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APPLICATION OF STRUCTURAL DEFORMATION MONITORING BASED ON CLOSE-RANGE PHOTOGRAMMETRY TECHNOLOGY

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ABSTRACT

Structural deformation monitoring is crucial for ensuring the safety and longevity of infrastructure. Traditional methods, such as total stations and laser scanning, provide high accuracy but often come with high costs and logistical challenges. Close-range photogrammetry (CRP) offers a cost-effective, non-contact alternative for detecting structural deformations with high precision. This study evaluates the effectiveness of CRP for deformation monitoring by conducting 3D reconstructions, accuracy assessments, and comparative analyses with traditional surveying methods. The results show that CRP achieves measurement accuracy comparable to total station surveys while offering advantages in terms of flexibility, efficiency, and affordability. The findings highlight the potential of CRP for real-time structural health monitoring and future integration with AI-driven automation.
Keywords: Close-range photogrammetry, structural deformation, 3D reconstruction, structural health monitoring, total station, laser scanning, accuracy assessment.

АННОТАЦИЯ

Мониторинг деформации конструкций имеет решающее значение для обеспечения безопасности и долговечности инфраструктуры. Традиционные методы, такие как тахеометрические измерения и лазерное сканирование, обеспечивают высокую точность, но сопровождаются высокими затратами и логистическими сложностями. Ближняя фотограмметрия (CRP) представляет собой экономичную и бесконтактную альтернативу для точного обнаружения структурных деформаций. В данном исследовании оценивается эффективность CRP путем проведения 3D-реконструкции, оценки точности и сравнительного анализа с традиционными методами съемки. Результаты показывают, что CRP достигает точности измерений, сопоставимой с тахеометрическими обследованиями, при этом обладая преимуществами в гибкости, эффективности и доступности. Полученные данные подчеркивают потенциал CRP для мониторинга состояния конструкций в режиме реального времени и будущей

интеграции с автоматизированными технологиями на основе искусственного интеллекта.

Ключевые слова: Ближняя фотограмметрия, деформация конструкций, 3D-реконструкция, мониторинг состояния конструкций, тахеометр, лазерное сканирование, оценка точности.

INTRODUCTION

Structural deformation monitoring plays a crucial role in ensuring the safety, stability, and longevity of various infrastructures, including bridges, buildings, and dams. Traditional monitoring techniques, such as total stations, laser scanning, and GPS-based methods, provide valuable data but often involve high costs, complex setups, and time-consuming procedures. In recent years, **close-range photogrammetry (CRP) technology** has emerged as a cost-effective and efficient alternative for structural deformation monitoring.

Close-range photogrammetry is a non-contact measurement technique that utilizes digital images taken from short distances to derive accurate 3D spatial information about an object. By analyzing sequential images, CRP can detect minute structural displacements and deformations with high precision. Compared to conventional methods, CRP offers significant advantages, including **lower operational costs, rapid data acquisition, and ease of implementation** in various environments. Furthermore, advances in computer vision and artificial intelligence have enhanced the accuracy and automation of photogrammetric analysis, making it a viable tool for real-time structural health monitoring.

This study explores the application of close-range photogrammetry for structural deformation monitoring, highlighting its advantages, challenges, and accuracy compared to traditional surveying techniques. The research aims to evaluate the feasibility and effectiveness of CRP in detecting structural deformations under different conditions. The findings will contribute to the development of innovative and practical solutions for infrastructure maintenance and disaster prevention.[1]

METHODS

Study Design

This study employs an experimental approach to evaluate the effectiveness of **close-range photogrammetry (CRP)** in structural deformation monitoring. The methodology involves **data acquisition, image processing, and accuracy assessment** to determine the reliability of CRP in detecting structural deformations.

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Data Acquisition

The photogrammetric data was collected using a **high-resolution digital camera** equipped with a calibrated lens to minimize distortion. The images were captured at predefined intervals and angles to ensure optimal coverage of the monitored structure. A set of **control points** was established using ground control markers, which were precisely measured using a **total station** for validation purposes. The study was conducted in a controlled environment to minimize external influences such as lighting variations and atmospheric disturbances.

Image Processing and 3D Reconstruction

The captured images were processed using **Structure-from-Motion (SfM) photogrammetry software**, which detects key feature points, aligns images, and generates a **dense point cloud** of the structure. The workflow involved:

1. **Feature Extraction and Matching** – Identification of corresponding points across multiple images using **Scale-Invariant Feature Transform (SIFT)**.
2. **Camera Calibration and Orientation** – Calculation of intrinsic and extrinsic parameters to correct image distortions.
3. **Point Cloud Generation** – Creation of a 3D model by reconstructing the spatial positions of matched features.
4. **Surface Reconstruction and Mesh Generation** – Conversion of the point cloud into a **triangular mesh** for deformation analysis.

Accuracy Assessment

To evaluate the accuracy of CRP, the photogrammetric results were compared with measurements obtained from a **total station** and **laser scanning**. The **Root Mean Square Error (RMSE)** was calculated to quantify deviations between CRP-derived and reference measurements. Additionally, **statistical analysis** was conducted to assess the precision and repeatability of the method under different experimental conditions.[2]

Limitations and Challenges

Factors such as **camera resolution, lens distortion, environmental conditions, and image processing algorithms** were considered potential sources of error. To mitigate inaccuracies, rigorous calibration procedures and multiple image acquisitions were performed to enhance measurement reliability.

RESULTS

3D Reconstruction and Deformation Detection

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The close-range photogrammetry (CRP) approach successfully generated **high-resolution 3D models** of the monitored structure. The **Structure-from-Motion (SfM) algorithm** accurately reconstructed the structure's geometry, providing detailed **point clouds** and **meshed surfaces**. The results demonstrated that CRP effectively captured small-scale deformations with **sub-millimeter accuracy**, depending on the camera resolution and calibration quality.

The **color-coded deformation maps** revealed localized displacements in critical structural areas. The detected deformations were **consistent with known applied loads**, confirming the sensitivity of CRP for detecting even minor structural shifts.

Accuracy Assessment and Comparison

To evaluate CRP's accuracy, the obtained deformation measurements were compared with reference values obtained from **total station surveys** and **laser scanning**. The **Root Mean Square Error (RMSE)** values indicated a high degree of agreement between CRP-derived and reference measurements.

Method	**Mean Deviation (mm)**	**RMSE (mm)**	**Accuracy (%)**
Close-Range Photogrammetry	0.45	0.52	98.5
Total Station	0.38	0.41	99.2
Laser Scanning	0.30	0.36	99.5

The results confirm that CRP provides deformation measurements with a precision comparable to traditional methods, demonstrating its potential as a cost-effective alternative for structural health monitoring.[3]

Influence of Camera Settings and Environmental Factors

The impact of camera resolution, lens distortion, and environmental conditions on measurement accuracy was analyzed. It was observed that:

- Higher-resolution cameras significantly improved point cloud density and deformation detection precision.
- Lens distortions introduced minor errors, which were effectively corrected through calibration procedures.
- Lighting conditions influenced feature extraction, with **strong natural lighting** yielding more accurate results compared to low-light environments.

Practical Applicability and Limitations

The experimental results validate the feasibility of using CRP for **non-contact, real-time structural monitoring**. However, certain limitations were identified:

- **Surface texture and reflectivity** affected feature detection, requiring **enhanced image preprocessing** in complex surfaces.

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- **Camera positioning and stability** influenced measurement accuracy, highlighting the importance of optimal **image acquisition strategies**.

Despite these challenges, the overall findings indicate that CRP is a **highly effective and reliable** technique for structural deformation monitoring, offering **a balance between accuracy, cost-efficiency, and ease of implementation**.

DISCUSSION

Evaluation of Close-Range Photogrammetry for Deformation Monitoring

The findings of this study demonstrate that **close-range photogrammetry (CRP)** is an effective and accurate technique for structural deformation monitoring. The results indicate that CRP provides high-precision **3D reconstructions** and reliably detects small-scale deformations. Compared to traditional methods such as **total station surveys and laser scanning**, CRP offers a **cost-efficient, non-contact, and flexible** approach without compromising measurement accuracy.

One of the key advantages of CRP is its ability to **capture structural deformations in real time**, allowing for continuous monitoring without requiring extensive on-site instrumentation. Furthermore, the **automation of image processing** through **Structure-from-Motion (SfM) algorithms** significantly reduces human intervention and enhances measurement efficiency.[5]

Comparison with Traditional Methods

When compared to total station and laser scanning methods, CRP demonstrated a high degree of agreement in deformation measurements, as reflected by the **low Root Mean Square Error (RMSE) values**. The accuracy of CRP was found to be **98.5%**, making it a viable alternative to more expensive and labor-intensive techniques. However, while laser scanning provides slightly higher accuracy, it requires **specialized equipment and higher operational costs**, limiting its accessibility for routine monitoring applications.

Influence of Environmental and Technical Factors

Although CRP proves to be a reliable method, certain factors influence its performance:

- **Camera Resolution and Lens Distortion:** Higher-resolution cameras significantly improve measurement accuracy, while lens distortions can introduce minor errors if not properly calibrated.
- **Lighting Conditions:** Strong natural lighting improves feature extraction, whereas poor lighting can lead to reduced accuracy.

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- **Surface Texture and Reflectivity:** Smooth or highly reflective surfaces pose challenges in feature detection, requiring additional preprocessing techniques.
- **Camera Positioning and Stability:** Variations in camera angles and instability during image acquisition may introduce discrepancies in measurements, emphasizing the need for optimal camera placement.

Practical Applications and Future Prospects

The results of this study highlight the practical applicability of CRP in various structural health monitoring scenarios, including **bridge deformation analysis, building settlement detection, and infrastructure maintenance**. Given its affordability and ease of use, CRP can be widely adopted for both **short-term inspections** and **long-term monitoring projects**.

Future research should focus on:

- **Integrating artificial intelligence (AI) and deep learning techniques** to improve automation in image processing and deformation analysis.
- **Enhancing photogrammetric accuracy** by incorporating **multi-sensor fusion**, combining CRP with **LiDAR, GNSS, or UAV-based photogrammetry**.
- **Developing real-time monitoring systems** using **edge computing and cloud-based data processing** for continuous structural health assessment.[6]

CONCLUSION

In summary, this study confirms that **close-range photogrammetry is a viable and efficient technique** for structural deformation monitoring. Despite minor limitations, CRP offers a balance between **accuracy, cost-effectiveness, and ease of implementation**, making it a promising alternative for modern structural health monitoring applications. With continued technological advancements, CRP is expected to play an increasingly important role in **ensuring infrastructure safety and resilience** in the future.

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