AP22788508. Development of Methodological Approaches for Monitoring Critical Hydraulic Infrastructure in Kazakhstan Using UAVs and Remote Sensing. sc. sp. – Nizametdinov N.F.

Relevance

Hydraulic structures are critically important infrastructure facilities. Violation of their integrity can potentially cause serious catastrophic consequences. Such accidents may inflict significant damage on the population, industrial enterprises, agriculture, and existing infrastructure, thereby negatively impacting the national economy. Therefore, attention must be focused on preventing such accidents and mitigating their negative consequences, given the importance of hydraulic structures.

The dam breaches at reservoirs in the Karaganda region in 2014–2015 led to flooding of residential buildings and territories, loss of human lives, harm to the health of local residents, the environment, and agricultural facilities. From 2009 to 2023, more than 13 major dam and dike failures occurred globally, resulting in significant casualties.

Thus, the scale and relevance of this issue extend beyond the regional level and impact the global context.

At present, special attention is paid to the state of hydraulic structures and water resources in the Republic of Kazakhstan. Accordingly, national projects such as “Technological Breakthrough through Digitalization, Science, and Innovation” and “Green Kazakhstan” emphasize the priority of digitalizing hydraulic structures for effective management and coordination of their operation.

Monitoring carried out using unmanned aerial vehicles (UAVs) and remote sensing (RS) data represents a cost-effective solution that has no negative impact on the environment or human health, while providing comprehensive and highly detailed information on the studied object in the shortest time possible.

The use of radar interferometry allows for area-wide, temporally differentiated visualization of vertical displacement values at any point of the studied area and any time prior to the actual survey date. Satellite radar imaging is performed in the ultra-shortwave (super high frequency) radio range, divided into X-, C-, S-, L-, and P-bands. For surface displacement monitoring and critical facilities, data in one or several of these bands will be selected based on the type of terrain, vegetation cover, expected displacement magnitudes, etc.

The Gaofen-3 satellite is a Chinese low-Earth orbit satellite that operates in the C-band with a resolution of up to 1 meter. GF-3 is capable of conducting twelve-mode radar imaging of the Earth’s surface 24 hours a day, regardless of weather conditions.

The use of high-resolution orthophotos and detailed point clouds allows for the comprehensive resolution of engineering-geological and mine-surveying-geodetic tasks. High-resolution orthophotos provide accurate and timely identification of deformation zones in embankment dams, as well as analysis of the nature and mechanisms of their deformation. The use of drones equipped with high-resolution thermal sensors enables the detection of water leakage and cracks.

Expected and Achieved Results

Achieved Results

It is proposed to develop methodological approaches for the systematic monitoring of the current state of hydraulic structures using the example of the Sherubai-Nurinskoye Reservoir. The monitoring process will employ advanced tools for collecting high-precision geospatial data, such as unmanned aerial vehicles (UAVs) and remote sensing (RS) data.

Using innovative data analysis methods and advanced computational technologies, including machine learning and artificial intelligence techniques, forecasting of possible geomechanical processes affecting the condition of hydraulic structures will be carried out. Based on monitoring results and data analysis, recommendations will be developed to improve the safety, reliability, and uninterrupted operation of critical infrastructure facilities. These methodological approaches will reduce the likelihood of catastrophic consequences that may harm enterprises, the population, the environment, and agricultural assets.

The scientific novelty of the Project lies in the development of a unique digital monitoring system for the surfaces of hydraulic structures, dams, and embankments. With the advancement of infocommunication technologies, including powerful tools such as data mining, big data processing,

deep learning, blockchain, Internet of Things (IoT), edge analytics, electronic identification (e-ID), web-scale IT, hybrid clouds, GIS, and geospatial analytics, as well as the emergence of UAVs and satellite data acquisition, new opportunities have opened up for monitoring critical infrastructure in Kazakhstan.

The research team is conducting monitoring of the Topar earth dam using modern geodetic and remote methods.

The team performs both classical measurements — class II leveling and tacheometry — and high-precision measurements using innovative technologies: UAVs, satellite data, and GNSS receivers in static mode. Aerial photography of the object is performed at a spatial resolution of 2.5 cm/pixel, along with the collection and processing of satellite imagery.

Based on the acquired data, multi-temporal digital terrain models, point clouds, 3D tile models, elevation maps, and orthophotos are created. This allows for detailed tracking of changes in the study area and identification of potential deformation processes.

As part of the project, the team conducts validation of the constructed models — comparing the coordinates of key points interpreted on digital models with results from traditional geodetic methods. This approach enables objective assessment of the accuracy and efficiency of the applied technologies and allows for recommendations to improve the reliability of monitoring and the safety of hydraulic facility operations.

Figure 1 – Orthophoto generated from aerial survey using Wingtra One UAV.

The project is aimed at developing a modern methodology for assessing the condition of hydraulic structures using remote sensing and geodetic control technologies. Monitoring was carried out using two types of unmanned aerial vehicles:

Wingtra One – used for high-resolution aerial photography, construction of a digital terrain model, and creation of an orthophotomap;

DJI Mavic 3 Thermal – used for thermal imaging to detect temperature anomalies on the surface of the dam.

Figure 2 – 3D model from Wingtra One data illustrates the structure and geometry.

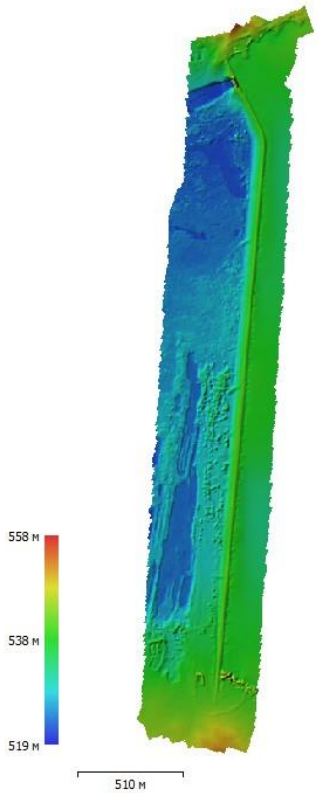

Figure 3 – Digital model analysis reveals areas of subsidence, deformation, and mass redistribution.

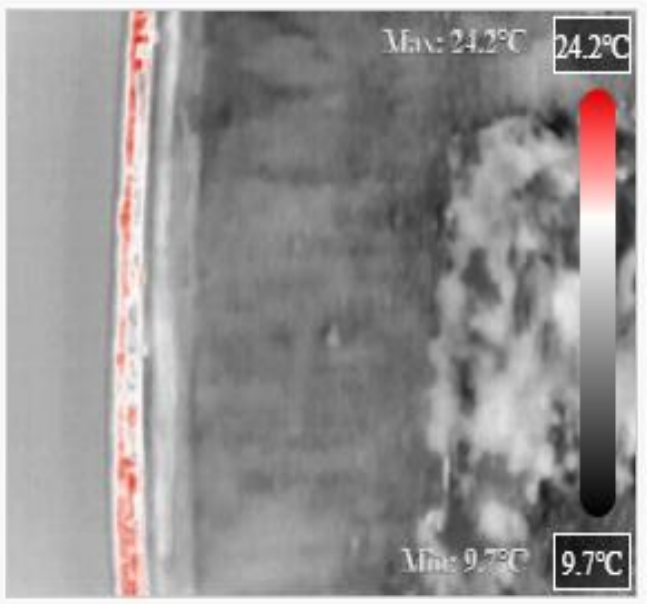

Figure 4 – Thermal imaging identified zones with signs of excess moisture and possible water seepage.

Additionally, leveling of the dam crest was performed, which made it possible to validate the data obtained using UAVs.

Figure 5 – Leveling is a key step in validating digital models and controlling vertical displacements.

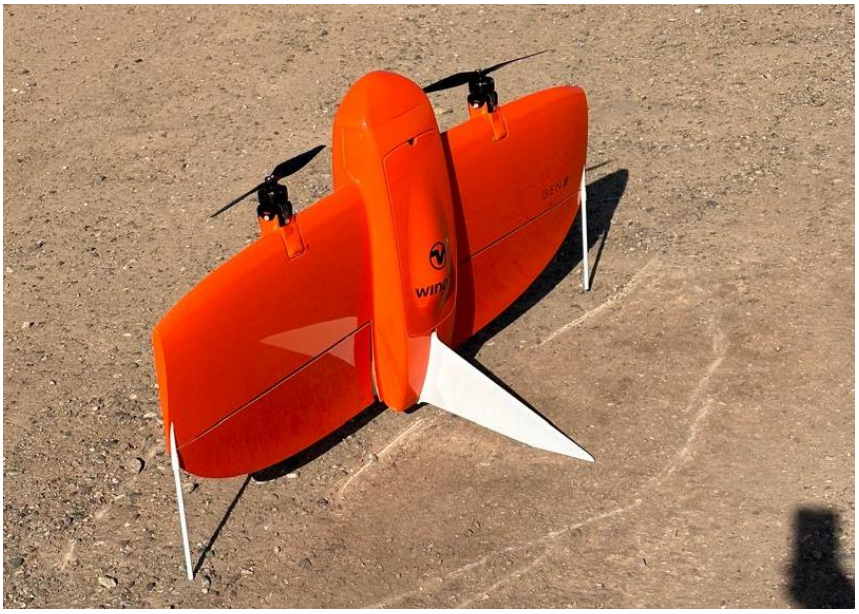

Figure 6 – Vertically launching UAV used for detailed aerial surveys.

Figure 7 – Mavic 3 Thermal equipped with thermal sensor for rapid technical diagnostics.

According to the project participants, combining visual, thermal, and geodetic data not only enables monitoring of the current condition but also allows the establishment of an early warning system for possible deformations. The developed methodological approaches are planned to be adapted for other dams and hydraulic facilities across Kazakhstan.

List of Publications by Research Team Members in High-Ranking Journals for 2024–2025

A patent application has been submitted as part of the project: **Patent No. 2024/0806.1 dated 02.10.2024** Applicants: Nizametdinov Nail Faritovich, Ozhigin Dmitry, Grossul Pavel, Kazantseva Viktoria, Kosarev Nikolay, Yartseva Vera, Baigali Ruslan, Satbergenova Asel, Kubaidullina Ulpan.

An article titled *"Development of an Integrated Geotechnical Monitoring System for Technogenic Facilities Based on Geospatial Data"* has been submitted to the **Journal of Mining Institute (**88th percentile, Q1**)** Authors: Kazantseva Viktoria, Ozhigin Dmitry, Kosarev Nikolay, Satbergenova Asel, Ozhigina Svetlana.

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Information for Potential Users

Based on the conducted research, in the upcoming project years, a mathematical model will be developed to forecast potential geomechanical processes using multi-temporal digital models of the study object, combined with machine learning and AI. This will allow integrating two or more series of measurements performed using UAV and RS methods to identify hazardous zones with high deformation probability.

Field of Application: Hydraulic structures

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