WARSAW UNIVERSITY OF TECHNOLOGY
Faculty of Geodesy and Cartography

UNIVERSITY OF WARMIA AND MAZURY
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ASSOCIATION OF POLISH SURVEYORS
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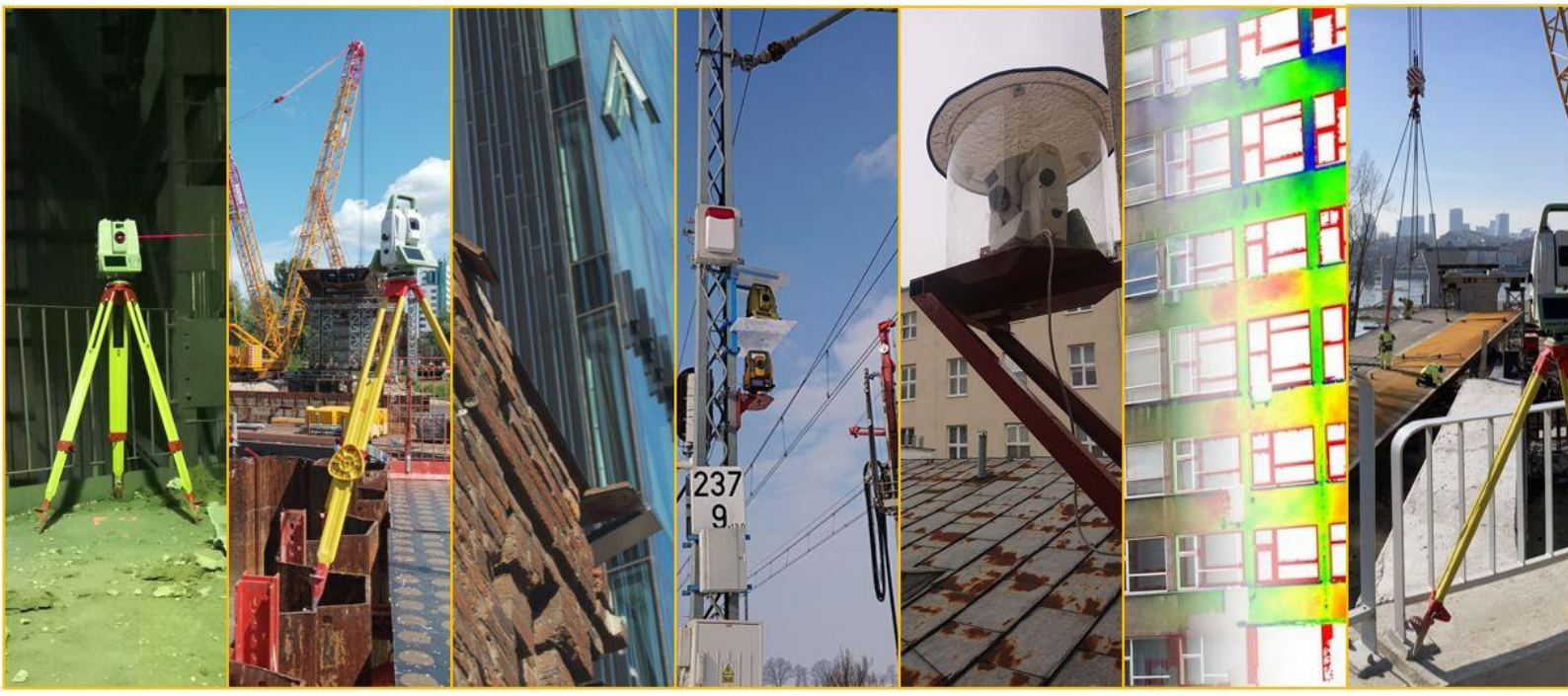
XVII International Science and Technology Conference
CURRENT PROBLEMS IN ENGINEERING SURVEYING

New challenges for engineering surveying in civil engineering and environmental monitoring

BOOK OF ABSTRACTS



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CONFERENCE TOPICS

1. Sensors and integrated measurement systems in engineering surveying
2. New algorithms and data processing techniques – time series analysis, deformation modeling, machine learning, reliability, statistical testing, big data
3. Geodetic and structural health monitoring of engineering and construction structures
4. Engineering surveying in the civil engineering and mining industry
5. Modern surveying technologies – GNSS, LiDAR, UAV, InSAR, photogrammetry, bathymetry, GPR, EDM, total station
6. Early warning systems and engineering measurements in risk management
7. BIM – modeling and information management on engineering objects, digital twins
8. Surveying techniques in geotechnics and geoengineering
9. Low-cost measurement systems
10. Reference systems

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Application of Own-Developed GNSS Antenna Vibration Simulator to Validate Dynamic Displacement Detection Systems

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Abstract

In this study, we present the performance of a bespoke GNSS antenna vibration simulator – shake table developed at the University of Warmia and Mazury in Olsztyn. The own-developed shake table is feasible for generating harmonic reciprocating motions with high frequency and low scale amplitude based on the movements of a rotary stepper motor. The device was used in validation studies of GNSS+IMU software and receivers dedicated to detecting dynamic displacements. In the study, we show the results obtained using high-rate GNSS data coupled with accelerometer records recorded under actual field conditions in the KGHM area in Lubin. The obtained results, generated time series of displacements using various detectors (IMU accelerometer, GNSS receivers), were subjected to detailed analysis using Fourier transform.

Keywords: vibration simulator, GNSS, low-cost GNSS receiver, IMU

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Environmental Research Applications of Global Navigation Satellite Systems (GNSS) and Synthetic Aperture Radar (SAR): Water Resources and Hydrology Approach

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Abstract

This review explores the synergistic application of Global Navigation Satellite Systems (GNSS) and Synthetic Aperture Radar (SAR) in environmental research. By leveraging GNSS's precise positioning and SAR's high-resolution, all-weather imaging capabilities, the combined approach significantly enhances accuracy, spatial coverage, and temporal resolution in ecological and climate monitoring. The integrated use of these technologies is pivotal for monitoring atmospheric water vapor, vegetation health, hydrological changes, and tectonic plate movements. Case studies using SAR imagery to delineate lake and river flood boundaries, along with manually determined water level measurements, demonstrate the effectiveness of the approach for environmental monitoring. Looking ahead, incorporating GNSS-based techniques—such as GNSS Reflectometry for near-real-time water level monitoring upstream—could enhance flood prediction models, with SAR imagery subsequently validating and refining flood extent estimates. The review also discusses challenges such as integrating heterogeneous datasets and the computational requirements for processing the data. It suggests that future research might explore more refined data fusion methods and additional applications, for example in climate adaptation and biodiversity conservation.

Keywords: Synthetic Aperture Radar, flood prediction, hydrological changes, environmental monitoring, GNSS reflectometry

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Research on the Quality of Photogrammetric Development of Cartographic Products for Architectural Monuments on the Example of the Bierzgłowski Castle Complex

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Abstract

Engineering surveying uses various measurement techniques, including photogrammetry, to assess the technical condition of a structure or its changes (deformations) resulting from the influence of various internal or external factors. A model developed using photogrammetric methods can serve as a reliable source of data for analyzing potential future deformations or damages in areas that may not be easily recognizable in the initial state image. This is one of the well-known advantages of photogrammetry; however, for the spatial effect to be effective, it must maintain sufficiently high quality concerning the entire recorded space. The aim of this study is to describe the works undertaken for the inventory of a historic building to prepare data for future assessments of its technical condition. The accuracy criterion for different computational variants was adopted as the basis for quality evaluation.
The subject of this study is the complex of the historic Teutonic Castle in the town of Bierzgłowo Castle. It serves as an example of architectural structures that, due to their historical significance, require detailed architectural inventory. For further analyses, cartographic models were developed based on photogrammetric registration – from both ground level and aerial perspectives. Alongside the classical approach to cartographic presentation, efforts are being made to create a 'digital twin' of the structure. These efforts began with an external model. Various processing parameter variants were applied and evaluated to achieve the desired accuracy effect. The presentation will present the results of the study along with an analysis of their potential future applications in engineering-related issues.

Keywords: photogrammetry, architectural inventory, cartographic products quality

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Feature Data Acquisition for Large-Scale Maps of Investment Area

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Abstract

The study presents analyses and discussions of the large-scale map data acquisition. In non-typical cases, for spatial territory and for hard-to-reach areas, today most of the geo-data are producing in-direct methods. In recent years, aerial photogrammetry systems are used for rapid acquisition of large-scale topographic map data. Lately most effective production of geo-data are realized on the Unmanned Aerial Vehicle (UAV). Usually, these solutions are used occasionally, depending on current needs. But there are also known comprehensive solutions for feature data acquisition of map's services. In many cases, however in field measurements are used integrated methods with total stations for terrestrial surveying and RTK GNSS for satellite surveying.

Keywords: large-scale map data, total station, real time GNSS, UAV photogrammetry

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Laser Scanning Data Processing Using M_{split} Estimation and Sliding Window Algorithm

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Abstract

Laser scanning systems are modern measurement techniques providing big data. Observations usually collected as a point cloud present the general results that can be visualized in special software. The final effect might be spectacular from a visualization point of view. However, it is not convenient for modeling or extracting detailed information about, for example, terrain, buildings, engineering structures, and deformations. Therefore, data from laser scanning systems require post-processing. Several methods in such a context concern different purposes or data processing stages, namely data segmentation, modeling, and filtration. M_{split} estimation is one of the methods that proved its applicability in laser scanning data processing and determination of terrain profiles, deformation, or building shapes. Processing the whole observation set is often inadequate because it requires high class computers and is time-consuming. Therefore, data are usually segmented. The paper concerns different types of segmentation that can be used in M_{split} estimation. It presents profile determination when data cut out from the original point cloud are divided into intervals of the same length or the sliding window algorithm is applied. The given examples show that the latter approach is much better and can provide more reliable results. The application of the sliding window algorithm requires some assumptions concerning estimation parameters. The paper addresses that problem, providing valuable information about both the width of the window and the slide size.

Keywords: sliding window, M_{split} estimation, laser scanning

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Observation Processing Techniques for Generating 2.5D Building Models Using Machine Learning and Monoscopic Satellite Imagery

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Abstract

The project "Wykorzystanie nauczania maszynowego oraz monospokowych zdjęć satelitarnych do generowania modeli 2.5D budynków", co-funded by the NCBR, aimed to develop an innovative technology for extracting 2.5D building models (footprints and heights) from single, monoscopic satellite images. The work began with manual tests, which allowed for the definition of methodological parameters, and subsequently focused on automating the process using Mask R-CNN machine learning algorithms.

The training dataset included over 321,000 buildings from 40 locations worldwide, covering diverse architectural styles and varying building densities. The process of building detection and segmentation was optimized through data augmentation, hyperparameter tuning, and the application of custom-developed tools.

The final product of the developed method consists of 2.5D building models, whose accuracy was verified using stereo satellite imagery. The achieved positional accuracy was CE90 = 3 m, and height accuracy LE90 = 4 m, with a 97% detection success rate.

The technology is characterized by high-speed data acquisition, low costs, and broad applicability, including urban planning, crisis management, telecommunications (5G network design), aviation (obstacle detection), change detection and solar exposure analysis.

Keywords: observation processing techniques, machine learning, monoscopic satellite imagery, 2.5D buildings

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Cave Mapping with Autonomous Laser Scanning Module

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Abstract

Point cloud techniques are widely used to develop 3D models of engineering structures and various other natural features. One of the special applications is surveying underground environments, like natural caves, which can be challenging due to the lack of light, narrow passages, high water levels, and extreme temperature and humidity. Applying mobile laser scanners integrated with robotic carriers could be a good opportunity in natural cave mapping, providing high-detail data very efficiently with minimal or no human intervention. State-of-the-art autonomous laser scanning modules use either LiDAR or Visual SLAM technology and an IMU for real-time precise positioning and reality capture.
In this study, an autonomous laser scanning module was used to survey a part of Imre Vass Cave, the fourth longest and one of the most explored caves in the Aggtelek Karst (in north Hungary). The cave is a UNESCO World Heritage Site, along with the other caves of the Aggtelek Karst and the Slovak Karst. As a result of the campaign, a dense, photo-realistic and georeferenced point cloud was derived. By combining the trajectory of the measurement and different point cloud processing methods, a 3D model and a traditional cave map with cross-sections were developed in an almost fully automatic way.

Keywords: cave, mapping, point cloud, laser scanning, autonomous, mobile

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Framework for Combining Remote Sensing Techniques and Decision Support System for Multi-Risk Assessment of Post-Mining Sites

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Abstract

Monitoring post-mining locations is essential for assessing hazards resulting from abandoned coal mines, where ground instability and environmental changes increase the overall risk. In this paper, it was used different remote sensing techniques to offer a valuable approach to detecting and analyzing such hazards over large areas. Recognizing the need for systematic hazard assessment and risk management in abandoned coal mining regions, the PoMHaZ initiative, funded by the Research Fund for Coal and Steel, was established to address these challenges. To complement this initiative, this study proposes a framework that integrates remote sensing techniques with POMHAZ Spatial Decision Support System (sDSS) API to enhance risk assessment through a monitoring component. This approach incorporates InSAR SBAS for detecting ground movements in post-mining areas. Additionally, Sentinel-2-derived NDWI and NDVI indices differentiate mining-induced deformations from other environmental changes, such as vegetation growth or hydrological variations. The framework was tested in the southern Ruhr area (Germany) demonstrating its capability to improve the assessment of abandoned coal mining sites by combining the identification of risk hotspots with monitoring of ground deformation. This improvement enhances the rapid identification of changing patterns, supporting the management and preservation of abandoned coal mine sites and their surrounding environment.

Keywords: monitoring, remote sensing, post-mining, multi-hazard, Decision Support System

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The Role of Geodetic Measurement Results in FEM Analyses of Building Objects on Deforming Ground

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Abstract

Geodetic measurements are the main source of data on the size of deformations of the terrain surface. The measurement results are used in FEM numerical analyses. The aim of these analyses is to study the influence of the deforming ground on existing buildings.
This paper presents examples of FEM modeling of the system: ground + building object. The discussed FEM models use the results of geodetic measurements to define boundary conditions. Selected development objects located in the post-mining basin in Bytom, in the Silesian Voivodeship, were selected for the study.
On the basis of the developed FEM models, based on the results of classic geodetic measurements, an assessment of the influence of measurement errors on the results of numerical analyses of the system: ground + building object was presented. Additionally, the use of numerical terrain models from 2001-2021 was also presented as a tool supporting the FEM modeling process.

Keywords: mining subsidence, digital terrain model, FEM, geodetic monitoring, building deformations

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Integrating Laser Scanning, BIM, and Gaming Technologies for Monitoring and Restoration of Historical Structures

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Abstract

This research delineates a pioneering methodology for cultural heritage preservation, synergizing advanced terrestrial laser scanning with Building Information Modeling (BIM) and immersive visualization. High-resolution 3D point cloud data was acquired from the 13th-century Benedictine Abbey in Sieciechów, Poland, facilitating precise geodetic control and deformation analysis. Preliminary data processing, including point cloud registration and georeferencing, was conducted using Leica Cyclone Register and N4CE software. These processed point clouds were transformed using BIM workflows into parametric models, enabling detailed structural vulnerability assessments, including crack propagation and material degradation. Integrating the Cintoo gaming engine and Virtual Reality applications facilitated the creation of interactive, immersive environments, enhancing stakeholder engagement and remote collaboration. This approach introduces a novel workflow, emphasizing non-invasive structural monitoring, automated BIM generation, and real-time comparative analysis. The methodology aligns with global initiatives in digital preservation, contributing to developing digital twins for heritage management and promoting preventive conservation strategies. By bridging geospatial precision with immersive technologies, this research offers a scalable model for safeguarding cultural heritage, enhancing accessibility through virtual tours, and reinforcing the significance of preventive conservation through precise surveying techniques.

Keywords: laser scanning, historical BIM, immersive visualization, virtual reality

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Evaluating Mobile Laser Scanning Accuracy and Applicability for HBIM Construction in the Historic Monastic Complex in Sieciechów, Poland

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Abstract

The historic post-Benedictine abbey in Sieciechów, a complex integrating Baroque architecture with remnants of 13th-century sacral structures, faces significant degradation from environmental and anthropogenic factors. To safeguard this invaluable heritage, a systematic approach encompassing risk assessment, advanced monitoring, and strategic contingency planning is imperative. This necessitates the development of a comprehensive Historical Building Information Model (HBIM), enabling precise analysis and informed conservation interventions. Utilizing mobile scanning technologies, the research focuses on constructing a coherent spatial representation of the abbey, quantifying scanning accuracy, and evaluating the influence of diverse factors on structural integrity. The resultant integrated HBIM model facilitates a thorough information audit, providing a functional framework for the preservation and management of this complex historical site. This methodology enables the precise documentation and analysis needed to mitigate deterioration and ensure the long-term preservation of Sieciechów Abbey.

Keywords: mobile laser scanning, structural monitoring, historical BIM, monument preservation, cultural heritage

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Application of Artificial Intelligence and Machine Learning in the Automatization of Geodetic and Geotechnical Monitoring – a Review of Research Directions and Practical Examples

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Abstract

Structural health monitoring (SHM) is a process of continuous collection of information about an engineering object: through measurements of changes in geometry and readings from geotechnical, hydro- and geological, seismic and other sensors indicating the physical condition of the object. Analysis of data sets ensures the safety of the object both during its construction and operation. Conducting real-time monitoring, and thus the greatest possible automation of the measurement process, is crucial for the quick identification and signaling of possible construction threats. Processing geodetic and physical data includes the use of mathematical calculation techniques, analysis and interpretation of various types of measurement quantities. These data are acquired using geotechnical sensors, satellite image processing, short- and long-range photogrammetry, laser scanning and typical geodetic instruments such as tachymeters and GNSS receivers. SHM sensors are most often electrical sensors (strain gauges, extensometers, thermocouples, electromechanical microcircuits) and fiber optics. In practice, SHM systems operate in parallel with geodetic monitoring. The key parameters of geodetic monitoring systems are reliability and accuracy. With the emergence of artificial intelligence (AI), in particular machine learning (ML) and deep learning (DL), new and innovative methods of processing, simulation, animation, as well as data management and interpretation have emerged. The article presents a cross-section of solutions for the practical use of artificial intelligence and automation processes in broadly understood geodetic and geotechnical monitoring found in the literature. Possible directions of further development in this area have also been analyzed.

Keywords: automatic geodetic monitoring, artificial intelligence, machine learning, structural monitoring

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Evaluation of the Suitability of the Static GNSS Method for the Surveying of Multi-Storey Buildings

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Abstract

Surveying is an indispensable part of the investment process. The investment process is a series of activities aimed at designing, modernizing or constructing a construction object. An extensive surveying task of such a process is the surveying service for the construction and installation of construction facilities. Such service during the construction of buildings is nothing more than a multi-stage staking of designed elements and control and inventory measurements during construction.

The basic and at the same time the initial activity of the surveying service of construction is the establishment and measurement of the realization control points. The article focuses primarily on the realization control points established for the purpose of implementation works. The implementation control points should be adapted, in terms of geometric construction and the accuracy of the location of its points, to the nature of the investment and the requirements specified in the construction documentation. The main purpose of its establishment is to ensure adequate accuracy of the staked points of the designed object.

The idea of the research is to check whether the use of different variants of the static GNSS method for the establishment of control points on individual floors of the building meets the set criteria, including accuracy criteria both in relation to other methods and to the key issue of obtaining repeatability on individual floors. Maintaining adequate repeatability is closely related to the accuracy of a particular method. Thus, two methods of establishing a realization control points were used for the study: The tacheometry method commonly used and the GNSS static method. In both cases, the staking of projected points is carried out using the free-station method and the polar method. Using the example of the construction of a multi-segment building and a multi-story building, an evaluation of the suitability of the GNSS method for surveying construction was carried out.

Keywords: realization control points, GNSS static method, reference stations

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Assessing Historic Structure Vulnerability to Extreme Precipitation: a Multi-Disciplinary Data Integration Study

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Abstract

Precise geodetic monitoring of structural displacements, particularly within subsidence-prone and post-extraction zones, necessitates a robust, multi-scalar data fusion approach. Comparative analyses must integrate archival and contemporary stratigraphic logs, geotechnical investigations, structural condition assessments, and historical construction records. Crucially, high-fidelity meteorological datasets spanning microclimatic (in-situ) and mesoscale (regional) observations are indispensable for discerning environmental influences. Employing rigorous statistical inference, this study investigates the temporal correlation between multi-source data streams concerning the historic Mieroszewski Palace in Będzin. Specifically, the analysis focuses on the nexus between high-precision hydrostatic inclinometer readings and meticulously acquired meteorological parameters sourced from both localized weather stations within the palace and the regional network of the Institute of Meteorology and Water Management. The investigation reveals that anomalous precipitation events, notably the extreme pluvial episode of early September 2024, which induced widespread regional flooding, significantly perturbed the dynamic stability of the palace structure. Furthermore, the study provides a preliminary assessment of the potential long-term geomechanical consequences of analogous extreme meteorological events on the structural integrity of the Mieroszewski Palace, emphasizing the need for proactive, resilience-focused conservation strategies.

Keywords: structural monitoring, pluvial effects, deformation surveys, precise inclinometer, meteorological data

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Smartphone Precise Positioning with MAFA Method – Preliminary Results

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Abstract

The authors present smartphone GPS positioning using phase observations on the L1 frequency. The study involved a Huawei P30 Pro, a Samsung S22 Ultra, and a Javad Triumph-1 geodetic receiver as the reference. All devices were placed 0.34 m apart on an aluminum base to ensure identical observation conditions, allowing for a direct comparison of GPS accuracy. The analysis was based on static GPS positioning using the Modified Ambiguity Function Approach (MAFA) method, with short baselines for testing.

For the first part of the test, 5-minute static sessions were conducted with both smartphones. The Huawei P30 Pro stabilized position after about 25 seconds, achieving centimeter-level accuracy after two minutes. The Samsung S22 Ultra stabilized also after 25 seconds but showed lower accuracy than the Huawei device. In post-processing RTK, 1, 3, 5, and 10-second solutions achieved decimeter-level accuracy, while 30 and 60-second solutions provided centimeter-level accuracy for the North and East components on both smartphones. The Up component remained below 0.3 m for both devices. For Huawei, the standard deviation (STD) for dN and dE at 1 epoch was around 0.12 m, improving to 0.03 m at 60 epochs. Samsung's results were similar. The authors proved that the MAFA method can be used for precise mobile phone positioning for short baselines.

Keywords: GPS, MAFA method, GNSS, smartphone

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A New Concept for Verification and Calibration of Active and Passive Measurement Systems: One-Stop-Lab CENAGiS

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Abstract

The rapid development of Mobile Mapping Systems (MMS) and other geospatial data acquisition technologies has created a growing need for advanced research facilities capable of comprehensive testing, calibration, and quality assessment of modern surveying devices and sensors. To address this demand, the Warsaw University of Technology (WUT) has established the One-Stop-Lab CENAGiS as part of the Centre for Spatial and Satellite Analyses project. This unique facility integrates multiple laboratories designed for testing a wide range of technologies, including laser scanners, cameras, GNSS receivers, rangefinders, and indoor/outdoor positioning systems.

CENAGiS is equipped with cutting-edge tools such as an industrial laser interferometer, linear rail systems for object movement simulation, and calibration fields compliant with VDI/VDE standards. The facilities include specialized test fields for UAV calibration, rangefinder validation, and indoor positioning system assessment. The laboratories are supported by a robust geo-cyberinfrastructure for big data processing and artificial intelligence applications. This innovative center enables researchers and industry developers to conduct holistic R&D activities in one location—from device calibration to application testing and advanced geospatial data processing. The integration of these laboratories facilitates the evaluation of individual sensors and multi-sensor platforms, offering new opportunities for the development of MMS technologies for applications such as autonomous navigation, urban mapping, and emergency response.

CENAGiS aims to bridge the gap between academia and industry by fostering collaboration and supporting the advancement of geodetic and navigation technologies. This paper explores the center's infrastructure and highlights key research projects undertaken in collaboration with industry partners.

Keywords: One-Stop-Lab, CENAGiS, calibration on surveying devices, mobile mapping systems, computing platform

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Integration of Multi-Source Data Using the TLS-SfM Approach for Multi-Temporal Investigation of Cultural Heritage Objects

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Abstract

Modern technologies are increasingly used to document and analyse architectural and industrial objects, particularly cultural heritage sites. These methods facilitate the generation of architectural documentation and 3D models, aiding in the research and preservation of historic structures. One of the key techniques in this field is Terrestrial Laser Scanning (TLS), which provides accurate data acquisition and processing for high-resolution architectural documentation. However, processing TLS data is a multi-stage process that begins with point cloud registration, requiring identification of corresponding points manually, semi-manually, or automatically. TLS point cloud's processing challenges include ensuring correct spatial distribution, marking control points, automation, and robustness analysis. These challenges become even more significant when studying large and complex heritage sites where marking control points is impractical. Additionally, orienting multi-temporal data poses issues in identifying corresponding reference points, necessitating automatic tie-point detection methods.

The Justice Court Tower at the Royal Castle in Warsaw is one of the heritage sites investigated using these digital techniques. Excavations were carried out to support archaeological and architectural research, integrating digital methods with traditional excavation techniques. Three measurement techniques were applied: TLS, close-range photogrammetry, and surveying. The study focused on determining the potential route of a wall on the tower's west side and its relationship with the lowest foundation layers. The results confirmed that the original tower collapsed in the Middle Ages, and the current structure is a newer construction that was built on the same site. Analysis of the foundation structure revealed at least two construction phases. Furthermore, a relic of a wall adjacent to the tower on the west side could have been part of earlier buildings integrated with the tower or a separate autonomous structure. The study of the torsion

angles of the lowest foundation layers in relation to slightly younger upper levels and the parallel alignment of adjacent structures helped resolve this issue.
This article evaluates the quality and completeness of the TLS registration process using 2D raster data in the form of spherical images. Additionally, Affine Hand-crafted, and Learned-based detectors were applied within the multi-stage TLS point cloud registration framework known as TLS-SfM. the study aims to improve data processing workflows for complex heritage sites, ensuring accurate and detailed architectural documentation by assessing the effectiveness of these methods.

Keywords: cultural heritage, multi-temporal analysis, point clouds, Structure-from-Motion (SfM), Terrestrial Laser Scanning (TLS), TLS-SfM

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The Metrological Evaluation of Range-Based Sensors Utilised the VDI/VDE CENAGiS Standard

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Abstract

The German organisation PTB (Physikalisch-Technische Bundesanstalt) developed the VDI/VDE 2634 guidelines, which are utilised for calibrating, verifying, and testing optical measurement systems. The requirements for standards used for acceptance are precisely defined and vary depending on the measurement range of the system. These standards should be scaled according to their size and form. It is crucial to verify the calibration of optical systems under specific operating conditions (e.g., temperature, mechanical vibrations, or lighting conditions) and modes of operation (e.g., type and intensity of illumination or measurement space). Within this standard, the following errors are analysed: (1) probing error, which pertains to the error of the optical head system; (2) sphere-spacing error, related to length determination; and (3) flatness measurement error.

Calibration fields based on the VDI/VDE standard are typically designed for small measurement ranges, often for structured light measurements. At the Center for Geospatial and Satellite Analysis, Faculty of Geodesy and Cartography, Warsaw University of Technology, a calibration standard has been developed for evaluating large measurement areas (1.5 m x 1.5 m x 2.0 m), specifically dedicated to active laser systems based on terrestrial laser scanners. This article presents the testing procedure for static and mobile laser scanners on the VDI/VDE-CENAGiS test field. The tests involved two terrestrial laser scanners, the Z+F5006h and Leica RTC360, a handheld laser scanner (MANDEYE) equipped with a Livox Mid-360 scanner (tested in both static and mobile modes), and the Leica Nova MS60 scanning total station. Measurement uncertainties, standard deviations, and classification of devices into accuracy categories were determined.

Keywords: range-based sensors, VDI/VDE standard, LIDAR, CENAGiS

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The Data Integration for Multi-Temporal Conservation Works – Image and Range-Based Approaches

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Abstract

Cultural heritage objects are vulnerable to deterioration caused by human activities and environmental factors, necessitating rescue conservation efforts to preserve them for future generations. This study explores the integration of rescue conservation methods and non-invasive measurements, focusing on the Blessed Ladislas' chapel in St. Anna's Church, Warsaw, Poland. The chapel, among the most endangered architectural fragments of the church, faced structural instability and extensive damage, including cracks and detachment of plaster layers. Its mural paintings, created by Walenty Żebrowski in the 18th century, had been repainted, damaged, and restored multiple times, significantly altering their original character.

The research employed Terrestrial Laser Scanning (TLS) and photogrammetry to document and analyze the dome's condition. High-resolution 3D models and panoramic images were developed before, during, and after conservation works, allowing for a precise assessment of structural and aesthetic damage. The investigation revealed significant insights into the dome's structural behaviour, patterns of stress-induced damage, and the extent of previous interventions. Conservation efforts restored the rococo character of the murals by cleaning, retouching, and reconstructing missing elements while addressing structural issues.

Results highlighted the importance of integrating advanced documentation techniques with art historical research to guide conservation practices. Limitations in detecting micro-damages and challenges in data registration were noted, emphasizing the need for closer collaboration between photogrammetrists and conservators. Despite these challenges, the study demonstrates the potential of combined methodologies in preserving and interpreting complex cultural heritage sites, contributing valuable insights into effective restoration strategies.

Keywords: cultural heritage, Terrestrial Laser Scanning (TLS), close-range photogrammetry, SfM-TLS, multitemporal analysis

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Application of Terrestrial Laser Scanning and Inclinometer for Comprehensive Monitoring of Deep Excavation

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Abstract

The article concerns comprehensive monitoring of the displacements of the diaphragm wall, which protects the deep excavation. The research object was located in a compact urban development, in the vicinity of the city moat and a communication tunnel. The typical monitoring is limited to measuring the control points located on the crown of the wall with the use of total stations. Geodetic measurements allow to detect displacements in an external reference system. However, the limitation is caused by the ability to measure the excavated parts of the retaining structure only. The application of an inclinometric technique allows to determine the displacements of the diaphragm wall also below the bottom of the excavation. The integration of these techniques allows to obtain the results of the inclinometer in external reference system. The use of a terrestrial laser scanning significantly increases the detailed control of the geometric condition of the deep excavation lining and gives the possibility to obtain a 3D model of the retaining structure. Giving an appropriate georeference to point clouds from individual measurement epochs, the authors determined the displacement values and used the point clouds to detect the humidity of the wall surface. It allowed for the identification of leaks. Based on the integrated results of inclinometric measurements and the point cloud, the authors determined the curvature of the diaphragm wall, which is the basis for estimating the bending moments in the structure. Limiting the values of bending moments allows to control the width of cracks in the concrete.

Keywords: displacement monitoring, total station, inclinometer, laser scanning, diaphragm wall

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Application of the Simulated Annealing Algorithm for Identification of the Constant Reference Points in 3D Deformation Analysis

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Abstract

Identification of the reference base in the deformation analysis is a key element in obtaining the correct deformations of the monitored object. Although the reference points are designed in a way to minimize the risk of displacement, there is always a possibility that some of the points will not be stable. For this reason, a stability check must be conducted as the initial stage of the deformation analysis. There are many methods for the identification of the actually stable points. Most of them apply for leveling or horizontal networks. The spatial (3D) solutions are not very popular. This study concerns the approach using a comparison of coordinates corresponding to two measurement epochs and coordinates transformation as a 3D deformation analysis method. The proposed algorithm is aimed at the selection of such coordinate transformation parameters that correspond to the acceptable transformation residuals for the points creating the reference base. The optimization algorithm (simulated annealing) and the robust objective function are applied for the search for desirable transformation parameters. The test on the simulated example network confirms the correctness of the adopted solution.

Keywords: stability analysis, 3D network, metaheuristic algorithm, simulated annealing, Monte Carlo method

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Potential and Limitations of LiDAR for Monitoring Reclaimed Landfill Deformation

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Abstract

Geodetic monitoring of reclaimed landfills is a crucial issue in ensuring geotechnical safety. It makes it possible to monitor the uniformity of subsidence of the landfill body and to indicate its possible deformation resulting from the biodegradation process of waste deposited inside the body of the landfill. Deformation of the landfill body can lead to adverse environmental consequences by emitting pollutants in the form of leachates and gases. Classical geodetic monitoring, based on point measurements (sparse discrete representation of the site), does not allow comprehensive monitoring of these changes. Therefore, the study proposes an approach using a LiDAR-based surface measurement method, which allows for a significant increase in the discretization of the landfill site by providing data in the form of point clouds. Thanks to this approach to surface monitoring, the analyses performed periodically respond not only to the needs of deformation determination but also to the assessment of the condition of the site and its management. The study presents the results of measurements using Terrestrial Laser Scanning (TLS) and Airborne Laser Scanning (ALS) using an Unmanned Aerial Vehicle (UAV). The studies were performed at the reclaimed municipal landfill Słabomierz-Krzyżówka, in Warsaw's suburbs. The paper discusses the potential of using 3D data from laser scanning in deformation monitoring and describes the limitations of the proposed methods.

Keywords: deformation monitoring, terrestrial laser scanning, aerial laser scanning, landfill

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The Problem of Resuming the Construction Axes During the Expansion of the Building by an Additional Floor

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Abstract

Article describes the geodetic post-construction inventory of building structures on the example of expanding the building with an additional floor. The received design for the addition of a floor for the educational complex was analyzed and a control measurement of the entire teaching building was made. Differences in the corners coordinates and the frontal measures between the real and projected data were calculated. They were also presented the encountered problems related to the correct delineation of the axis of the third floor if the building. Geodetic determining the storey axis and columns corners is described. Discrepancies were found in the number of building corners and the values of the frontal measures of building edges. It was found that it was impossible to implement the received construction project and that the map for design purposes was incorrectly prepared by the previous surveying service.

Keywords: geodetic post-construction inventory, control measurement, storey of the building, construction axes, frontal measures, building edges, inconsistencies in the project

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On the Feasibility of Precise Vibration Detection Based on the Fusion of Low-Cost GNSS and MEMS Accelerometer

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Abstract

In this study, we validate a fusion of low-cost GNSS receivers and MEMS accelerometers for retrieving millimeter-level vibrations observed in structural health monitoring (SHM). In the experiment, we use two low-cost GNSS receivers, namely u-blox ZED-F9P and Septentrio Mosaic-X5, and RedShift Labs UM7 MEMS sensor providing accelerations. The data are processed with bespoke algorithms and software responsible for GNSS positioning and sensor coupling. First, the quality check of GNSS data and accelerometer records is performed. The observation assessment reveals that the accuracy of low-cost GNSS data is competitive with high-grade receivers and, under some circumstances, it is even higher. Next, based on an experiment with a shake table simulated vibrations, we inspect the accuracy of the solution coupling high-rate GNSS-PPP derived displacements and MEMS accelerometer records. Several artificial harmonic motions of amplitude ranging from 20 down to 1 mm were induced. The integrated GNSS+accelerometer solution is investigated in terms of the accuracy of the retrieved characteristics of the harmonic motions. The amplitude and frequency of the displacement time series are related to the benchmark values defined in the simulation. The coupled solution is also validated against the GNSS-PPP-only one. We confirm the high performance of the solution based on low-cost sensors and the feasibility of retrieving millimeter-level displacements with mass-market sensor coupling. We report an advantage of the integrated solution over the GNSS-only one documented with a meaningful reduction of the displacement error. The time-frequency analyses also indicate that both coupled and single-sensor solutions may successfully detect the vibration frequencies.

Keywords: GNSS, displacements, vibrations, structural health monitoring

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Problems of Determining Reference Systems in Inclinometric Measurements

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Abstract

This presentation addresses the challenge of determining a reference system for geodetic and inclinometric measurements to monitor horizontal displacement. The study reveals that using an inclinometer sensor to measure horizontal displacement typically involves selecting the centre point at the bottom of the guide pipe as the origin for calculating displacements of upper points. However, directly surveying the stability of this bottom point is problematic, and any movement of this point leads to inaccurate observations. To ensure stability, the guide pipe must be installed in a stable rock layer, often deeper than the diaphragm walls in soft ground, making proper placement difficult. Geodetic methods offer a solution by accurately observing the displacement of the point at the top of the guide pipe with absolute displacement values. These values, determined at stable benchmarks, represent the pipe's displacement. An integrated approach allows the point at the top of the pipe to be the origin for calculating displacements within the diaphragm wall, with calculated values calibrated against inclinometer observations for high reliability. An experiment combining geodetic and geotechnical methods was conducted to validate this integrated solution, ensuring accurate monitoring of diaphragm wall movements.

Keywords: inclinometric measurements, reference system, diaphragm wall

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On the Applicability of Smartphones to Structural Health Monitoring

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Abstract

The progress in GNSS technology now allows us to use low-cost receivers in demanding applications where even subcentimeter accuracy is required. We distinguish low-cost receivers into two groups, namely the applications boards with GNSS modules and chipsets embedded in smartphones. Nowadays, the latter group is gaining more and more attention from a vast group of users. This is partially induced by a potentially highly dense GNSS network of smartphones possessed by society members. Typically, the quality of such measurements is considered lower than that of geodetic receivers. Furthermore, they are often affected by unwanted effects that have to be taken into account during processing. Despite this, the broad application of smartphones is a topical subject of GNSS technology.

These abovementioned advances and challenges motivate us to evaluate the applicability of smartphones for the detection of short-term variations. In this way, we address the scientific question of their applicability to structural health monitoring. We conducted the field experiment with simulated motion of three mobile devices, i.e. Google Pixel 7, Xiaomi 13, and Realme GT Neo 3. As a reference, we use the Trimble Alloy geodetic receiver. The first part of the results aims at cross-validation of smartphones' data, proving the discrepancies between particular devices and geodetic instruments. The observed effects include data drift and inhomogeneities between the pseudoranges and phase measurements. The analysis also depicts the low level of the latter, and thus, we evaluate their applicability for the detection of the simulated motion. The tests were performed by analyzing a single-differenced phase series and confirmed the effectiveness of smartphone-derived data for monitoring the oscillations of centimeter-level amplitude.

Keywords: GNSS, structural health monitoring, smartphone

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Time Series Processing Using Deep Learning

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Abstract

Sensors installed in autonomous environments generate a vast amount of time series data. Processing this observed data requires increasingly automated methods. Intensive developments in artificial intelligence (AI), particularly in speech and natural language processing as well as generative AI, have led to the creation of many new methods for managing and forecasting time series using deep learning algorithms. The proliferation of low-cost sensors often results in noisy data, which presents an additional challenge during processing.

Today, in addition to traditional statistical methods, there are specialized artificial neural networks designed to handle both univariate and multivariate time series. This includes one-dimensional convolutional neural networks (CNNs), Long Short-Term Memory (LSTM) networks, Recurrent Neural Networks (RNNs), and Gated Recurrent Units (GRUs).

Currently, Python is one of the most popular programming languages in the field of data engineering. The open-source community has produced many excellent packages for deep learning methods, such as Keras, TensorFlow, PyTorch, and Scikit-Learn.

There are several application areas where deep learning algorithms can be utilized with time series data, including curve fitting, regression, classification, forecasting, segmentation, clustering, and anomaly detection.

In addition to introducing the methods used, this poster presents several examples demonstrating the capabilities of Python and Keras, which is an open-source library providing a Python interface for various types of artificial neural networks.

Keywords: time series, deep learning, open-source

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Cm accurate transformation to the Hungarian EOV

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Abstract

The open-source PROJ is a powerful and widely used software designed for transforming geospatial coordinates between different coordinate reference systems (CRS). It supports various transformations, cartographic projections, geodetic conversions, and datum shifts. In many cases, direct coordinate transformation between different CRSs with a set of parameters is only possible with limited accuracy. One way to mitigate this issue is to apply grid shift files containing location-dependent horizontal and vertical corrections. National mapping agencies or other organisations provide grid shift files and make them available through the PROJ data collections.

In Hungary, the official grid shift-based transformation method between the ETRF2000 realization of the European Terrestrial Reference System 1989 (ETRS89) and the Hungarian Datum 1972 (HD72) is known as VITEL. Its recent version, VITEL2014, was released about a decade ago and provides accuracy of a few centimetres. Its transformation grid files do not have an open licence, and their use is compulsory for cadastral activities for quality assurance reasons. In practice, the geographical coordinates expressed in HD72 are usually projected to the national projection system (EOV).

VITEL-like grid shift files have been developed at the Budapest University of Technology and Economics. Applying the BME grid shift files yields practically the same results within mainly one centimetre as using VITEL2014. After registering the relevant EPSG codes and uploading the grid shift files into the PROJ data repository in 2024, the most recent versions of GIS software, like QGIS v3.40, have the centimetre accurate transformation between ETRF2000 and HD72-EOV by default.

Keywords: transformation, cartographic projection, grid shift files, open-source, Hungarian EOV, PROJ

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Application of Terrestrial Laser Scanning Technology for Wind Turbine Blade Defect Detection

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Abstract

The transition to renewable energy sources is essential for combating climate change, with wind power playing a key role in sustainable electricity generation. Ensuring the optimal condition of wind turbine blades is crucial for both safety and efficiency, as structural defects can significantly reduce energy output. This study explores non-destructive techniques for blade condition monitoring, focusing on the potential of terrestrial laser scanning (TLS) as an alternative to photogrammetry. The research investigates the effectiveness and cost efficiency of these methods, emphasizing defect detection, including cracks, cavities, and erosion, through radiometric analysis of point clouds, which represents a novel aspect of this study. Additionally, the impact of laser beam incidence angles on data quality and interpretation was examined. The study was conducted in two stages, developing and comparing different measurement approaches to determine the most effective and economically viable method for wind turbine blade inspections.

Keywords: Terrestrial Laser Scanning (TLS), intensity parameter, measurement methodology, wind turbine blades, condition surveying, defects detection

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Accuracy Assessment of Low-Cost GNSS Observations for Displacement Monitoring

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Abstract

Geodetic-class equipment provides accuracy on the millimeter level. Therefore, it has been employed in the applications where high accuracy and precision are needed. However, its high cost is often a significant constraint for institutions with limited budgets, which can discourage the use of GNSS technology. The development of low-cost GNSS chipsets and advances in processing algorithms that mitigate hardware limitations, enable the use of this equipment in new areas of engineering and science, making them an attractive alternative for large-scale monitoring projects.

The study focuses on the validation of GNSS observation processing for displacement monitoring using low-cost GNSS receivers. The goal is to compare the accuracy of results from low-cost receivers with those from standard geodetic receivers. Two experiments are carried out: the first involves analyzing GNSS observation data from a network of 15 low-cost receivers, while the second simulates ground displacement to assess the ability of the low-cost equipment to detect it. The observations are processed using the Bernese GNSS Software in relative static mode. The analysis reveals high consistency between the results from low-cost and geodetic receivers, with coordinate differences generally below 5 mm. In the second experiment, displacements simulated by artificially shifting the antenna position on one of the stations are successfully detected based on low-cost GNSS data, with errors less than 3 mm for the height and less than 1 mm for the horizontal coordinates. Overall, the study confirms that low-cost GNSS receivers provide accurate results for displacement monitoring, with accuracy comparable to geodetic receivers.

Keywords: GNSS, displacement, low-cost receivers

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Photovoltaic Farm Diagnostics Using UAVs: Defect Detection Analysis

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Abstract

This study investigates the application of Unmanned Aerial Vehicles (UAVs) equipped with thermal and digital cameras for diagnosing a photovoltaic (PV) farm located in Kąty Drugie, Poland. The primary objective was to evaluate the effectiveness of UAV-based thermographic and visual inspections in identifying defects such as bypass diode failures, microcracks, delamination, and soiling on PV panels. Two independent flights, conducted nine days apart, were performed to collect high-resolution thermal and RGB imagery. The data were manually analyzed to detect anomalies, with 97 defects identified in the first flight and 105 in the second. The results demonstrated consistent detection of bypass diode failures and internal panel defects across both datasets, confirming the reliability of UAV-based diagnostics. However, soiling patterns varied significantly between flights, indicating their transient nature or the impact of cleaning interventions. The study highlights the importance of optimal flight parameters, including altitude, overlap, speed, and environmental conditions such as ambient temperature and solar irradiance, to ensure data accuracy. The findings underscore the potential of UAVs as a cost-effective and efficient tool for large-scale PV farm inspections, enabling rapid fault identification and maintenance planning. Future work should focus on automating defect detection using machine learning algorithms to further enhance the scalability and precision of UAV-based PV diagnostics.

Keywords: Unmanned Aerial Vehicles (UAVs), thermographic diagnostics, photovoltaic inspection, fault identification, panel efficiency degradation, UAV photogrammetry, thermal data analysis

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The Influence of Training Datasets from TLS and UAV in Machine Learning Models on Stability Assessment of Historical Objects – a Case Study of the Castle in Bedzin, Poland

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Abstract

Current hazards, such as climate change, environmental degradation, and human activities, pose serious challenges to preserving cultural heritage. Modern survey technologies, particularly terrestrial laser scanning (TLS) and unmanned aerial vehicles (UAV) support the documentation and monitoring of the technical condition of historic buildings. However, this method of inventorying is associated with the problem of detecting changes in the structure of objects based on point clouds.

The subject of the study is Bedzin Castle, Poland - an example of late medieval defensive architecture. The purpose of the study is to demonstrate the performance of TLS technology in detecting deformations of castle walls and towers. The research was based on spatial data analysis using point clouds acquired at different measurement epochs. Machine learning algorithms implemented in MATLAB were used to automate the identification of cracks. The model learns to recognize patterns based on a training dataset of input information and corresponding class labels. The key challenge in this process is the accurate selection of the characteristic features of the points in the cloud, which allows the model to effectively detect object changes with the highest possible probability of correct classification.

The results indicate that using laser scanning combined with geometric analysis and machine learning is an effective tool in the damage identification process. The proposed method is applicable to structures with irregular geometry, for which traditional measurement techniques are insufficient.

Keywords: machine learning, point cloud, TLS, UAV, classification

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Spatiotemporal Analysis of Displacements of Concrete Tank Segments During Assembly Works

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Abstract

Concrete tanks are commonly used in a variety of industries. Some of them consist of multiple segments that must be properly installed and sealed to meet the design intent. Modern surveying techniques such as robotic total stations and laser scanners make it possible to obtain detailed information about the geometry of building structures and to monitor changes in these structures over time. Measurements of the displacements of concrete tank segments are crucial to ensure the correct installation process, which determines durability of a tank and its subsequent safe operation. In this paper, a spatiotemporal analysis of horizontal displacements of concrete tank segments induced by prestressing perimeter steel cables located at 13 levels of the tank was carried out. The displacements were determined on the basis of robotic total station measurements and terrestrial laser scanning. Both phases of prestressing the cables (the first phase, up to half of the design tension force, and the second phase, to the full design tension force) started from the lower cables. This process usually caused the upper segments to swing towards the outside of the tank. Next, the tensioning of the upper cables caused the upper parts of the segments to return, first to their initial position and, in the final phase of the assembly work, to move these parts of the segments towards the inside of the tank. It was also noted that the greatest changes in displacement values occurred opposite the point of force application (actuator mounting). The displacement changes recorded with the total station ranged from -2 mm to +2 mm, and the results from the point cloud analysis oscillated between -3 mm and +3 mm.

Keywords: robotic total station, terrestrial laser scanning, point cloud, radial displacement, concrete tank

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Graphical Programming Environment for Prototyping Structural Health Monitoring Systems Using Low-Cost Sensors

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Abstract

The maintenance of transport infrastructure requires the development of modern monitoring tools that ensure real-time data processing, the required measurement accuracy, and cost efficiency. This became the motivation for prototyping, based on the Arduino platform's low-cost sensors and NI LabVIEW software, a scalable Structural Health Monitoring (SHM) platform. The study presents a sample system architecture taking into account sensor integration methods in the context of prototyping and testing measurement and data analysis systems. Various prototype system configurations were developed, analyzed and tested. The prototype system relies on sensors, such as accelerometers and environmental sensors, connected to an Arduino platform to perform continuous measurements of acceleration, vibration, shock, angular velocity, environmental parameters and motion detection. Such a solution has lower implementation costs, allowing implementation in pilot and small-scale projects. It also provides the capability to generate alerts when predefined threshold values are exceeded. The study demonstrates that the integration of low-cost Arduino sensors with the LabVIEW environment can be effectively applied in the rapid design and deployment of railway infrastructure monitoring systems. The research findings highlight the crucial role of prototyping in designing and developing efficient and scalable SHM systems. They are also an important contribution to the development of infrastructure monitoring methodologies and highlight the potential of SHM automation.

Keywords: Structural Health Monitoring (SHM), sensors, prototyping, automation, graphical programming environment, railway infrastructure, transport