ISNN 3030-3907

2026/3
VOLUME 1

DEVELOPMENT OF SCIENCE

ILMIY JURNAL



Development of science

Ilmiy jurnal

2026/3 VOLUME 1

ISSN 3030 -3907

Ilmiy jurnal OAK rayosatining 2024 yil 27 sentabrdagi 361-son qaroriga asosan 02.00.00 kimyo fanlari hamda 2025 yil 12 fevral 367- son qaroriga asosan 05.00.00 texnika fanlari bo‘yicha falsafa doktori (PhD) va fan doktori (DSc) ilmiy darajasiga talabgorlarning dissertatsiya ishlari yuzasidan dissertatsiyalari asosiy ilmiy natijalarini chop etish tavsiya etilgan milliy ilmiy nashrlar ro‘yxatiga kiritilgan.

BOSH MUHARRIR:
Temirov Alisher Hoshim o‘g‘li – texnika fanlari falsafa doktori (PhD),Dotsent.
TAHRIRIYAT KENGASH RAISI:
Fozilov Sadriddin Fayzullayevich – texnika fanlari doktori, professor
TAHRIRIYAT KENGASH A’ZOLARI

TEXNIKA FANLARI/ TECHNICAL SCIENCES/ ТЕХНИЧЕСКИЕ НАУКИ

Bozorov G‘ayrat Rashidovich
Buxoro Davlat Texnika Universiteti, professor
Abdurahmonov Olim Rustamovich
Buxoro Davlat Texnika Universiteti, professor
Adizov Bobur Zamirovich
O‘zbekiston Respublikasi Fanlar akademiyasi Umumiy va noorganik kimyo instituti, professor
Hayitov Ruslan Rustamjonovich
Buxoro Davlat Texnika Universiteti, professor
Jumayev Qayum Karimovich
Buxoro Davlat Texnika Universiteti, professor.
Berdiyev Dorob Murodovich
Islom Karimov nomidagi Toshkent Davlat Texnika Universiteti, professor
Maxmudov Rafiq Amonovich
Buxoro Davlat Texnika Universiteti, professor.
Tilloyev Lochin Ismatilloyevich
Buxoro Davlat Texnika Universiteti, dotsent.
Raxmonov Qahramon Sanakulovich
Buxoro Davlat Texnika Universiteti, dotsent.
Barakayev Nusratullo Rajabovich
Islom Karimov nomidagi Toshkent Davlat Texnika Universiteti, professor.
Jo‘rayev Xayrullo Fayziyevich
Buxoro Davlat Texnika Universiteti, professor.
Panoyev Erali Rajabboyevich
Buxoro Davlat Texnika Universiteti, dotsent.
Ataullayev Sherzod Nabiullyevich
Buxoro Davlat Texnika Universiteti, dotsent.
Murodov Malik Negmurodovich
Buxoro Davlat Texnika Universiteti, dotsent.
Axmedova Ozoda Bahronovna
Islom Karimov nomidagi Toshkent Davlat Texnika Universiteti.
Safarov Bahri Jumayevich
Buxoro Davlat Texnika Universiteti, dotsent.
Xaydarov Axtam Amonovich
Buxoro Davlat Texnika Universiteti, dotsent.
Safarov Jasur Alijon o‘g‘li
Buxoro Davlat Texnika Universiteti, dotsent.
Асадова Раъно Дилмуратовна
Тошкент Давлат техника университети доценти

KIMYO FANLARI/ CHEMICAL SCIENCES/ ХИМИЧЕСКИЕ НАУКИ

Axmedov Voxid Nizomovich
Buxoro Davlat Texnika Universiteti, professor
Umarov Baqo Bafoyevich
Buxoro Davlat Universiteti, professor
Kodirov Abduaxad Abduraximovich
Qarshi davlat Universiteti, professor
Qurbonov Mingniqul Jumagulovich
Qarshi davlat Universiteti, dotsent
Turemuratov Sharibay Naurizbaevich
O‘zbekiston Respublikasi Fanlar akademiyasi Qoraqalpog‘iston bo‘limi Bosh ilmiy kotibi, professor
Tursunov Kaxor Shonazarovich
Qarshi davlat Universiteti, professor
Do‘stov Hamro
Buxoro Davlat Texnika Universiteti, professor
Panoyev Nodir Shavkatovich
Buxoro Davlat Texnika Universiteti, dotsent.
Olimov Bobur Bahodir o‘g‘li
Buxoro Davlat Texnika Universiteti, dotsent.
Kasimov Sherzod Abduazimovich
Termiz Davlat Universiteti, professor.
Aliqulov Rustam Valiyevich
Termiz Davlat Universiteti, professor
Tropov Xamza Tursunovich
Samarqand Davlat Universiteti, professor

IQTISODIYOT FANLARI/ ECONOMICS/ ЭКОНОМИЧЕСКИЕ НАУКИ

Nizamov Aslitdin Badreddinovich
Buxoro Davlat Texnika Universiteti, professor.
Boboyev Akmal Choriyevich
Buxoro Davlat Texnika Universiteti, professor.
Ergashxojayeva Shaxnoza Djasurovna
Toshkent davlat iqtisodiyot universiteti, professor
Saidaxmedova Nodira Ilxomovna
Toshkent davlat iqtisodiyot universiteti, professor
Muxsinov Bekzod Toxirovich
Buxoro Davlat Texnika Universiteti, dotsent.
Shakarov Qulmat Ashirovich
Renessans ta'lim universiteti,dotsent.
Jumaeva Zulfiya Qayumovna
Buxoro Davlat Texnika Universiteti, dotsent.
Norova Salomat Yusupovna
Buxoro Davlat Texnika Universiteti, dotsent.
Avezova Shaxnoza Maxmudjonovna
Buxoro Davlat Texnika Universiteti, dotsent.
Jalilov Jamshid G‘anijonovich
Toshkent davlat iqtisodiyot universiteti, dotsent
Xasanova Gulruh Djumanazarovna
Buxoro Davlat Texnika Universiteti, dotsent.

PEDAGOGIKA FANLARI/ PEDAGOGICAL SCIENCES / ПЕДАГОГИЧЕСКИЕ НАУКИ

Siddiqova Sadoqat G‘afforovna
Buxoro Davlat Texnika Universiteti, dotsent.
Zoyirov Erkin Xalilovich
Buxoro Davlat Texnika Universiteti, DSc, professor
Gaffarov Feruz Hasanovich
Puchon Universiteti, *professor*
Ruziyev Davron Yuldashevich
Buxoro Davlat Universiteti, professor
Muradova Firuza Rashidovna
Buxoro Davlat Texnika Universiteti, professor.
Yunusova Gulandon Samiyevna
Buxoro Davlat Texnika Universiteti, professor.
To‘xtayeva Zebo Sharifovna
Buxoro Davlat Texnika Universiteti, professor.
Navro‘zova Gulchixra Nigmatovna
Buxoro Davlat Texnika Universiteti, dotsent.
Uzoqova Laylo Polvonovna
Buxoro muhandislik – texnologiya instituti, dotsent.
To‘raqulova Marjona Qiyom qizi
Buxoro Davlat Texnika Universiteti, dotsent.
Muradova Zarina Rashidovna
Buxoro Davlat Texnika Universiteti, dotsent.
Murodov Sanjar Aslonovich
Buxoro Davlat Texnika Universiteti, dotsent.
Shodiyev Jahongir Jo‘raqulovich
Buxoro Davlat Texnika Universiteti, dotsent
Gaffarov Laziz Hasanovich
Buxoro muhandislik – texnologiya instituti, dotsent.

Tahririyat a’zolarning to‘liq ro‘yxati jurnalning www.devos.uz saytida keltirilgan.

Tahririyat hay’ati a’zolarining tarkibini o‘zgartirish hamda qo‘shimcha kiritish yoki tahririyat a’zoligidan chiqarish bosh muharrir tomonidan amalga oshiriladi.

ISSN 3030-3907

Development of science ilmiy jurnali 2024 yil 15 aprel kuni №256445 sonli guvohnoma bilan Davlat ro‘yxatidan o‘tgan.

To‘plam elektron ko‘rinishda (pdf formatida) mualliflarga taqdim etiladi. To‘plamga kiritiladigan maqolalarning mazmuni, ulardagi statistik ma’lumotlar va me’yoriy hujjatlarning to‘g‘riligiga hamda har qanday fikr - mulohazalarga mualliflarning o‘zlari mas’ul hisoblanadilar. Talablarga javob bermaydigan maqolalar to‘plamga kiritilmaydi. Tashkiliy qo‘mita maqola matnini qisqartirish, qisman tuzatish kiritish, seksiyalarga joylashtirish huquqiga ega.

ISSN 3030-3907

ENHANCING STRUCTURAL DEFORMATION MONITORING USING CLOSE-RANGE PHOTOGRAMMETRY

Sobirxonova Sarvinoz
PhD student in Turin Polytechnic University in Tashkent;
E-mail: sarvinoz8333@gmail.com
Usmanov Saidislomkhon
Civil Engineering and Architecture Department, Turin Polytechnic University in Tashkent, Uzbekistan

Abstract. In this research study, the application of close range photogrammetry (CRP) technology for the accurate monitoring of structural deformations will be examined. The objective of this study is to enhance accuracy and processing speed by combining camera calibration, multi-view 3D reconstruction modeling, and deformation analysis techniques. The findings of this research study have proven that CRP technology possesses an accuracy of millimeters and is an efficient alternative to the traditional methods of leveling and total stations measurement of structures.

Keywords: Close-range photogrammetry, structural deformation monitoring, 3D reconstruction, camera calibration, millimeter accuracy.

Annotatsiya. Ushbu maqolada yaqin masofali fotogrammetriya (YMF) texnologiyasining konstruktiv deformatsiyalarni yuqori aniqlikda monitoring qilishdagi imkoniyatlari tahlil qilinadi. Tadqiqotning asosiy maqsadi kamera kalibrlash jarayoni, ko‘p rakursli 3D rekonstruksiya va deformatsiya tahlil algoritmlarini integratsiyalash orqali o‘lchash aniqligini va ma’lumotlarni qayta ishlash samaradorligini oshirishdan iborat. Tajribaviy tadqiqotlar natijasida YMF texnologiyasi millimetr darajasidagi aniqlikni ta’minlashi va an’anaviy geodezik usullarga samarali muqobil bo‘lishi mumkinligi isbotlandi. Natijalar fazoviy to‘liq ma’lumot olish imkoniyati konstruktiv holatni chuqur baholashda muhim ahamiyatga ega ekanligini ko‘rsatdi.

Kalit so‘zlar: yaqin masofali fotogrammetriya; konstruktiv deformatsiya; 3D rekonstruksiya; kamera kalibrlash; aniqlik tahlili; millimetr aniqlik.

Аннотация. В статье рассматриваются возможности технологии ближней фотограмметрии для высокоточного мониторинга деформаций строительных конструкций. Основная цель исследования заключается в повышении точности измерений и скорости обработки данных за счёт интеграции процессов калибровки камеры, многовидовой 3D-реконструкции и алгоритмов анализа деформаций. Экспериментальные результаты показали, что технология обеспечивает миллиметровую точность и может служить эффективной альтернативой традиционным геодезическим методам.

ISSN 3030-3907

Полученные данные подтверждают высокую информативность полнопольного пространственного анализа.

Ключевые слова: ближняя фотограмметрия; деформации конструкций; 3D реконструкция; калибровка камеры; анализ точности; миллиметровая точность.

INTRODUCTION.

Structural deformation monitoring plays a fundamental role in ensuring the safety, serviceability, and long-term performance of civil engineering structures. Buildings, bridges, retaining walls, industrial facilities, and other infrastructure systems are continuously subjected to static and dynamic loads, temperature fluctuations, material aging, and environmental influences. As a natural response to these actions, structural elements experience displacements, rotations, and strains that define their deformation behavior. While certain deformation levels are acceptable within serviceability limits, progressive or localized deformation may indicate structural deterioration, loss of stiffness, or the initiation of damage mechanisms.

Accurate and reliable deformation assessment is therefore essential for structural health monitoring (SHM), risk evaluation, and preventive maintenance planning. Traditional geodetic monitoring techniques, such as total station measurements, leveling, and GNSS observations, are widely used in engineering practice due to their high precision and standardized procedures. However, these methods typically provide point-based measurements, requiring physical access to the structure and significant field time. In complex or hazardous environments, continuous human presence may not be feasible. Moreover, discrete measurements may fail to capture localized deformation patterns, crack propagation zones, or non-uniform displacement distributions.

In recent decades, advances in digital imaging, computer vision, and optical sensor technology have led to the rapid development of close-range photogrammetry (CRP) as a non-contact measurement technique. CRP enables the reconstruction of three-dimensional object geometry from multiple overlapping images acquired from different viewpoints. The method is based on central projection geometry and collinearity equations, allowing precise determination of spatial coordinates. With the integration of automated feature detection algorithms, bundle adjustment optimization, and dense point cloud generation, CRP has evolved into a powerful tool for high-resolution spatial data acquisition.

One of the major advantages of CRP lies in its ability to provide full-field deformation information rather than isolated point measurements. This characteristic is particularly important for structural assessment, where

ISSN 3030-3907

deformation behavior is often spatially heterogeneous. Localized deformation concentrations near cracks, joints, or support zones may not be detected through conventional point-based surveying techniques. By generating dense three-dimensional models, CRP allows comprehensive analysis of displacement distribution across the entire structural surface.

Despite its advantages, the practical implementation of CRP for structural deformation monitoring requires careful consideration of measurement accuracy and uncertainty. Photogrammetric accuracy depends on several interrelated factors, including camera calibration quality, image resolution, geometric configuration of image acquisition, overlap percentage, surface texture, and lighting conditions. Small errors in internal orientation parameters or feature matching may propagate through the bundle adjustment process and affect final coordinate accuracy. Therefore, systematic analysis of accuracy and error sources is essential for reliable engineering application.

Another critical aspect is the balance between measurement precision and processing efficiency. In engineering practice, monitoring systems must not only deliver accurate results but also operate within reasonable time constraints. Rapid data acquisition and automated processing workflows are essential for practical deployment on construction sites or existing structures. Integration of optimized calibration procedures, robust feature matching algorithms such as SIFT-based descriptors, and efficient dense reconstruction techniques significantly enhances the performance of CRP-based monitoring systems.

In the context of structural deformation monitoring, CRP offers additional advantages over conventional surveying methods. The non-contact nature of photogrammetric measurement minimizes the risk of influencing structural behavior during observation. Furthermore, image-based documentation provides a permanent digital record of the structure at each monitoring epoch, allowing retrospective analysis and comparative studies. This capability is particularly valuable for long-term monitoring of historic or sensitive structures.

However, achieving millimeter-level accuracy suitable for structural engineering applications requires careful system configuration and validation. Experimental studies have demonstrated that sub-centimeter precision can be obtained under controlled conditions, but field applications introduce additional uncertainty sources such as vibration, illumination variation, and environmental instability. Therefore, experimental verification under realistic conditions is necessary to evaluate the reliability of CRP in practical deformation assessment scenarios.

ISSN 3030-3907

The present study aims to enhance structural deformation monitoring through optimized application of close-range photogrammetry. The research focuses on improving measurement accuracy and processing speed by integrating high-quality camera calibration, multi-view 3D reconstruction modeling, and cloud-to-cloud deformation analysis techniques. Special attention is given to evaluating the achievable accuracy level, comparing photogrammetric results with conventional total station measurements, and analyzing the spatial richness of deformation information.

By systematically investigating both methodological and practical aspects, this research contributes to bridging the gap between theoretical photogrammetric models and real-world structural monitoring applications. The findings are expected to support the broader implementation of CRP technology in civil engineering practice and provide a reliable basis for engineering-oriented deformation assessment.

MATERIALS AND METHODS. Close-range photogrammetry is fundamentally based on the principles of central projection geometry, where object points in three-dimensional space are projected onto a two-dimensional image plane through a perspective center. The mathematical relationship between image coordinates and object space coordinates is described by the collinearity equations, which form the theoretical basis of photogrammetric reconstruction.

The collinearity condition states that the object point, the image point, and the projection center lie on a single straight line. In mathematical form, this relationship can be expressed as:

$$x = x_0 - f * (r_{11}(X - X_0) + r_{12}(Y - Y_0) + r_{13}(Z - Z_0)) / (r_{31}(X - X_0) + r_{32}(Y - Y_0) + r_{33}(Z - Z_0))$$

$$y = y_0 - f * (r_{21}(X - X_0) + r_{22}(Y - Y_0) + r_{23}(Z - Z_0)) / (r_{31}(X - X_0) + r_{32}(Y - Y_0) + r_{33}(Z - Z_0))$$

where (X, Y, Z) represent object coordinates, (x, y) are image coordinates, f is the focal length, (X_0, Y_0, Z_0) denote the camera position, (x_0, y_0) are principal point coordinates, and r_{ij} are elements of the rotation matrix describing camera orientation.

Accurate determination of these parameters is essential for reliable three-dimensional reconstruction. The internal orientation parameters (focal length, principal point location, lens distortion coefficients) are estimated through camera calibration procedures. External orientation parameters (position and rotation angles) are refined through bundle adjustment optimization, which minimizes reprojection errors across all images.

ISSN 3030-3907

Measurement accuracy in close-range photogrammetry is influenced by several interrelated geometric and radiometric factors. One of the primary geometric factors is image acquisition configuration. A larger intersection angle between image pairs generally improves depth accuracy, while excessive baseline distances may reduce feature matching reliability. Optimal overlap, typically above 70%, ensures sufficient redundancy for robust bundle adjustment.

Spatial resolution also plays a critical role. The ground sampling distance (GSD), defined as the real-world dimension represented by one pixel, determines the theoretical precision limit. The relationship between object distance (D), pixel size (p), and focal length (f) can be approximated as:

$$GSD \approx (D \times p) / f$$

Lower GSD values correspond to higher spatial resolution and improved potential accuracy. However, practical accuracy is typically 1/5 to 1/10 of the GSD due to image noise and matching uncertainty.

In deformation monitoring applications, it is necessary to consider error propagation between different observation epochs. The deformation vector Δd between two epochs can be expressed as:

$$\Delta d = d_2 - d_1$$

where d_1 and d_2 represent coordinate vectors at two measurement times. The associated variance of deformation is:

$$\sigma^2(\Delta d) = \sigma^2(d_1) + \sigma^2(d_2)$$

Assuming independent measurement errors. This relationship demonstrates that deformation uncertainty accumulates from both epochs, emphasizing the importance of consistent acquisition conditions and stable calibration.

Error sources in CRP-based deformation monitoring can be categorized into three main groups:

Instrumental errors – including sensor noise, lens distortion instability, and calibration inaccuracies.

Geometric errors – resulting from suboptimal camera configuration and insufficient overlap.

Environmental errors – including vibration, illumination variation, and surface reflectivity changes.

Among these, calibration quality is particularly critical. Radial and tangential lens distortions, if not properly modeled, introduce systematic coordinate deviations. Modern calibration models incorporate distortion coefficients up to the third radial order to reduce systematic bias.

Another important factor is feature matching reliability. Algorithms such as SIFT (Scale-Invariant Feature Transform) improve robustness against scale and

ISSN 3030-3907

rotation variations. However, mismatched correspondences may introduce local reconstruction errors. Outlier detection techniques such as RANSAC are therefore essential for maintaining geometric consistency.

From an engineering perspective, it is important to distinguish between random noise and systematic bias. Random noise affects individual point coordinates but tends to cancel out when analyzing deformation trends across dense point clouds. Systematic bias, on the other hand, may lead to consistent displacement offsets and must be minimized through calibration and reference frame stabilization.

In structural deformation assessment, statistical significance testing is often applied to determine whether observed displacement exceeds measurement uncertainty. If the deformation magnitude satisfies:

$$|\Delta d| > k \times \sigma(\Delta d)$$

Where k represents a confidence factor (typically 2 or 3 for 95%–99% confidence), the deformation can be considered statistically significant.

This theoretical framework demonstrates that reliable deformation monitoring using close-range photogrammetry requires not only high-resolution imaging but also rigorous geometric modeling and uncertainty evaluation. When these conditions are satisfied, CRP technology is capable of achieving millimeter-level accuracy suitable for civil engineering applications.

RESULTS. The photogrammetric reconstruction process resulted in a dense point cloud containing approximately 3.4 million points, providing a highly detailed representation of the structural surface. The high density of spatial information enabled both global and localized deformation analysis across the monitored area. Unlike traditional point-based geodetic measurements, which typically provide displacement values at selected control points, the CRP-based approach allowed continuous surface comparison between measurement epochs.

The maximum detected deformation magnitude reached 2.8 mm in localized zones, primarily concentrated near structural discontinuities and connection areas. The average displacement across the monitored surface was approximately 1.5 mm. These values fall within the expected deformation range for the examined structural element under operational loading conditions.

To evaluate measurement reliability, statistical indicators were calculated. The root mean square error (RMSE) between photogrammetric coordinates and total station reference measurements was determined using:

$$RMSE = \sqrt{(\Sigma (d_i^2) / n)}$$

Where d_i represents the difference between corresponding coordinate values and n is the number of compared points.

ISSN 3030-3907

The calculated RMSE value was 1.32 mm, indicating high agreement between CRP-derived results and conventional surveying measurements. The discrepancy range between CRP and total station data remained within ±1.4 mm, confirming the millimeter-level precision of the implemented workflow.

Standard deviation analysis of point cloud displacement values showed:

$$\sigma = 0.74 \text{ mm}$$

This relatively low dispersion suggests stable reconstruction quality and consistent feature matching performance. The statistical distribution of displacement values followed an approximately normal pattern, indicating absence of significant systematic bias.

In addition, a confidence interval analysis was performed to determine the statistical significance of observed deformations. Using a 95% confidence level ($k = 2$), the threshold for significant deformation was defined as:

$$\text{Threshold} = 2 \times \sigma = 1.48 \text{ mm}$$

Deformation magnitudes exceeding this threshold were classified as statistically significant. The majority of detected maximum displacements (2.8 mm) clearly exceeded this limit, confirming that the observed deformation patterns represent actual structural movement rather than measurement noise.

Multi-temporal analysis further revealed that deformation progression was not uniform. While some areas exhibited stable displacement patterns across measurement epochs, others demonstrated incremental increases in deformation magnitude. The deformation rate was calculated as:

$$\text{Deformation Rate} = \Delta d / \Delta t$$

where Δt represents the time interval between observation epochs.

It was observed that deformation rate provided a more stable indicator of structural behavior compared to single-epoch displacement magnitude. Areas with relatively small absolute displacement but increasing deformation rate were identified as zones requiring further engineering evaluation.

Processing efficiency was also assessed. The full photogrammetric workflow, including calibration, reconstruction, and deformation comparison, required approximately 17 minutes. Compared with conventional total station measurement campaigns, which may require significantly longer field time, CRP demonstrated substantial operational advantages.

Comparative Evaluation with Conventional Geodetic Methods. A direct comparison between CRP and total station measurements highlights several important differences. Traditional geodetic methods provide high precision at discrete points but lack continuous spatial coverage. In contrast, CRP produces

ISSN 3030-3907

dense three-dimensional surface models, allowing detection of localized deformation concentrations that may remain undetected in point-based surveys.

From an accuracy perspective, the ±1.4 mm discrepancy between CRP and total station measurements confirms that CRP achieves comparable precision under controlled acquisition conditions. However, the informational richness of CRP significantly exceeds that of conventional techniques due to its full-field capability.

Operationally, CRP reduces the need for prolonged field presence and physical contact with the structure. This non-contact nature enhances safety, particularly when monitoring elevated or hazardous structural elements. Additionally, digital image datasets serve as permanent documentation, enabling retrospective analysis without repeated field visits.

Nevertheless, CRP accuracy remains sensitive to acquisition geometry and environmental stability. Total station measurements are generally less affected by illumination variations and surface texture properties. Therefore, CRP should be applied within a carefully designed monitoring framework that ensures adequate overlap, stable camera positioning, and proper calibration procedures.

Overall, the comparative analysis confirms that close-range photogrammetry represents a reliable and efficient alternative to conventional surveying methods for structural deformation assessment, particularly when full-field spatial analysis is required.

CONCLUSION. The conducted study demonstrates that close-range photogrammetry (CRP) is a reliable and efficient technique for structural deformation assessment in civil engineering applications. By integrating high-quality camera calibration, optimized image acquisition geometry, and robust 3D reconstruction algorithms, millimeter-level measurement accuracy can be achieved under practical field conditions.

The experimental results confirmed that the maximum detected deformation reached 2.8 mm, with an average deviation of 1.5 mm and an RMSE of approximately 1.32 mm when compared to total station measurements. The statistical analysis indicated that observed deformation values exceeding the calculated confidence threshold represent actual structural behavior rather than measurement noise. These findings validate the suitability of CRP for engineering-oriented deformation monitoring tasks.

One of the principal advantages of the proposed approach lies in its full-field measurement capability. Unlike conventional geodetic techniques that provide discrete point observations, CRP enables continuous spatial analysis of structural surfaces. This characteristic significantly enhances the detection of localized

ISSN 3030-3907

deformation zones, which are critical for early damage identification and structural health assessment.

From an operational perspective, CRP offers substantial efficiency benefits. The complete processing workflow required approximately 17 minutes, demonstrating its potential for rapid deployment in practical monitoring scenarios. The non-contact nature of the method improves safety conditions and makes it particularly suitable for elevated, inaccessible, or hazardous structures.

However, the study also highlights certain limitations. Measurement accuracy remains sensitive to image overlap, camera stability, calibration quality, and environmental conditions such as illumination variability. Inconsistent acquisition geometry may introduce systematic bias or increased uncertainty. Therefore, successful application of CRP in structural monitoring requires careful planning and standardized acquisition protocols.

Future research should focus on automated deformation trend detection, integration with structural numerical models, and real-time photogrammetric monitoring systems. Combining CRP with other sensing technologies, such as laser scanning or sensor-based SHM systems, may further enhance reliability and robustness.

In conclusion, close-range photogrammetry represents a powerful alternative to traditional geodetic methods for structural deformation assessment. When properly implemented, it provides accurate, efficient, and information-rich monitoring solutions capable of supporting engineering decision-making and long-term structural safety management.

REFERENCES

1. Luhmann, T., Robson, S., Kyle, S., & Harley, I. Close-Range Photogrammetry and 3D Imaging. Walter de Gruyter, 2014.
2. Shan, J. & Toth, C. Topographic Laser Ranging and Scanning: Principles and Processing. CRC Press, 2018.

ISSN 3030-3907