisição de dados mais confiável e reproduzível. Este estudo apresenta uma análise comparativa da caracterização de fissuras utilizando técnicas de luz estruturada e *Structure from Motion* (SfM). Ambas geram nuvens de pontos das quais é possível extrair informações geométricas, como a abertura de fissuras. O estudo foi realizado em uma fissura localizada no Restaurante Universitário Botânico, em Curitiba, Paraná. A aquisição de dados foi feita com um scanner portátil de luz estruturada e um smartphone para o SfM, utilizando alvos calibrados referenciados por estação total. Os resultados indicam que ambas as técnicas são adequadas, sendo a luz estruturada mais estável em medições locais, enquanto o SfM apresenta melhor acurácia na geometria global.

Palavras-chave: Nuvem de Pontos 1; Ensaios não destrutivos 2; Integridade Estrutural 3; Manifestação Patológica 4.

Received: 13/05/2026; Accepted: 11/09/2026; Published: 01/10/2026.

1. Introduction

The accelerated development of civil construction, driven by increasing societal demands, has promoted significant scientific and technological advances (AMBRÓSIO, 2004). However, this rapid growth has also led to an increase in structures exhibiting unsatisfactory performance due to factors such as unintentional failures, lack of expertise, improper use of materials, and design errors. These issues contribute to structural deterioration and, consequently, to the emergence of pathological manifestations (ARIVABENE, 2015).

Among the various pathological manifestations in buildings, cracks are the most prevalent, especially in concrete structures, and represent a major concern regarding structural performance and durability (MACHADO, 2002). Early detection and proper characterization of such defects are essential for implementing effective mitigation measures (ZANETTI, 2020). Therefore, continuous monitoring throughout both the construction phase and the service life of structures is necessary to prevent failures that may result in significant human, environmental, and economic losses (MONICO, 1988).

Cracks are among the most visually evident pathological manifestations, often causing user discomfort and raising concerns regarding structural safety. According to Veiga (1998), they can generate feelings of insecurity, visual discomfort, and concerns regarding building safety. In addition to aesthetic degradation and infiltration problems, cracks may indicate underlying structural issues and compromise the durability of construction systems. For this reason, structural monitoring should not be limited to initial project stages but must also include continuous assessment of structural safety (GONZÁLEZ-AGUILERA *et al.*, 2008).

Both destructive and non-destructive methods can be employed for monitoring concrete structures. Destructive methods involve extracting material samples for laboratory analysis. Although these tests leave marks on the structure, they generally do not compromise its stability. However, their use has become less desirable, particularly in structures already in service (FREITAS *et al.*, 2014). In contrast, non-destructive testing (NDT) methods are defined as techniques that do not impair the performance of the evaluated element, although some may cause minor surface damage (BUNGEY *et al.*, 2006).

Conventional methods for crack assessment include plaster or glass seals, crack gauges, and visual inspection. More advanced approaches involve the use of instruments such as calipers, displacement sensors, ultrasonic devices, and acoustic emission systems. The selection of an appropriate method depends on factors such as cost, accessibility, and required accuracy (PALAORO; RODRIGUES, 2017; ROCHA, 2017).

In general, crack evaluation is still largely based on manual or visual inspection, requiring experienced professionals to assess structural conditions. These approaches are time-consuming, labor-intensive, and may pose safety risks, particularly in hard-to-reach areas. Moreover, their reliability is strongly dependent on the inspector's experience and subjective judgment (KANG, 2018).

Given these limitations for non-destructive techniques that enable more automated, accurate, and reliable assessments of structural conditions. Recent technological advances in engineering have introduced new monitoring approaches, among which point cloud-based methods stand out.

Point clouds consist of sets of three-dimensional coordinates (X, Y, Z) defined in a Cartesian system, representing points captured from a single scene or from multiple scenes combined to describe an object or area of interest. These datasets can be generated through image-based reconstruction techniques or using 3D scanning technologies, such as laser scanners and photogrammetry (VAN GENECHTEN *et al.*, 2008; MÜLLER FILHO, 2015).

Among the various 3D data acquisition techniques, close-range photogrammetry has garnered significant attention owing to its operational flexibility, cost-effectiveness, and capability to simultaneously deliver spatial geometry and radiometric (texture) data. The evolution of Structure-from-Motion (SfM) and multi-view stereo algorithms has expanded its implementation in structural inspection, enabling dense surface reconstruction from convergent imagery acquired across diverse perspectives. Recent literature underscores the efficacy of photogrammetric workflows and image-derived dense point clouds in facade survey, surface condition assessment, and structural damage characterization (ZHU *et al.*, 2023; MAJIDI; OMIDALIZARANDI; SHARIFI, 2023).

Within the specific scope of crack mapping and characterization, image-based spatial modeling has shifted from qualitative visual interpretation toward rigorous geometric and morphological modeling of damage. For instance, Majidi, Omidalizarandi, and Sharifi (2023) investigated the 3D surface reconstruction of cracks using close-range photogrammetric datasets, validating the spatial fidelity of these techniques for defect modeling. In parallel, recent investigations have focused on sensor fusion and the integration of 2D spectral data with 3D point cloud coordinates for

automated defect extraction, with notable applications in concrete infrastructure and industrial tank inspections (ALAMDARI; EBRAHIMKHANLOU, 2023, 2024; GUO et al., 2024; HU et al., 2024).

Accordingly, this investigation evaluates point clouds generated from distinct non-destructive sensing modalities—specifically structured light 3D scanning and SfM photogrammetry—to perform a comparative assessment of crack feature extraction. The analysis addresses spatial resolution, surface representation fidelity, mensuration accuracy, and the sensitivity of the models to image network geometry, sensor parameters, and dense-matching pipeline variables. Ultimately, this work seeks to advance the standardization of objective, accessible, and geodetically robust inspection workflows for diagnosing structural pathologies.

2. Materials and methods

To carry out this research, tests were carried out on a fissure located in the Botanical University Restaurant, located on the campus of the Botanical Garden of the Federal University of Paraná. Although is a relatively recent man-made concrete structure, inaugurated in 2012, it already presents visible cracking issues.

For field support, measuring devices were used with 15 cm (Figure 1), fixed with adhesive tape next to the fissure. These devices were used as a reference for the moment of processing and were calibrated by means of measurements with a TS15 Total Station. For this purpose, the station was leveled, and the coordinates of points A and B located in the centers of the circular targets were measured in the direct and inverse position and their x, y and z coordinates of each point were noted so that their results could be calculated, thus obtaining the distance between the points, the process was repeated for points C and D.

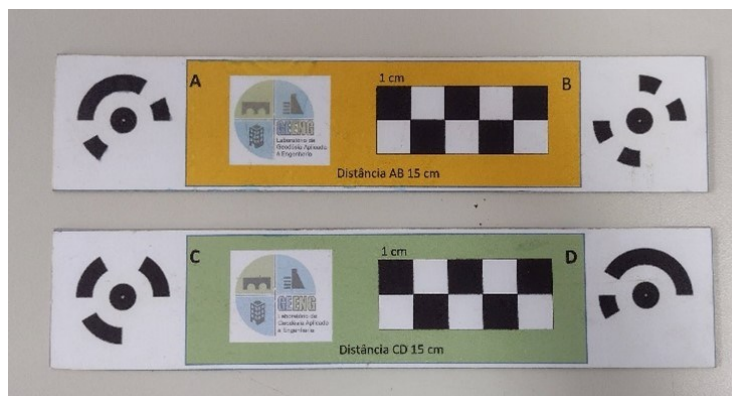


Figure 1 – Graduated measuring devices.
Source: The authors (2026).

The measurements were performed using a TS15 total station with an angular accuracy of 1" and a distance measurement accuracy of $\pm (1 \text{ mm} + 1.5 \text{ ppm})$, ensuring high precision in the determination of control point coordinates. The use of control points calibrated with a high-precision total station contributes to reducing measurement uncertainties and improving the reliability of the extracted geometric parameters.

2.1 Structured light

Structured light is an active sensing technique that uses a controlled light source to scan an object or surface and generate digital data capable of providing three-dimensional information. This method relies on the projection of known patterns onto the surface and the capture of their deformation using optical sensors. From the reflected and distorted patterns, it is possible to reconstruct the geometry of the object without physical contact (ROBINSON et al., 2004).

2.1.1 Point cloud acquisition and processing

For point cloud acquisition, the crack was scanned using the 3D Scanner Pro 1.0, a portable device manufactured by XYZprinting. The equipment has a scanning resolution ranging from 1 to 2.5 mm, a minimum capture volume of $50 \times 50 \times 50$ mm, and a maximum volume of $1000 \times 1000 \times 2000$ mm. Its operating distance ranges from 300 to 500 mm from the target surface. As a structured light system, the scanner is equipped with two cameras (left and right) and an infrared projector.

The initial step consisted of connecting the scanner to a notebook to start the data acquisition process (Figure 2). The device offers four scanning modes: object ($600 \times 600 \times 300$ mm), head ($800 \times 500 \times 800$ mm), body ($1000 \times 1000 \times 2000$ mm), and face (approximately the size of a human face).



*Figure 2 – Structured light scanning of the crack.
Source: The authors (2026).*

After preliminary tests, the head mode was selected as the most suitable for capturing the crack geometry. To minimize signal loss and ensure data quality, the scanner was moved uniformly along the surface, avoiding abrupt movements and oscillations. The scanning process lasted approximately 5 minutes.

The scanner operates using proprietary software, XYZscan Handy, which processes the captured data and converts it into a point cloud. The generated dataset can be visualized within the software, where basic operations such as measurements and quality improvements can be performed, including noise reduction and hole filling.

Finally, the point cloud was exported in Polygon File Format (PLY), which allows not only the storage of X, Y, and Z coordinates but also additional attributes such as color, intensity, and surface normals. The PLY file was subsequently imported into CloudCompare (Figure 3), where more detailed analyses and refined measurements of the crack features were performed.

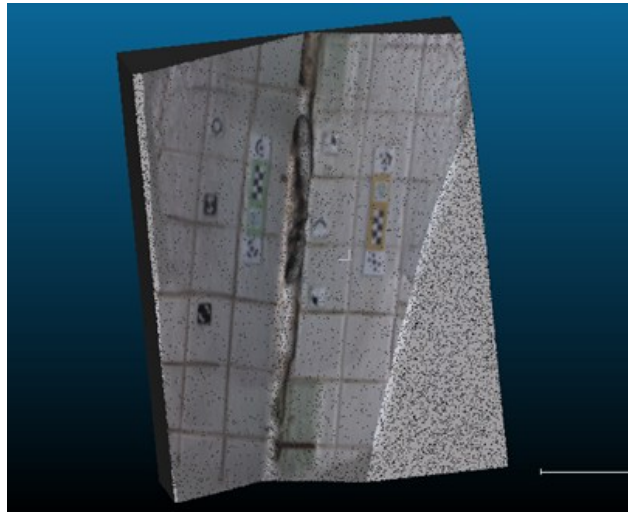


Figure 3 – Point cloud generated from structured light in CloudCompare.
Source: The authors (2026).

It is important to note that the scanner resolution may limit the detection of very fine crack widths, particularly those below the millimeter scale, which should be considered when interpreting the results.

2.2 Structure from Motion

Structure from Motion (SfM) is a photogrammetric processing technique that emerged in the 1980s, driven by advances in feature detection and matching algorithms. It enables the reconstruction of three-dimensional digital models through point cloud generation (WESTOBY *et al.*, 2012).

According to Graça (2019), SfM can be described as a sequence of steps including automatic feature detection and matching (tie points), bundle adjustment (simultaneous estimation of camera positions and orientations along with the three-dimensional coordinates of homologous points), and, in many cases, point cloud densification. The method is based on the fundamental principles of photogrammetry, where 3D coordinates are derived from multiple overlapping images. However, unlike conventional photogrammetry, SfM automatically estimates scene geometry as well as camera positions and orientations, without requiring prior knowledge of object-space coordinates.

2.2.1 Image acquisition and processing

For the SfM method, a Samsung Galaxy A32 smartphone was used, featuring a main camera with a resolution of 64 MP, image resolution of 9000×7000 pixels, and a sensor size of approximately $1/4.0''$. The device was moved around the crack and the reference targets, capturing a series of images from different angles while maintaining stability to ensure image sharpness.

The images were acquired with sufficient overlap, ensuring that each photograph covered part of the previously captured area. This approach is essential to facilitate accurate feature matching and reliable 3D reconstruction. After a visual inspection, a total of 53 images were selected (Figure 4), based on criteria such as image quality, sharpness, adequate exposure, sufficient overlap, and any blurred or poorly exposed photographs that could compromise the reconstruction process. The selected images were then transferred to a computer for processing.



*Figure 4 – Image acquisition for the SfM method.
Source: The authors (2026).*

After image acquisition, the photogrammetric processing was carried out using Agisoft Metashape software, following a structured workflow to ensure the generation of a reliable and accurate point cloud.

The first processing step consisted of image alignment. In this stage, the software automatically detected and matched homologous features (tie points) between overlapping images using feature detection algorithms. Based on these correspondences, a bundle adjustment was performed to simultaneously estimate the internal camera parameters and their spatial positions and orientations. This step resulted in a sparse point cloud representing the general geometry of the scene. Subsequently, a quality assessment of the alignment was conducted by analyzing the reprojection error and the spatial distribution of tie points. When necessary, poorly matched points were removed to improve the robustness of the solution. After alignment refinement, the dense point cloud was generated using a multi-view stereo (MVS) algorithm. This step significantly increased the number of points, allowing for a more detailed representation of the crack geometry. The quality settings were configured to balance processing time and level of detail. Following the generation of the dense point cloud (Figure 5), a three-dimensional mesh was created to represent surface geometry. The mesh was then used as a basis for texture mapping, in which the original images were projected onto the model to produce a realistic representation of the surface.



*Figure 5 – Dense point cloud generated in Agisoft Metashape.
Source: The authors (2026).*

To ensure metric consistency, the calibrated targets positioned near the crack were identified and manually marked in the images within the software. These targets were used as control points to define the scale of the reconstructed model. The reference distances adopted in this process correspond to the values obtained from the total station measurements of the graduated measuring devices. Specifically, the distances between the centers of the circular targets (A–B and C–D), were introduced into the software to accurately scale and adjust the model. This procedure ensured that the generated point cloud was metrically consistent with the real dimensions of the structure, reducing scaling errors, and improving the reliability of the geometric measurements extracted from the SfM reconstruction.

It is important to note that the accuracy of the SfM method depends on factors such as image quality, lighting conditions, camera calibration, and the level of overlap between images, which may influence the quality of the reconstructed point cloud. Compared to structured light, SfM provides a low-cost and flexible solution, although it typically presents lower geometric accuracy.

2.3.1 Statistical analysis

To quantitatively evaluate the performance of the structured light and Structure from Motion (SfM) techniques, a set of statistical metrics was computed based on the comparison between measured distances and reference values obtained from the total station. The analysis included error-based and variability-based indicators to assess both accuracy and precision.

The accuracy of each method was evaluated through the calculation of the mean error (bias) and the Root Mean Square Error (RMSE). The mean error was defined as the arithmetic average of the differences between measured and reference values, allowing the identification of systematic deviations. The RMSE was used to quantify the overall magnitude of the error, considering both systematic and random components.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - x_{ref})^2}$$

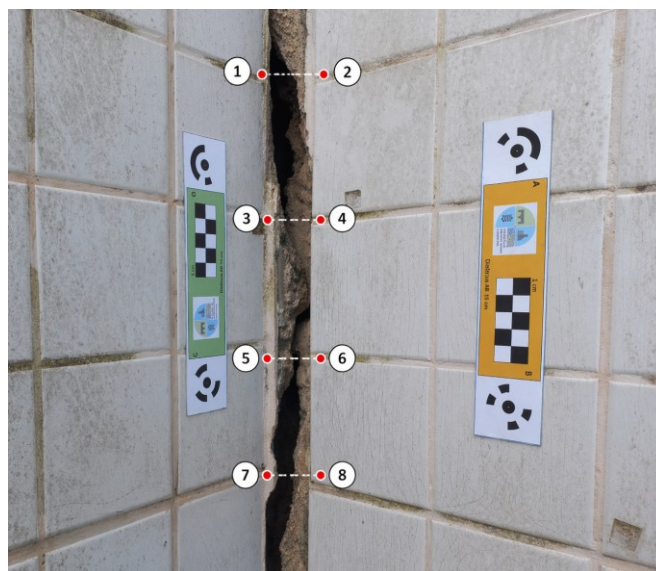
Additionally, the precision of crack width measurements was assessed using the standard deviation, computed from multiple sampling segments along the crack. This metric provides an estimate of the dispersion of measurements and reflects the internal consistency of each technique.

All statistical calculations were performed considering the sample-based formulation, using $n-1$ in the denominator for variance estimation. The combination of these metrics enables a comprehensive evaluation of the methods, distinguishing between systematic bias, overall accuracy, and measurement variability.

The reference distances obtained from the total station were used as ground truth to quantitatively assess the accuracy of both techniques. Based on these values, error metrics were computed to evaluate the performance of each method.

3. Results and discussion

The crack under investigation, along with the positioned graduated measuring devices, is presented in Figure 6, which illustrates the spatial arrangement adopted for the extraction of geometric measurements.



*Figure 6 – Crack and measuring devices.
Source: The authors (2026).*

The reference distances obtained from the total station (Table 1) were used as ground truth to evaluate the accuracy of the point clouds generated by both techniques. In addition to the nominal distances between targets (A–B and C–D), the inclusion of the complementary segments (D–A and C–B) provided a more robust dataset for validation.

Table 1 – Distances measured by total station (reference values).

Segment	Distance (cm)
A → B	15.01
C → D	14.99
D → A	19.66
C → B	19.52

Source: The authors (2026).

3.1 Accuracy assessment of distance measurements

To evaluate the accuracy of the structured light method, the distances between the same reference points (1–2, 3–4, 5–6, and 7–8) were measured using the generated point cloud. The PLY file was imported into CloudCompare, where the “Point Picking” tool was used to select the centers of the circular targets and automatically compute the distances (Figure 7).



*Figure 7 – Crack and measuring devices.
Source: The authors (2026).*

The distances extracted from the structured light point cloud (Table 2) show a consistent overestimation when compared to the reference values. For the segments A–B and C–D, deviations of approximately +0.57 cm and +0.66 cm were observed, respectively. Similarly, for the longer segments (D–A and C–B), differences of about +0.43 cm and +0.55 cm were identified. The computed mean error (bias) was +0.55 cm, indicating a systematic deviation.

The algebraic sign consistency of the errors represents one of the most significant findings of this analysis. Across all four monitored segments, the euclidean distances derived from the structured light sensor systematically exceeded the ground-truth values established by total station measurements, yielding absolute errors ranging from 0.43 to 0.66 cm. Consequently, the observed behavior cannot be characterized merely by random observational dispersion; rather, it exhibits a relatively uniform positive systematic trend. These results indicate that, under the evaluated experimental setup, structured light scanning presented a predominantly systematic error budget in metric spatial reconstruction.

These discrepancies denote a clear overestimation bias inherent to the structured light pipeline, likely attributable to scale factor misspecification or surface triangulation artifacts during reconstruction. This finding is corroborated by an

RMSE of 0.56 cm, confirming that the deviations are not only systematic but also exhibit spatial uniformity across the varying baseline lengths. Such a trend points to the presence of an unmodeled scale factor error warping the reconstructed geometry.

This outcome demonstrates that a dense point cloud may achieve high internal precision (repeatability) while concurrently exhibiting significant datum or metric bias relative to the true reference frame. Therefore, measurement consistency or internal precision must not be used in isolation as a proxy for positional accuracy. The presence of such systematic bias highlights the imperative for rigorous sensor calibration protocols, ground control point (GCP) constraints, and metrological scale validation whenever point clouds are deployed for high-fidelity structural damage quantification.

Table 2 – Distances measured using structured light.

Segment	Distance (cm)
A → B	15.58
C → D	15.65
D → A	20.09
C → B	20.07

Source: The authors (2026).

The same procedure was applied to the point cloud generated using the SfM technique, in which the corresponding distances were extracted from the reconstructed dataset following the same measurement criteria adopted for the structured light data (Table 3).

Table 3 – Distances measured using SfM.

Segment	Distance (cm)
A → B	15.01
C → D	14.99
D → A	19.69
C → B	19.58

Source: The authors (2026).

The mean error was approximately +0.05 cm, while the RMSE was approximately 0.05 cm, indicating minimal deviation and high geometric fidelity. These results demonstrate that the scaling procedure based on control distances was effective in ensuring metric consistency.

A comparative analysis of both methods reveals distinct behaviors: while structured light presents a systematic overestimation likely associated with scaling or reconstruction effects, SfM shows negligible bias and superior accuracy in representing global geometry.

3.2 Crack width analysis

The crack width measurements obtained from both techniques are presented in Tables 4 and 5, based on multiple sampling segments distributed along the fissure.

The structured light results (Table 4) show crack widths ranging from 4.44 cm to 4.69 cm, with a mean value of 4.53 cm and a standard deviation of 0.12 cm, indicating low dispersion and high internal consistency.

Table 4 – Crack width measured using structured light.

Crack	Distance (cm)
1 → 2	4.69
3 → 4	4.44

5 → 6	4.56
7 → 8	4.44

Source: The authors (2026).

The SfM measurements (Table 5) range from 4.09 cm to 4.32 cm, with a mean value of 4.23 cm and a standard deviation of 0.10 cm. Although the variability is similarly low, the values are consistently smaller than those obtained from structured light.

Table 5 – Crack width measured using SfM.

Crack	Distance (cm)
1 → 2	4.09
3 → 4	4.27
5 → 6	4.32
7 → 8	4.22

Source: The authors (2026).

This systematic difference suggests that structured light tends to slightly overestimate local geometric features, while SfM may underestimate them due to limitations related to image resolution and surface reconstruction.

The observed discrepancy between both sensing modalities yields a mean difference of approximately 0.30 cm, with the structured light system and SfM photogrammetry reporting mean values of 4.53 cm and 4.23 cm, respectively. Although both methods exhibit low internal dispersion (high precision), the systematic shift between their sample means demonstrates that this discrepancy is not merely governed by stochastic observation noise. This finding is critical, as it highlights that crack feature assessment within a dense point cloud is governed not only by measurement repeatability, but fundamentally by the sensor's radiometric and geometric capability to resolve and reconstruct boundary edges delineating the aperture.

3.2 Comparative performance analysis

The statistical results highlight two complementary characteristics of the evaluated techniques:

- Structured light provides more consistent local measurements but presents a systematic positive bias in distance estimation;
- SfM demonstrates superior accuracy in global geometry, with minimal bias and significantly lower RMSE.

The joint synthesis of these findings reveals a critical distinction between internal precision and absolute accuracy. The structured light system exhibited minimal measurement dispersion across the crack aperture evaluations; however, the control baseline residuals exposed a systematic translation relative to the reference datum. Conversely, Structure from Motion (SfM) demonstrated superior compliance with total station ground-truth baselines, while reliably recovering the evaluated morphological dimensions of the crack.

The results of this investigation do not advocate for the outright substitution of one sensing modality over the other; rather, they underscore their operational complementarity. SfM delivered superior spatial fidelity within the analyzed network geometry, particularly in conforming to the geodetic reference baselines. In contrast, structured light scanning provided robust local measurement repeatability, albeit coupled with a systematic overestimation bias. Consequently, the selection between these modalities must be governed by the target tolerance thresholds, survey scale, ambient illumination conditions, stand-off distance, ground sampling distance (GSD) or spatial resolution, and available computational or field resources.

4. Conclusions

This study presented a comparative evaluation of crack characterization based on point clouds generated by structured light and Structure from Motion (SfM) techniques, incorporating statistical metrics to quantitatively assess their performance.

The results demonstrated that SfM achieved higher accuracy in representing global geometry, as evidenced by its low mean error and RMSE when compared to reference measurements obtained from the total station. This indicates that, when properly scaled using control distances, SfM can provide reliable dimensional information for structural assessment.

In contrast, the structured light approach exhibited a systematic overestimation of distances but showed greater consistency in crack width measurements, reflected by its low variability. This suggests that structured light is more suitable for detailed local analysis, where measurement stability is critical.

The combined use of multiple reference distances and sampling segments contributed to a more robust evaluation, allowing the distinction between global accuracy and local precision. These findings reinforce that the performance of each technique is strongly influenced by its intrinsic characteristics, and therefore, their applicability depends on the specific requirements of the analysis.

Overall, structured light is recommended for high-resolution local characterization of cracks, while SfM represents a flexible and cost-effective solution with superior performance in large-scale geometric reconstruction. Future work should explore the integration of both approaches, as well as improvements in calibration and scaling procedures, to further enhance accuracy and expand the applicability of point cloud-based methods in structural health monitoring.

References

- Alamdari, A. G.; Ebrahimkhanlou, A. Multi-scale robotic scan ning of surface cracks in concrete structures. In: *Nondestructive Characterization and Monitoring of Advanced, Aero space, Civil Infrastructure, and Transportation XVIII*. SPIE, p. 197-203, 2024.
- Alamdari, A. G.; Ebrahimkhanlou, A. A robotic approach for crack detection through the integration of cameras and LiDARs. *Sensors and Smart Structures technologies for Civil Infrastructure, Mechanical, and Aerospace Systems 2023*. SPIE, p. 21-29, 2023.
- AMBÓSIO, T. S. *Patologia, tratamento e reforço de estruturas de Concreto no metrô de São Paulo*. São Paulo, 2004. 138p. Trabalho de Conclusão de Curso (Engenharia Civil). Universidade Anhembí Morumbi, São Paulo - SP, 2004.
- Arivabene, A. C. Patologias em estruturas de concreto armado: Estudo de caso. *Revista Especialize On-line IPOG*, v. 3, n. 10, 1-22, 2015.
- Bungey, J. H. et al. *Testing of Concrete in Structures*. New York, USA: Taylor & Francis, 2006. 352p.
- Freitas, J. G. et al. Utilização de termografia infravermelha para avaliação de fissuras em fachada com revestimento de argamassa e pintura. *Ambiente Construído*, v. 14, 57-73, 2014.
- GRAÇA, N. L. S. S. *Estudo da influência da geometria de voo na obtenção de produtos cartográficos empregando recobrimento aéreo com VANT e técnica fotogramétrica SFM*. Curitiba, 2019. Tese (Doutorado em Ciências Geodésicas). Programa de Pós-Graduação em Ciências Geodésicas, Universidade Federal do Paraná, Curitiba-PR, 2019.
- González-Aguilera, D. et al. A new approach for structural monitoring of large dams with a three-dimensional laser scanner. *Sensors*, v. 8, 5866-5883, 2008.
- Guo, M. et al. Intelligent extraction of surface cracks on LNG outer tanks based on close-range image point clouds and infrared imagery . *J Nondestruct Eval*, 43(3):84, 2024.
- Hu, K. et al. 3D vision technologies for self-developed structural external crack damage recognition robot. *Autom Const*, 2024.
- Kang, D.; Cha, Y. J. Autonomous UAVs for structural helath monitoring using deep learning and ultrasonic beacon system with geo-tagging. *Computer-Aided Civil and Infrastructure Engineering*, v. 33, n. 10, 885-902, 2018.

-
- Machado, A. P. *Reforço de estruturas de concreto armado com fibras de carbono*. São Paulo, São Paulo: Pini, 2002.
- Majidi, S.; Omidalizarandi, M.; Sharifi, M.A. Intelligent 3D crack reconstruction using close range photogrammetry imagery. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, n. 10, 443-450, 2023.
- MONICO, J. F. G. *Ajustamento e Análise Estatística de Observações Aplicados na Detecção de Deformações*. Niterói, 1988. 97f. Dissertação (Mestrado em Ciências Geodésicas). Programa de Pós-Graduação em Ciências Geodésicas, Universidade Federal do Paraná, Curitiba-PR, 1988.
- MULLER FILHO, A. V. *Ajustamento e Análise Estatística de Observações Aplicados na Detecção de Deformações*. Florianópolis, 2015. Trabalho de Conclusão de Curso (Engenharia Civil). Universidade Federal de Santa Catarina, Florianópolis-SC, 2015.
- PALAORO, D.G.; RODRIGUES, L. H.C.H. *Estudo de viabilidade técnica para utilização da régua potenciométrica na monitoração contínua de fissuras em concreto*. Vitória, 2017. Trabalho de Conclusão de Curso (Pós-Graduação em Patologia nas Obras Civas). Instituto IDD, Vitória - ES, 2017.
- Robinson, A. et al. Methods for Indexing Stripes in Uncoded Structured Light Scanning Systems. *Journal of WSCG, Union Agency-Science Press*, v. 12, n. 1-3, 371-378, 2004.
- ROCHA, R. S. M. *Posicionamento geodésico com GPS no suporte a detecção de deslocamento em barragens*. Presidente Prudente, 2017. 144f. Dissertação (Mestrado em Ciências Cartográficas). Programa de Pós-Graduação em Ciências Cartográficas, Universidade Estadual Paulista, Presidente Prudente - SP, 2017.
- Van Genechten, B. et al. *Theory and practice on Terrestrial Laser Scanning*: Training material based on practical applications. Valencia, Spain: Universidad Politecnica de Valencia Editorial, 2008.
- VEIGA, M. R. *Comportamento de argamassas de revestimento de paredes*: contribuição par o estudo da sua resistência à fendilhação. Porto, 1998. Tese (Doutorado em Engenharia Civil). Laboratório Nacional de Engenharia Civil. Programa de Pós-Graduação em Engenharia Civil, Universidade do Porto, Porto-PT, 1998.
- Westoby, M. et al. Structure-from-Motion 'photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, v. 179, 300-314, 2012.
- Zanetti, G. Z. et al. Monitoramento Estrutural por GNSS: Análise do PPP e Posicionamento Relativo na UHE Mauá. *Anuário do Instituto de Geociências*, v. 43, n. 3, 240-249, 2020.
- Zhu, Z. et al. A quantitative investigation of the effect of scan planning and multi-technology fusion for point cloud data collection on registration and data quality: a case study of Bond University sustainable building. *Buildings* 13(6):1473, 2023.