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ANALYSIS OF METHODS FOR MONITORING THE CONDITION OF BUILDING FACADES BASED ON VISUAL DATA

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Abstract*—The article explores the use of information technology to monitor the condition of building facades based on visual data obtained from unmanned aerial vehicles. The study highlights the growing role of unmanned aerial vehicles in structural inspections, noting their key advantages, including increased safety, efficiency, and accuracy, compared to traditional methods. The study is structured into three main sections. The first section provides an overview of existing approaches to facade monitoring, comparing traditional inspection methods with UAV-based methods. The second section discusses the technological aspects of data collection, processing, and analysis, focusing on artificial intelligence, computer vision, and photogrammetry. The final section presents the practical application of these technologies, an overview of relevant software tools, examples, and economic benefits. The results show that unmanned aerial vehicles, combined with advanced image processing technologies, significantly increase the efficiency and reliability of building facade assessments.*

Keywords—Facade monitoring; unmanned aerial vehicles; computer vision; artificial intelligence; neural networks; Gaussian filter; crack segmentation.

I. INTRODUCTION

In Ukraine, as in many European countries, a significant part of the housing and industrial stock was built in the second half of the 20th century. Today, a large number of buildings are operated beyond their standard service life, which, combined with the lack of scheduled repairs, the influence of external factors and modern monitoring, leads to a progressive decrease in their reliability. This requires close attention to their safety and functionality. To ensure long-term operation of facilities, it is necessary to regularly conduct their technical assessment. Traditional methods of facade inspection are often labor-intensive, risky for personnel and ineffective for hard-to-reach areas, which leads to long downtimes and increased costs. Small or hidden defects often go unnoticed, and the quality of the conclusions depends entirely on the experience of the inspector [1] – [3].

The use of unmanned aerial vehicles (UAVs) in civil aviation continues to expand. In the construction industry, they enable efficient data collection during site inspections, allowing managers to monitor project progress in real time. UAVs also provide safe inspection of complex engineering structures such as bridges, overpasses, and industrial chimneys without the need for climbers or bulky equipment. In the past decade, UAV-based monitoring methods have evolved rapidly, enabling the collection of visual and multispectral data integrated into photogrammetric software and BIM/GIS systems (Building Information Modeling and Geographic Information Systems), along with computer-vision algorithms for automated defect detection [4] – [6]. UAV usage significantly reduces inspection time and costs and forms the basis for creating digital twins of buildings.

The aim of this study is to analyze modern methods of facade monitoring, evaluate the potential of integrating UAVs with computer vision methods and neural network algorithms, and determine prospects for their implementation in BIM/GIS systems for building digital twins.

II. BASIC APPROACHES TO MONITORING BUILDING FACADES

A wide range of instrumental methods is used to assess the technical condition of building structures. They have been actively used in construction practice over the past decades, but they have a number of limitations, which stimulate the search for new solutions.

The sclerometric (impact) method is one of the most common means of non-destructive testing of the surface strength of concrete and plastered facade structures. Its principle of operation is based on measuring the rebound height or recoil force of an elastic impact striker after contact with the surface of the material. The higher the strength of the surface layer, the greater the rebound and, accordingly, the higher the device reading.

In practice, a standard device is used to inspect facades—the Schmidt hammer (Fig. 1). Modern digital modifications, such as Proceq Original Schmidt or SilverSchmidt, allow you to automatically record indicators, build statistical distributions, and transfer data to software for analysis. Measurements are taken at several points on each section of the facade, after which the average value corresponding to the conditional strength of the surface layer is determined. The method is effectively used for a quick assessment of the uniformity of facade panels, identification of areas with reduced strength, damaged by atmospheric influences or carbonization.

However, sclerometry has a number of limitations. The method only examines a thin surface layer (2–3 cm), so it does not provide an idea of the internal condition of the structure. In addition, the results depend significantly on the moisture content of the material and the presence of paint, plaster, or other coatings. In such cases, the readings may be overestimated or underestimated. Human error, incorrect angle of application of the device, or insufficient number of measurements also contribute to the error. The sclerometric method is advisable to use as a primary screening to assess the general condition of facades and locate potentially weakened areas [1] – [3]. To confirm and refine the results, it should be combined with other methods: ultrasonic, impact-pulse, or thermography.

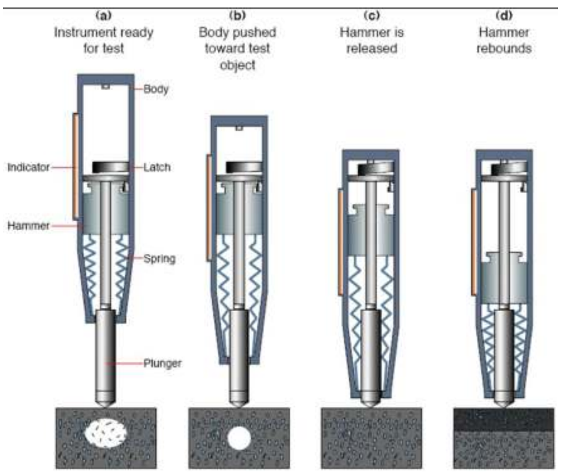

Fig. 1. Schematic representation of Schmidt's hammer [4]

The ultrasonic pulse method is one of the most informative non-destructive testing methods used to examine facade structures made of concrete, stone, brick, and composite materials. It involves measuring the time it takes for an ultrasonic wave to pass through the material and then determining its propagation speed. The more homogeneous and stronger the material, the faster the wave travels through it. In places with defects – cracks, voids, areas of increased porosity – the signal slows down or attenuates significantly.

In the field, portable devices such as the Proceq Pundit PD8000, GE USM Go+ (Waygate Technologies), and Olson Instruments CTG-2 are used to inspect facades. These systems are equipped with piezoelectric transducers that can operate in different configurations:

- direct circuit – sensors are located on opposite surfaces of the element (rarely used, as facades are usually accessible from only one side);
- semi-direct circuit – sensors are installed at an angle;
- indirect (surface) circuit – both sensors are mounted on the same surface (the most common option for facades).

Special gels or lubricants are used to ensure high-quality acoustic contact between the sensor and the surface. After the pulse is triggered, the device records the time it takes to pass, calculates the wave velocity, and stores the data for further processing. Based on these results, it is possible to assess: the presence and depth of internal cracks; the level of porosity and homogeneity of the material; the degree of moisture in wall elements; the location of areas of delamination of cladding or insulation.

This method has some advantages: it allows you to "look" inside the structure, detect defects at depth, and perform inspections without damaging the material. At the same time, it has its limitations. First, the results depend on the condition of the surface and humidity: the wave velocity is higher in wet concrete than in dry concrete. Second, the heterogeneity of the masonry (different joint thicknesses, inclusion of stones) can complicate interpretation. Third, the quality of the result depends on the operator's experience. In view of this, the ultrasonic method is considered optimal for refining the results of initial screenings (visual or thermographic) and for examining historic facades where destructive testing is prohibited [5], [6].

The impact-echo method is used to diagnose panel facade elements, as well as stone or ceramic tile cladding. It involves exciting the structure with a short impact (e.g., with a special hammer or piezoelectric transducer) and recording the vibration response with a sensitive sensor. Each structure has its own resonance frequencies, which depend on the thickness and integrity of the material. The presence of voids, cracks, or areas of delamination changes these frequencies, allowing defects to be identified. In practice, the measurement is performed as follows: the striker is applied to the surface of the facade, the sensor (often a MEMS accelerometer or a special sensor) registers the vibrations, which are analyzed in the frequency domain using a Fourier transform, the principle of operation is shown in the diagram (Fig. 2). If the structure is solid and homogeneous, the signal has a stable spectrum. If there is a void or delamination, a characteristic shift or additional peaks appear in the spectrum. Modern Impact-Echo systems allow you to automate the data collection process and work with arrays of measurements. For example, the Olson Instruments IE System (USA) or compact MEMS-based sensors described in recent studies allow you to quickly evaluate large facade surfaces.

This method is particularly useful for detecting "empty" tiles, areas of stone cladding delamination, and localizing delamination in concrete panels. In combination with thermography, Impact-Echo is used as a confirmatory method: if a suspicious spot is detected on a thermal image, Impact-Echo allows you to determine the depth and boundaries of the defect. The main advantages of the method are the ability to assess internal defects without damaging the structure and its suitability for thick elements and cladding. Disadvantages: the need for a regular measurement grid (to cover the entire surface), sensitivity to ambient noise and vibrations, and the need for professional interpretation of spectra. The impact-pulse method is an effective tool for spot diagnostics of facade systems, especially where it is necessary to check the quality of the adhesion of the cladding to the base or the integrity of the panel elements [7], [8].

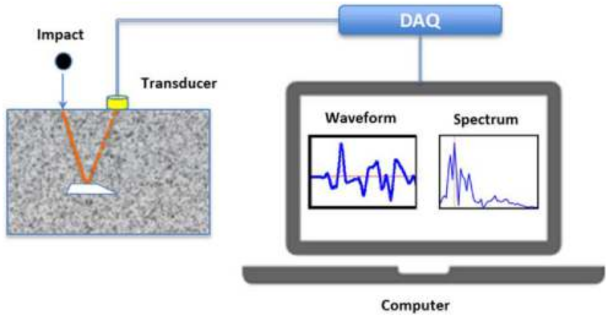

Fig. 2. Scheme Impact-Echo [8]

Infrared thermography (IRT) is one of the most effective non-destructive testing methods for assessing the condition of facades. Its principle is based on the detection of infrared radiation emitted by the surface of a building. Each material has a certain thermal conductivity and thermal inertia, so if there are internal defects – voids, areas of delamination, areas with increased humidity or cold bridges – the temperature distribution changes and characteristic anomalies appear on the thermogram.

Thermographic inspection of facades can be performed in two modes:

- passive – recording natural temperature differences between defective and undamaged areas. The survey is carried out in the morning or evening hours when the temperature difference is most pronounced.
- active – a controlled thermal load (heating or cooling) is created, after which the thermal response of the structure is measured. This mode is particularly effective for detecting delamination of tiles, thin cladding, and composite panels.

Modern thermal imagers, such as FLIR T1020, Testo 885, or drones with IR cameras (DJI Mavic 3T), are used for inspection. They allow you to quickly cover large areas of facades and obtain images with high spatial and temperature resolution. The data is often integrated with 3D models of facades created using photogrammetry. The method allows you to detect: areas of increased humidity and leaks; voids under plaster, tiles, or stone; delamination in insulation systems (EIFS); areas of heat loss in places with poor insulation.

The main advantages of IRT are that it is completely non-contact, fast, and can be used on high-rise facades without scaffolding. However, the method has limitations: its interpretation depends on weather conditions (solar radiation, wind, ambient temperature), requires the right time for shooting, and a highly skilled operator to interpret the thermograms [9].

Georadar sounding is an effective non-destructive method for diagnosing facade structures, especially multi-layer systems: concrete with cladding, brick walls with insulation, ventilated facades. The method is based on emitting short high-frequency electromagnetic pulses (from tens of MHz to several GHz) into the material and recording signals reflected from layer boundaries or inhomogeneities. Each material has its own dielectric permeability, which affects the speed of electromagnetic wave propagation. When a wave encounters the boundary between two media with different permeabilities (e.g., concrete – air cavity, brick – insulation), part of the electromagnetic wave is reflected. By analyzing the delay time and amplitude of the reflected signal, it is possible to determine the depth and nature of internal defects.
Advantages of this method: the ability to "see" the internal structure without damage; application to

various materials (concrete, brick, stone, composites, insulation); obtaining cross-sections and 3D reconstructions of the internal structure of the facade. Disadvantages of the method: complexity of data interpretation; need for an experienced operator; limited effectiveness in wet materials (the signal is greatly attenuated in wet concrete or brick); high cost of equipment [10].

The acoustic emission (AE) method is used to monitor active destruction processes in facade materials. Its principle is based on the fact that during the formation or opening of cracks, delamination of cladding, or the development of corrosion of metal elements, short elastic wave pulses occur in the material. These pulses propagate in the form of high-frequency acoustic waves (20 kHz – 1 MHz) and can be recorded by sensitive piezoelectric sensors installed on the surface of the structure. How it works: sensors detect acoustic pulses generated during the formation of microdefects. Each pulse is characterized by amplitude, energy, duration, and signal arrival time. These parameters can be used to locate the source of the defect, assess its development, and distinguish the type of process–for example, crack propagation or corrosion. The method makes it possible to monitor the corrosion of metal fasteners and anchors that hold the cladding in place; detect active processes of tile or stone delamination; monitor crack formation in concrete panels; and conduct long-term monitoring of the condition of historic buildings.

Advantages: records active processes as defects develop in real time; allows the rate of degradation to be assessed; suitable for long-term remote monitoring.

Disadvantages: the method does not provide complete information about existing defects, but only signals new or progressive damage; high sensitivity to background noise; complexity of data interpretation, need for special software [11] – [13].

Table I compares the main methods of non-destructive testing of facades according to their principle of operation, type of defects, depth of diagnosis, advantages, and limitations.

TABLE I. COMPARATIVE TABLE OF METHODS FOR MONITORING THE CONDITION OF FACADES

Method	Principle of operation	What it reveals	Devices	Advantages	Disadvantages
Sclerometric (impact)	Measurement of the rebound of an elastic striker after impact on a surface.	Surface strength, uniformity of concrete/plaster.	Proceq Original Schmidt, SilverSchmidt (Switzerland).	Simplicity, low cost, speed, portability.	Only the surface (2–3 cm), sensitivity to moisture and paint, does not see internal defects.
Ultrasonic pulse	Measuring the propagation time of ultrasonic pulses through a material.	Internal cracks, cavities, heterogeneity, degree of moisture content.	Proceq Pundit PD8000, GE USM Go+, Olson CTG-2.	Detects hidden defects, in various materials.	Requires high-quality contact (gel), affected by humidity, difficult to interpret.
Impact-Echo	Excitation by short pulse and analysis of resonance frequencies.	Delamination, voids, tile/stone detachment, internal panel defects.	Olson IE System (USA), MEMS sensors.	Diagnosis of internal defects, suitable for cladding.	Point method, requires interpretation of spectra, sensitive to noise.
Infrared thermography (IRT)	Recording thermal radiation and temperature anomalies.	Moisture, voids, delamination, cold bridges, insulation defects.	FLIR T1020, Testo 885, DJI Mavic 3T (with IR camera).	Non-contact, fast coverage of large areas.	Dependence on weather and time of day, need for standards
Georadar sounding	Emission of electromagnetic pulses and recording of reflected signals.	Layering, voids, reinforcement, anchors, wet areas.	GSSI StructureScan Mini XT, Mala Easy Locator	"Sees" multilayer structures, 3D slices, versatility.	Difficulty of interpretation, weak signal in wet materials, expensive equipment.
Acoustic emission (AE)	Recording of high-frequency waves generated during crack/corrosion formation.	Active processes of destruction, crack progression, corrosion of fasteners.	MISTRAS Pocket AE-2, Vallen AMSY-6, PAC AE Systems.	Detects defects in real time, monitors degradation rate.	Sensitivity to noise, difficult interpretation.

Table I shows that no single method is universal: surface defects are quickly detected by sclerometry and thermography, while internal defects are better diagnosed by ultrasound, Impact-Echo, and GPR. In practice, it is advisable to combine several methods depending on the facade material, layering, and access conditions.

III. UAV Technologies for Aerial Surveillance

The main trend in solving monitoring tasks in the construction industry is the widespread use of UAV technologies for aerial observation of the technical condition of industrial infrastructure, as well as for monitoring hazardous man-made processes. This is aimed at improving safety and reducing the risk of emergencies. Particular attention is paid to the inspection of structures in order to identify potentially hazardous areas [14], [15]. Thanks to their ability to take off vertically and hover in confined spaces, UAVs are used for safe inspection of high-rise facades and hard-to-reach areas of buildings. They provide maneuverability, stable positioning near vertical surfaces, and rapid data transmission, allowing visual inspections to be carried out without the use of scaffolding or climbers. This is especially important in cases where it is necessary to minimize risk to personnel and obtain data in potentially hazardous conditions [15], [16]. Thus, UAVs form a separate direction of modern facade monitoring methods, combining efficiency, safety, and the ability to operate in difficult conditions.

Research into the use of UAVs for building inspection is actively developing worldwide. Foreign publications highlight aerial surveillance systems and data processing methods that allow the technical condition of structures to be assessed in real time [14], [16] – [18]. In Ukraine, the developments of the Dnipro State Academy of Civil Engineering and Architecture are well known. In recent years, the role of UAV technologies in the construction industry has been growing for aerial visual observation of the technical condition of industrial infrastructure, as well as for monitoring the development of hazardous man-made processes in order to ensure safety and minimize the risk of emergencies. Safety issues during construction work and the inspection of structures to identify potentially hazardous areas are of particular importance. The technical condition of buildings is determined by visual and visual-instrumental methods with the involvement of specially trained workers. Such surveys are labor-intensive and, in some cases, even dangerous. The two most difficult processes that can be performed by UAVs are the inspection of chimneys and high-rise structures and the investigation of building destruction [19]. Climbers are involved in inspecting chimneys. However, their capabilities are limited: it is not always possible to secure themselves to a specific section of the pipe, it is impossible to inspect areas beyond direct visibility, and it is difficult to effectively use bulky measuring instruments, photo and video equipment, repair tools, etc. The UAV does not have these disadvantages. It does not need to be fixed in space, is capable of conducting inspections while moving away from / approaching the object, moving along any trajectory (Fig. 3), and even "looking" inside (Fig. 3).

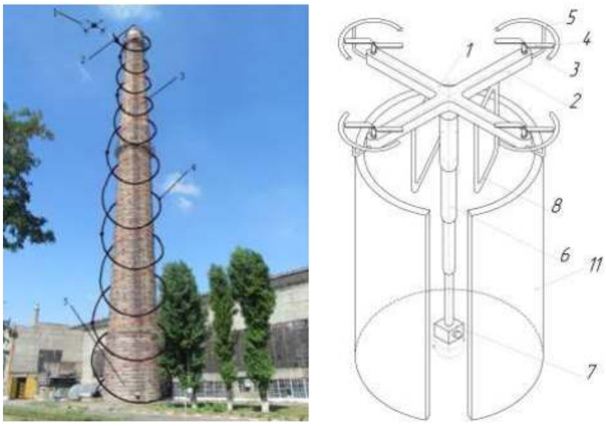

Fig. 3. Inspection of a high-altitude object by a UAV [18]

IV. Using FPV Cameras to Monitor Facades with UAVs

Unmanned aerial vehicles equipped with first-person view (FPV) cameras are used for real-time monitoring of facades. These cameras provide online video streaming to the operator's ground station, allowing for initial visual analysis of the object during flight without the need to wait for further data processing. The FPV system consists of a compact RGB camera (Red, Green, Blue – three-channel color image), a video transmitter, and a receiving monitor or operator goggles. In the case of facade monitoring, this allows not only to orient the UAV during the flight around the building, but also to detect gross defects (cracks, delamination, damaged fasteners) directly in flight. Thus, the FPV channel is used as a quick diagnostic tool that complements high-quality shooting from the main cameras [20].

Modern industrial UAVs (e.g., DJI Matrice 300 RTK, DJI Mavic 3 Enterprise) have integrated FPV cameras that are used for navigation and preview. Additionally, high-resolution RGB cameras, thermal imagers (e.g., DJI Zenmuse H20T, FLIR Vue

TZ20), and other sensors can be installed on them. This combines the speed of FPV monitoring with the accuracy of detailed photo and thermal imaging diagnostics. In addition to the FPV camera, which provides navigation and preliminary inspection, high-resolution RGB cameras and infrared (IR) thermal imagers are used for detailed diagnostics of facades. RGB images allow you to analyze visible defects: cracks, corrosion spots, plaster or cladding delamination. IR cameras (e.g., DJI Zenmuse H20T, FLIR Vue TZ20) record thermal anomalies that indicate cavities, wet areas, cold bridges, and insulation defects [21]. The combination of RGB and IR data on a single drone provides a multispectral approach: detection of both surface and hidden damage. This data is then integrated into photogrammetric models of facades for accurate positioning of defects.

Digital image processing involves the use of various operations and algorithms to improve image quality. Problems such as blurring, low resolution, and monochrome images often arise during analysis, which has led to the development of numerous processing methods. Traditionally, there are three main stages: obtaining source data, image analysis, and modification. Sequential execution of these stages allows you to obtain a result with improved characteristics [21], [22].

One of the most widely used filters in image and video analysis is the Gaussian filter. The process of blurring an image using the Gaussian function is known as "Gaussian filtering" or "Gaussian blurring," named after mathematician Carl Friedrich Gauss. This low-pass filter helps blur individual areas of the image and reduces noise by filtering out high-frequency components [21], [23]. It is implemented as a symmetric kernel of odd size (a matrix in digital image processing) that is moved over each pixel in the image region of interest to achieve the desired effect. When used in environments with fixed computational accuracy, the Gaussian filter improves processing efficiency and reduces computational costs. However, creating a 2D Gaussian filter for real-time applications requires significant computational resources. The Gaussian filter is also used in defect detection programs. It reduces noise in images taken by a camera mounted on a UAV. In grayscale, this filter smooths out local brightness variations, allowing for better surface structure differentiation. The method is considered effective because it provides up to 85% accuracy in defect detection on both textured and non-textured images [24].

V. Software Libraries for Computer Vision

OpenCV (Open Source Computer Vision Library) is one of the most popular libraries for image and video processing. It contains a wide range of algorithms for computer vision, including: edge detection; object detection; working with depth maps and 3D facade reconstruction; image filtering and quality improvement. Thanks to its high performance and support for Python and C++ languages, OpenCV is an excellent choice for basic facade analysis and image preprocessing [21], [22]. TensorFlow and PyTorch, the two most popular platforms for working with neural networks, are most often used to implement artificial intelligence algorithms in facade condition monitoring.

TensorFlow is a powerful deep learning framework from Google that is widely used for image recognition and facade classification. Key advantages: support for convolutional neural networks (CNN) for segmentation and recognition of architectural elements; optimization of calculations on GPU/TPU, which speeds up the analysis of large data sets; use of pre-trained models, such as EfficientNet or MobileNet, for facade damage recognition. TensorFlow is well suited for in-depth facade analysis, including crack detection, material identification, and surface condition assessment [19], [21].

Another popular framework is PyTorch, which is actively used for computer vision. Its advantages include flexibility in creating custom neural network architectures; dynamic graph computation, which facilitates model debugging; and high performance for facade segmentation and texture recognition tasks. PyTorch is particularly popular in scientific research and projects that require rapid experimentation with model architecture [15], [22].

Packages for photogrammetry and 3D modeling

Agisoft Metashape and Pix4Dmapper – used to build orthophoto plans and 3D models of facades based on a series of images obtained from UAVs. This allows defects to be integrated into spatial models.

GIS/BIM systems (ArcGIS, Autodesk Revit) – ensure the integration of analysis results into digital building models, which creates the basis for digital twins [17], [25].

VI. Integration of UAVs and Intelligent Algorithms for Facade Monitoring

The use of unmanned aerial vehicles in combination with computer vision algorithms and neural networks opens up new opportunities in the field of facade diagnostics. This approach allows for the automation of inspection processes, reduces the human factor, and provides data on hard-to-reach areas. FPV cameras are used for UAV navigation and preliminary visual inspection. Thanks to online video transmission, the operator can quickly assess the overall condition of the facade during flight, identifying large cracks, delamination, or damaged elements. The main data set is formed using high-resolution RGB cameras. Such images are used for detailed analysis of cracks, corrosion spots, and plaster damage. To make the data suitable for automatic analysis, noise filtering (Gaussian filter) is used, as well as image processing methods that allow removing small artifacts, detecting the contours of cracks and damage, smoothing their outlines, and more accurately determining the shape of defects [18], [21], [22]. Infrared thermography is an important addition to the use of RGB images. Thermal imaging cameras installed on UAVs allow you to detect areas with high humidity, voids, and heat loss zones that cannot be seen in the visible range. Such diagnostics are most effective in conditions of temperature contrast – in the morning or evening hours. In addition to photography and video recording, photogrammetry is a promising direction, which allows you to build orthophoto plans and three-dimensional models of facades using a series of images. Defect maps obtained from image analysis can be superimposed on these models. This approach provides a basis for integration with BIM and GIS systems. LiDAR scanning (Light Detection and Ranging – laser scanning technology) ensures high accuracy in reproducing the geometry of facades. The resulting point clouds make it possible to assess deformations and deviations from the design shape. Machine learning algorithms and clustering methods are used to analyze such data in order to structure point clouds and identify groups of defects [15], [17], [26]. Further data analysis is performed using OpenCV, TensorFlow, and PyTorch libraries. The most common architectures include convolutional neural networks (CNN), such as U-Net for crack segmentation, Mask R-CNN for accurate delineation of damaged areas, and ResNet for improved classification accuracy [21] – [23]. The combination of UAVs and intelligent algorithms forms comprehensive facade monitoring systems that are capable of operating in near real time. This allows not only to detect defects, but also to integrate the results into digital twins of buildings, which significantly increases the efficiency of operational control.

VII. ANALYSIS OF RESEARCH RESULTS

The study analyzed the main methods of non-destructive testing of building facades, including sclerometry, ultrasonic measurements, the impact-echo method, infrared thermography, ground-penetrating radar, and the acoustic emission method. Their effectiveness, advantages, and limitations were evaluated in the context of their application to different facade materials and operating conditions. In addition, the possibilities of using UAVs with FPV, RGB, and IR cameras for data collection in hard-to-reach places were considered, as well as modern software tools such as OpenCV, TensorFlow, PyTorch, photogrammetric complexes, and BIM/GIS systems. A comparative analysis showed that the most promising approaches are integrated ones that combine the advantages of classical methods with automated data processing using computer vision algorithms and neural networks.

It has been established that traditional non-destructive testing methods remain important tools, but their effectiveness is limited in the case of large and high-rise facades. The use of UAVs eliminates these limitations by providing fast and safe data collection in real time. The application of computer vision algorithms and deep neural networks has made it possible to automate the detection of cracks, delamination zones, and moisture anomalies, increasing the accuracy of assessing the technical condition of facades. Integration with photogrammetry, LiDAR, and BIM/GIS systems has demonstrated the promise of creating digital twins of buildings for systematic monitoring. Thus, the study not only confirmed the advantages of using UAVs in combination with intelligent algorithms, but also outlined directions for their further development in the practice of technical inspection of facades.

VIII. CONCLUSION

The analysis showed that traditional non-destructive testing methods – sclerometry, ultrasonic measurements, impact-echo method, thermography, laser vibrometry, shearography, ground-penetrating radar, and acoustic emission method – remain important tools for assessing the condition of facades. Each of them has its own advantages and limitations, so their use is appropriate in different conditions depending on the type of construction materials and the nature of possible damage. At the same time, the development of UAV technology opens up new opportunities for facade monitoring. The use of UAVs makes it possible to safely inspect buildings, including those in hard-to-reach places. In doing so, various types of information can be obtained: visual images, infrared thermography results, and laser scanning data. Combining the capabilities of UAVs with computer vision algorithms, machine learning, and deep neural networks enables automated analysis, high-precision defect detection, and integration of results into digital building models.

Of particular note is the ability to combine RGB images, thermal imaging data, and 3D models built using photogrammetry or LiDAR into a single analytical environment. This creates the basis for the formation of digital twins of buildings integrated into BIM and GIS systems, which corresponds to current trends in the development of smart cities and intelligent infrastructure management systems. The most promising direction is the development of integrated facade monitoring systems, in which UAVs act as the main data collection tool, and computer vision algorithms and neural networks as the core of automated analysis. This will allow a transition from sporadic inspections to systematic monitoring in near real time, which will significantly improve the efficiency of technical operation of buildings.

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А. В. Тищенко. Ю. М. Шепетуха. Аналіз методів моніторингу стану фасадів будівель на основі візуальних даних

У статті досліджено використання інформаційних технологій для моніторингу стану фасадів будівель на основі візуальних даних, отриманих з безпілотних літальних апаратів. Дослідження підкреслює зростаючу роль БпЛА в структурних перевірках, відзначаючи їхні ключові переваги, зокрема підвищену безпеку, ефективність і точність, у порівнянні з традиційними методами. Дослідження структуровано у три основні розділи. Перший розділ містить огляд існуючих підходів до моніторингу фасадів, порівнюючи традиційні методи перевірки з методами на основі безпілотних літальних апаратів. У другому розділі розглядаються технологічні аспекти збору, обробки та аналізу даних, зосереджуючись на штучному інтелекті, комп'ютерному зорі та фотограмметрії. У останньому розділі представлено практичне застосування цих технологій, огляд відповідних програмних засобів, прикладів та економічних переваг. Результати показують, що безпілотні літальні апарати в поєднанні з передовими технологіями обробки зображень значно підвищують ефективність і надійність оцінки фасадів будівель.

Ключові слова: моніторинг фасадів; безпілотні літальні апарати; комп'ютерний зір; штучний інтелект; нейронні мережі; фільтр Гауса; сегментація тріщин.

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