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Development of an Accessible Remote Method for Monitoring Landslide Processes

Fakhraddin Gabibov[1*], Arzu Zeynalov[2], Konul Bayramova[3]

Abstract. *Remote methods for studying and monitoring exogenous processes have been used since ancient times. In the 18th century, the determination of the size and spatial position of objects was done through their drawn images in central projection, which were obtained using a camera obscura from elevated places and ships. The next stage in the development of remote methods was the invention of photography, the photographic lens, and the stereoscope. Photographs of the landscape, taken from a bird's-eye view using balloons and kites, received high cartographic recognition. Currently, drones equipped with cameras are effectively used for studying and monitoring the development of landslide processes. However, even this method has its drawbacks. Thus, it is virtually impossible to fix a drone with photographic equipment in a stationary position for an extended period at a chosen high near-distance observation point. The authors have proposed a simplified method of photogrammetric surveying for near-distance research on large landslide processes. The method involves using various flying vehicles instead of aerial photography. Periodic photography is carried out from elevated points of seismic-resistant high-rise buildings and structures (television towers, chimneys, high masts, and high-voltage power line towers) located outside the landslide-prone area. The method, in comparison to aerial photography, is significantly simpler, cheaper, and allows for more accurate information about the dynamics of landslide, erosion, and abrasion processes due to the possibility of conducting multiple surveys from stationary points over different periods. First of all, we achieve the effect of stationary, relatively inexpensive research on the development of the landslide process over a long period, during which periodic photography of the designated area or object on the landslide slope surface is carried out automatically according to a set program. The method can also be implemented using two or more cameras installed on two or more seismic-resistant high-rise structures located in the vicinity of the large landslide area under study. The equipment installed on the elevated structures can be equipped with automatic systems programmed for emergency response to the rapid development of the landslide process and alerting operators via mobile or satellite communication networks. The development is distinguished by its relative affordability, accuracy, and accessibility.*

Keywords: *landslide, periodic photography, high-rise buildings, method, landslide process*

[1]Scientific Research Institute of Construction and Architecture, PhD in Technical Sciences, Baku, Azerbaijan
[2]Azerbaijan Scientific Research Institute of Construction and Architecture, Baku, Azerbaijan
[3]Azerbaijan University of Architecture and Construction, Baku, Azerbaijan
[*]Corresponding author. E-mail: farchad@yandex.ru
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Introduction

The primary goal of all human achievements is improving the quality of life. However, it is evident that the world is becoming neither safer nor cleaner due to the growing global population and increasing anthropogenic and technogenic pressure on the environment. This can be attributed to ongoing social and geo-environmental changes, insufficient funding, as well as the attitudes of people toward one another and toward the environment.

Managing the quality of the surrounding geological environment is difficult to envision without the use of information technologies. In this context, information technologies are understood as a set of methods, production tools, and software-technological resources integrated into a technological chain ensuring the collection, storage, processing, output, and dissemination of information. Management, in turn, is defined as the deliberate and purposeful informational influence exerted by management entities and bodies on people and objects, aimed at directing their actions and achieving desired outcomes (Elias et al., 2003).

For the identification of various types of risks and the prediction of large-scale landslides, the use of Geographic Information System (GIS) methods proves to be highly effective. Since GIS is a complex integrated system, it adheres to all principles of systems analysis. In systems analysis, a system is understood as a set of elements interconnected in such a way as to form a specific integrity and unity. The effectiveness of GIS in the study and prediction of major landslides is determined by its ability to integrate, on the one hand, with geoinformation collection systems (such as remote sensing, geodetic surveying, and monitoring of the surrounding geological and geoecological environment); on the other hand, with information storage systems (including information retrieval systems, databases, knowledge bases, and expert systems); thirdly, with geoinformation processing systems (such as image processing, modeling, and generalization); and finally, with geoinformation visualization systems (including computer graphics, electronic maps, and the creation of three-dimensional video models and scenarios). The fundamentals and current developments in GIS are presented in the monographs by Kapralov et al. (2005), Lurye (2002), Mitchell (2000), Shaytura and Zhurkin (2009), and others.

Remote methods for the study and monitoring of exogenous processes have been used since ancient times. In the 18th century, the dimensions and spatial positions of objects were determined using drawn images in central projection, obtained with the help of a camera obscura from elevated locations and ships. The next stage in the development of remote methods was marked by the invention of photography, the photographic lens, and the stereoscope. Aerial photographs taken from balloons and kites were highly valued for cartographic purposes. Today, drones equipped with cameras are effectively used to study and monitor the development of landslide processes. However, even this method has certain limitations, specifically the difficulty of maintaining a drone with photographic equipment in a fixed position for extended periods at a stationary point suitable for close-range aerial observation. Remote methods for studying geoecological, engineering-geological, and geotechnical processes are addressed in the monographs by Elias et al. (2003), Izrael (1985), Knizhnikov (1997), Revzon (1992), Korsakov and Korchuganov (2009), Shanda (1990), Kuchko et al. (1997), Ries (2006), Kranberg (1998), and others.

The term “monitoring” and its derivatives are widely used across various fields of knowledge. According to Izrael (1985), “Monitoring is a system of observations that allows for the identification of changes in the biosphere under the influence of human activity (monitoring of anthropogenic changes in the environment).” An invaluable contribution to the development of theoretical and practical methods for monitoring geological and natural-technical systems has been made by Bondarik and Yarg (1990), Parabuchev (1992), Epishin and Trofimov (1985), Korolev (2007), Vinogradov (1984), Hansvind and Lebedev (2010), Shubin (2005), Bezuglova and Motuzova (2007), and others.

Methods

Development of a Cost-Effective Method for Monitoring Large-Scale Landslides in Densely Populated Areas and at Critical Engineering Sites

The authors propose a simplified method of photogrammetric surveying for close-range investigation of large-scale landslide processes. Photogrammetric methods for measuring various parameters characterizing landslide, abrasion, rockfall, and other similar processes share a common feature: direct field measurements of objects are replaced by measurements taken from images of those objects. Mathematical processing of the measurement results allows for the calculation of all required parameters. The advantages of photogrammetric methods over traditional geodetic field measurements include a significant reduction in both the volume and duration of fieldwork, the ability to conduct measurements in hard-to-reach areas where other surveying methods are practically infeasible, the detail and objectivity of the resulting data, and the photographic documentation of the studied objects. High-precision measuring instruments are used for the photogrammetric processing of images. Depending on the method of image processing, rigorous photogrammetric methods are divided into two types:

1. Analytical image processing;
2. Processing using universal stereo photogrammetric instruments.

According to the newly developed method, instead of aerial photography using various types of aircraft, periodic imaging is carried out from elevated points on seismically stable high-rise buildings and structures (such as television towers, chimneys, tall masts, and high-voltage transmission towers) located on adjacent stable areas outside the zone of landslide impact or landslide-prone slopes.

These stable high-rise structures must be situated in close proximity to the landslide-prone area under investigation. Specialized photographic or cinematographic equipment is installed at an accessible elevated point on the stable high-rise structure and is temporarily secured there, operating in a pre-set automatic mode. Photo or video imaging is then conducted, focusing either on specific surface zones of the landslide-prone area or on special markers placed at designated surface points of the active landslide or potentially unstable section. Figure 1 shows a landslide slope (1) in the initial stage of development. Outside the landslide slope (1), on an adjacent stable area (2), a tall radio communication mast (3) is installed. This mast (3) is constructed with consideration for the seismic conditions of the area and is seismically stable. At a designated height on the mast (3), photographic equipment (4) is mounted on a special platform and securely fixed. The camera is directed toward the landslide or landslide-prone area under investigation, where special observation markers (5) may be placed as needed.

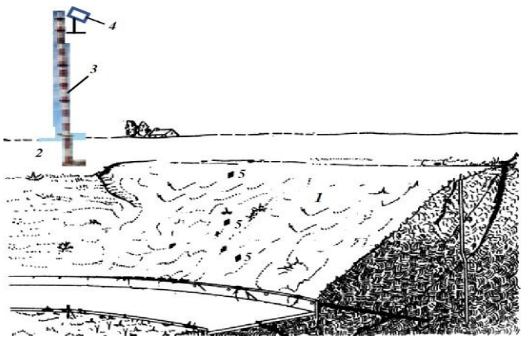

Figure 1

Landslide slope with a tall mast installed on an adjacent stable area, equipped with mounted photographic equipment: 1–landslide; 2–adjacent stable area; 3–tall mast; 4–photographic equipment; 5–observation markers

Variants of the New Method for Monitoring Large-Scale Landslides Using Photography from Stable High-Rise Structures

At a fixed point on a seismically stable high-rise structure, three photo or video cameras can be installed simultaneously to conduct parallel monitoring in the areas of the crown, body, and toe of an active landslide or landslide-prone site. If several stable high-rise structures are present in the vicinity of the active landslide or potentially unstable slope, it is possible to use at least three such structures located in different adjacent zones outside the landslide-affected area for equipment installation. In this case (Fig. ...), photographic equipment for monitoring the crown (2) of the landslide is installed on the first high-rise structure (e.g., a smokestack) (1); equipment for monitoring the body (4) of the landslide is installed on the second high-rise structure (3) (e.g., a multi-story building); and equipment for monitoring the toe (6) of the landslide is mounted on the third high-rise structure (5) (e.g., a power transmission tower). Observation and recording photographic or video equipment may also be mounted on a trolley that can be remotely controlled, moved, and fixed in place along a special metal cable stretched between two stable high-rise structures located in opposite adjacent stable zones of an active landslide or landslide-prone area.

The proposed method can be effectively applied within the landslide forecasting approach developed by Gabibov (2012, pp. 172–173), which studies both pre-landslide and post-landslide processes occurring on landslide-prone slopes. By analogy with earthquake research methods (foreshocks and aftershocks), it has been suggested to refer to pre-landslide slope deformations as *foreslides* and post-landslide deformations as *afterslides* (Gabibov, 2012, pp. 172–173). In the case of cyclic development of landslide processes on unstable slopes, particular interest lies in the transitional phase where afterslides evolve into foreslides. The process remains virtually unexplored and requires a systematic analytical approach. In comparison to traditional aerial photography, the proposed method is significantly simpler, more cost-effective, and enables more accurate monitoring of the dynamics of landslide development due to the possibility of conducting repeated imaging from fixed observation points over different time periods.

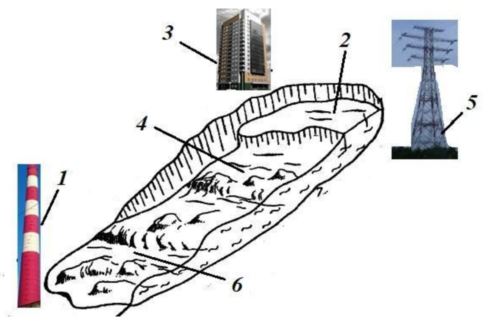

Figure 2

Landslide slope with high-rise structures installed on adjacent stable areas, equipped with mounted photographic equipment: 1–tall smokestack; 2–landslide crown; 3–multi-story building; 4–landslide body; 5–power transmission tower; 6–landslide toe

First, this approach provides the benefit of stationary and relatively low-cost monitoring of landslide progression over extended periods. During this time, periodic imaging of a specified area or surface feature on the landslide slope can be carried out automatically according to a pre-programmed schedule. Photographic equipment installed on high-rise structures can be equipped with automated systems programmed to respond to emergency developments in the landslide process. These systems are capable of sending alerts to operators via mobile or satellite communication networks. The proposed method is characterized by its relative affordability, precision, and accessibility.

Results

The use of Geographic Information System (GIS) methods is highly effective for the identification of various risks and the prediction of large-scale landslides. For the purpose of conducting efficient monitoring of large landslide-prone slopes, it is essential to apply close-range observation methods to the object under investigation. The authors propose a simplified method of photogrammetric surveying for close-range investigation of large-scale landslide processes. According to the newly developed method, instead of aerial photography using various types of aircraft, periodic imaging is carried out from elevated points on seismically stable high-rise buildings and structures located on adjacent stable areas beyond the impact zone of the landslide or landslide-prone slope.

As variations of the proposed method, the following approaches are suggested: installation of three cameras on a single high-rise structure to enable parallel monitoring of the crown, body, and toe zones of the landslide; conducting the same type of observations from three separate nearby high-rise structures; and performing observations using photographic equipment mounted on a trolley moved along and fixed to a special metal cable stretched between two stable high-rise structures located on opposite stable zones of the active landslide area. In comparison to aerial photography, the developed method is significantly simpler, more cost-effective, and enables the acquisition of more accurate information on the dynamics of landslide development, owing to the ability to conduct repeated imaging from stationary points over various time intervals.

Discussion

The proposed method offers an alternative approach to conventional landslide monitoring techniques by combining the advantages of close-range photogrammetry with the stability of fixed observation platforms. Unlike UAV-based surveys, which often require repeated field operations, trained personnel, and favorable weather conditions, the suggested system allows for long-term and continuous observations from stationary locations. This feature is particularly valuable for monitoring slow-moving landslides and detecting subtle deformations that may precede catastrophic failures.

The effectiveness of the method largely depends on the availability and spatial distribution of seismically stable high-rise structures near the landslide-prone area. In urban environments and industrial zones, where such structures are common, the proposed approach may provide a practical and economically feasible monitoring solution. In remote mountainous regions, however, the applicability of the method may be limited unless specially designed towers or support structures are constructed.

Another important advantage of the proposed system is the possibility of automating data acquisition and emergency notification procedures. Integration with mobile communication networks, satellite systems, GIS platforms, and image-processing algorithms may significantly improve the efficiency of landslide early-warning systems. Periodic photographic records obtained from identical observation points also create valuable long-term datasets that can be used for studying the temporal evolution of landslide activity and validating predictive models.

Despite these advantages, several limitations should be acknowledged. The accuracy of displacement measurements may be affected by atmospheric conditions, lighting variations, vegetation cover, and potential movements of the supporting structures themselves. Therefore, regular calibration procedures and verification of the structural stability of observation platforms are essential. Furthermore, additional research is required to quantify the accuracy of the proposed method in comparison with established monitoring techniques such as UAV photogrammetry, terrestrial laser scanning, GNSS observations, and satellite interferometry.

Future investigations should focus on the field implementation of the method in different geological settings and on the development of automated image-processing workflows capable of detecting and interpreting slope movements in near real time. Comparative studies involving multiple monitoring technologies would also contribute to identifying the most effective combinations of methods for specific landslide scenarios.

Overall, the proposed approach represents a promising, accessible, and cost-effective contribution to landslide monitoring practice. By facilitating repeated observations from fixed viewpoints, it has the potential to enhance both scientific understanding of landslide dynamics and the practical management of geohazards in vulnerable areas.

Conclusion

The present study proposes a practical and cost-effective remote method for the long-term monitoring of large-scale landslide processes using stationary photographic equipment installed on seismically stable high-rise structures located outside landslide-prone areas. The proposed method enables repeated observations from fixed viewpoints, providing more reliable information on the temporal dynamics of landslide development than conventional periodic aerial surveys.

The method offers several important advantages, including reduced operational costs, simplified implementation, continuous long-term observations, and the possibility of integrating automated image acquisition with emergency warning systems through mobile or satellite communication networks. The use of multiple observation points or several synchronized cameras further enhances monitoring efficiency and expands the applicability of the proposed approach under different geological conditions.

The developed monitoring concept represents an accessible and reliable alternative to conventional UAV-based surveys, particularly in densely populated areas and around critical engineering infrastructure where permanent monitoring is required. Although further field validation and quantitative accuracy assessment are recommended, the proposed method has considerable potential to improve landslide monitoring, early warning, and geohazard risk management through its simplicity, affordability, and suitability for long-term automated observations.

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