FUSION OF UAV PHOTOGRAMMETRY AND DEEP LEARNING FOR DIAGNOSTICS OF LARGE-SCALE STRUCTURES

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The paper presents an integrated UAV-based approach for diagnostics of large-scale structures using photogrammetric 3D modeling and deep neural networks. The method enables safe, accurate, and fast defect detection, as proven by inspections of critical infrastructure damaged during military aggression. Real-case examples include 3D models and automated damage detection results, demonstrating the system's practical value.

Keywords: UAV, photogrammetry, deep learning, structural diagnostics, non-destructive testing

Introduction. Amid military aggression against Ukraine and the intensive use of critical infrastructure, the demand for advanced non-destructive inspection technologies is rapidly increasing. Ensuring the structural integrity of large-scale facilities such as communication towers, power pylons, or reinforced supports requires reliable, safe, and efficient diagnostic methods. These structures are continuously affected by external factors – including corrosion and static or dynamic loads – which may lead to degradation or catastrophic failure over time. Regular monitoring is essential to detect early-stage damage and plan appropriate maintenance activities.

Traditional inspection techniques often involve significant risks, labor intensity, and time consumption due to the use of climbing equipment and manual access to dangerous zones. In this context, unmanned aerial vehicles (UAVs) offer a powerful solution, enabling remote visual access to complex structures and collecting detailed spatial data without direct human contact.

Modern UAVs have become indispensable tools for remote infrastructure assessment, particularly in the inspection of tall or large-scale engineering structures. Their use significantly increases the speed and accuracy of diagnostics while reducing manpower, costs, and safety risks [1-3]. Integrating UAV-based aerial photography with photogrammetric modeling and artificial intelligence (AI) enables a comprehensive, data-driven approach to structural condition assessment with high reliability.

E. O. Paton Electric Welding Institute of NAS of Ukraine has developed a UAV-based diagnostic system for large-scale structures, combining drone-acquired imagery, photogrammetric 3D reconstruction, and AI-based damage detection. UAVs used in the project include DJI Air 2S and DJI Mavic 3 Enterprise with RTK, which allow safe and efficient data collection from areas that are difficult or dangerous to access manually.

The workflow includes generating 3D models via photogrammetry using 3DF Zephyr software and further processing the data with computer vision algorithms [4].

Photogrammetry is a method that provides accurate spatial information about physical objects and their surroundings through image recording, measurement, and interpretation from multiple viewpoints. It integrates digital photography, georeferencing to GIS, and optionally laser scanning [5]. Photogrammetric analysis enables the detection of geometric deformations and structural displacements. Prior to reconstruction, available settings in 3DF Zephyr are analyzed to select the optimal model generation preset based on the diagnostic goal and required output quality (Fig. 1).

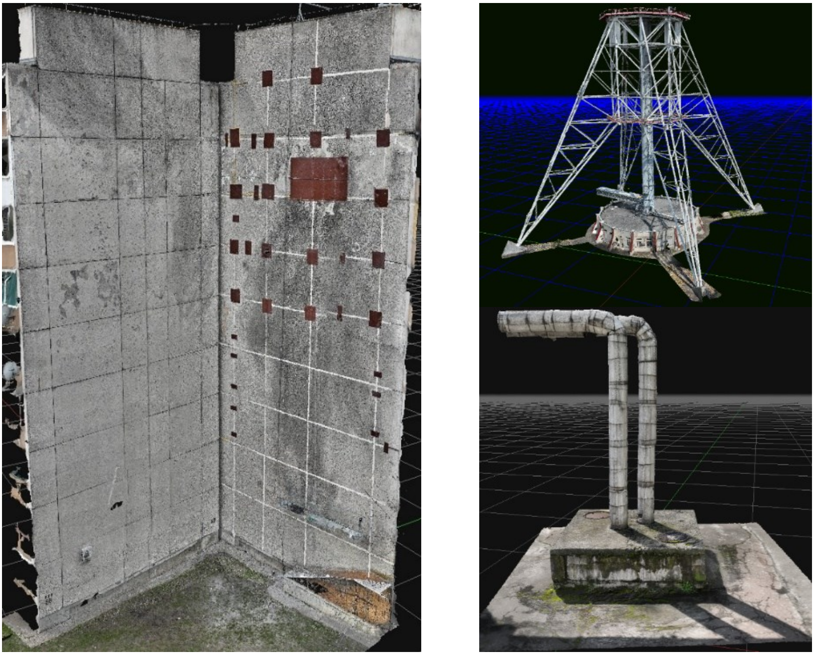

Fig. 1. Examples of 3D models generated in 3DF Zephyr.

In the next stage, captured images are processed using deep neural networks (e.g., YOLO), enabling automatic detection of structural damage (e.g., cracks, corrosion, dents, tears) (Fig. 2) and fasteners (e.g., bolts, nuts, washers) (Fig. 3).

Custom datasets were created to train deep learning models, containing annotated images acquired by UAVs under real-world inspection conditions. This allows the models to adapt to the specifics of engineering structures and improves detection accuracy.

Fig. 2. Automatic detection of defects.

a b

Fig. 3. Results of neural network processing of UAV images: deep learning-based fastener detection (a) and segmentation (b).

The diagnostic system has been successfully tested on various critical infrastructure objects, including the Kyiv TV tower after missile damage [6–8], residential buildings affected by drone strikes, and telecommunication towers. The outputs include detailed damage visualization, spatial measurements, and automated identification of critical defects with associated probability estimates.

The approach has proven effective under complex technical and operational conditions and shows high potential for implementation in automated diagnostics of engineering structures, both in peacetime and under wartime conditions. It offers high assessment accuracy, minimizes human involvement, reduces inspection time and resource consumption, and increases safety for inspection personnel. Further development of the system will include integration with cloud platforms and real-time monitoring capabilities.

Conclusions. The presented UAV- and AI-based diagnostic technology has demonstrated significant potential in monitoring large-scale infrastructure under real conditions. The fusion of high-resolution UAV imaging with deep learning significantly enhances the speed and precision of defect detection, minimizes human presence in hazardous environments, and enables detailed spatial modeling of the structural state. The use of artificial intelligence transforms conventional inspections into adaptive, intelligent monitoring systems capable of learning from data and improving with each betterment.

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