

AKTUELNO STANJE U OBLASTI PRAĆENJA KLIZIŠTA I DOSTUPNE TEHNOLOGIJE

Anastasija Božić¹ Đuro Krnić² Tatjana Budimirov³ Zoran Sušić⁴ Vladimir Bulatović⁵

Rezime: Savremene tehnologije, zasnovane na upotrebi pametnih senzora i koncepta IoT (*Internet of Things*), sve više se primenjuju u brojnim oblastima rada. Njihov značaj i prednosti primene su višestruke, upravljanje veštačkim objektima i izvođenje različitih zadataka je značajno olakšano njihovom primenom. Shodno tome, u ovom radu je ukratko prikazano stanje u oblasti praćenja klizišta, kao i pregled najčešće korišćenih senzora i tehnologija. Dalje, u skladu sa navedenim, koncept projekta GeoNetSee (*An AI/IoT-based sistem of GEOsensor NETWORKS for real-time monitoring of UNSTABLE TERRAIN and artificial structures*), koji se bavi primenom pametnih senzora, koncepta IoT i veštačke inteligencije u oblasti praćenja klizišta, ukratko je predstavljen. Pored toga, definisani su njegovi glavni ciljevi, očekivani rezultati i značaj primene u ovoj oblasti.

Ključne reči: klizište, monitoring, senzori, tehnologije, GeoNetSee, regulative

CURRENT STATE IN THE FIELD OF LANDSLIDE MONITORING AND AVAILABLE TECHNOLOGIES

Abstract: Modern technologies, based on the use of smart sensors and the Internet of Things (IoT) concept, are increasingly being applied in numerous areas and field of work. Their importance and application advantages are severe, the management of artificial objects and the performance of tasks is significantly facilitated. Accordingly, this paper gives the state of the art in the field of landslide monitoring, as well as an overview of the most commonly used sensors and technologies. Further, in accordance with the above, the concept of the GeoNetSee (*An AI/IoT-based system of GEOsensor NETWORKS for real-time monitoring of unStable tErrain and artificial structures*) project, which deals with the application of smart sensors, the IoT concept and artificial intelligence in the field of landslide monitoring is briefly presented. In addition, its main goals, expected results and importance in this field are defined.

Key words: landslide, monitoring, sensors, technologies, GeoNetSee, regulations

1. INTRODUCTION

A landslide is a mass movement of material, such as rock, earth or debris, down a slope. They can happen suddenly or more slowly over long periods of time. When the force of gravity acting on a slope exceeds the resisting forces of a slope, the slope will fail and a landslide occurs. External factors can lead to landslides happening, such as heavy rainfall leading to saturation of the ground, erosion of the base of a slope or changes to the material's strength through weathering. The importance of landslide monitoring is reflected in the monitoring of soil movement and obtaining information in near real time in order to create alarms and take actions with the aim of reducing damage and saving human lives. Accordingly, general tendency is to apply modern technologies and smart sensors, connected to the Internet, with the ability to send data to the monitoring center in real time, based on which decisions are made and certain actions are taken.

¹Teaching associate, BSc, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, e-mail: anastasija.bozic@uns.ac.rs:

²Teaching assistant, MSc, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, e-mail: djuro.geo@uns.ac.rs:

³Teaching assistant, MSc, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, e-mail: tatjana.kuzmic@uns.ac.rs:

⁴Full professor, PhD, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, e-mail: zsusic@uns.ac.rs:

⁵Full professor, PhD, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, e-mail: vbulat2003@uns.ac.rs:

Accordingly, the paper provides a brief overview of the state of the art in this area in the Republic of Serbia, describes the technologies used in this area and provides an overview of the GeoNetSee project, which is currently engaged in improving the landslide monitoring system in the Danube region. The project leader is the Faculty of Electrical Engineering, University of Belgrade, and a member of the project is the Faculty of Technical Sciences, University of Novi Sad. The project aims to develop a smart sensor system for landslide monitoring based on the concept of IoT and artificial intelligence. In addition, the system will include a complete solution in terms of system power supply, implementation of communication protocols, a database for storing all data, and data processing. The system will be tested at selected pilot sites in several countries of the Danube region, all with the aim of creating a validated and integrated real-time landslide monitoring system.

2. ANALYSIS OF CURRENT STATE IN THE FIELD OF LANDSLIDE MONITORING IN THE REPUBLIC OF SERBIA

The territory of the Republic of Serbia belongs to areas threatened by landslides. The emergence, development and intensification are contributed to by the complex geological structure, climatic and other characteristics of the territory, as well as inadequate use of the terrain. The prevalence of landslides in relation to the total territory of the Republic of Serbia is 20-25% [1]. In the Republic of Serbia territory in 2007, a multi-year project was started to create a cadastre of landslides and unstable slopes. During 2022, as part of the works of the Geological Survey of Serbia, a cooperation project with local self-government units was started for the purpose of identifying landslides and engineering geological research for the rehabilitation of landslides [2]. Following that, an appropriate procedure was created that includes two types of completed documentation/requests: a request to record landslides of the local self-government unit and a request to develop Terms of reference for remediation of the instability phenomenon. The working group for the preparation of the risk assessment of landslides, escarpments and erosion was formed by the Ministry of Mining and Energy in 2017. Based on the working group's work, the Landslide Hazard Map of the Republic of Serbia 1:300,000 was created, showing the positions of identified landslides. Based on an overview of the map, a high and very high hazard from landslides is present in the western part of Serbia (Krupanj, Valjevo, Užice, Novi Pazar). Also, a high hazard level was registered in the southern part of the Belgrade region and in the eastern part of Serbia (the area between Veliko Gradište and Kladovo). In the area of Vojvodina (northern part of Serbia), there is mainly a low hazard of landslides, except in the area of Fruška Gora, where there is a medium to high hazard of landslides, as well as in a smaller area in the northwestern and southeastern parts of Vojvodina.

The state invests significant resources in developing technologies to monitor natural and climatic disasters such as earthquakes, floods and landslides. For many years, the Republic of Serbia has participated in European programs such as Horizon 2020, which defines cooperation with the European Research Center and initiatives related to the strategy of smart specialization. At the level of state initiatives, there are goals for improving communication between the scientific sector and the economy, emphasising open access to scientific publications. Adhering to the strategy strengthens research and innovation capacity, which is a solution to challenges such as natural disasters and the development of science and technology infrastructure [3].

Four science and technology parks have been established in the Republic of Serbia: Belgrade, Novi Sad, Niš and Čačak. The parks provide an ecosystem of product development laboratories, mentors, investors and potential partners, knowledge exchange and all kinds of assistance for faster growth [4]. These parks have the technology and professional staff that, working together, can significantly contribute to the development of sensor technology and software solutions and the implementation of IoT and AI in the monitoring processes of dams, bridges, landslides and other artificial objects.

2.1. Examples of strategies in Serbia

Republic of Serbia has adopted several strategies in order to advance technological development and innovation and develop real-time monitoring application for disaster risk prevention:

- Strategy of scientific and technological development of the Republic of Serbia for the period from 2021 to 2025 "The Power of Knowledge" - strengthens the research and innovation system [5];
- Strategy of smart specialization in the Republic of Serbia for the period from 2020 until 2027 - supports new technologies in priority industries and food production [6];
- Strategy of Industrial policy of the Republic of Serbia from 2021 to 2030 – digital transformation and AI investment growth [7];
- Strategy for the development of education and upbringing in the Republic of Serbia until 2030 [8];
- Information society and information security development strategy in Republic of Serbia for the period from 2021 to 2026 – use of AI, IoT, blockchain, and big data [9];
- Strategy for the development of digital skills in the Republic of Serbia for the period from 2020 to 2024 – promotes digital literacy through innovative technologies [10];
- Public administration reform strategy in the Republic of Serbia for the period from 2021 to 2030– e-governance and data-driven public services [11] and
- Strategy for the development of the startup ecosystem of the Republic of Serbia for the period from 2021 until 2025 – boosts entrepreneurship, innovation, and startup support [12].

3. REVIEW OF LANDSLIDE MONITORING SENSORS

In landslide risk assessment, landslide monitoring plays a crucial role as it provides essential data on surface displacements and subsurface conditions. To achieve this, landslide monitoring involves the application of both surface and subsurface methods, integrating qualitative and quantitative approaches [13]. These methods have their own advantages and limitations, and they can be classified into three main groups: geodetic, geotechnical methods and remote sensing [14], [15].

Geodetic monitoring methods enable the observation of points displacement in area of interest. The use of these methods allows for the acquisition of data on the absolute displacements of the landslide [16], [17]. Geodetic techniques for landslide monitoring can be classified into ground-based methods (tachymetry and terrestrial laser scanning) and Global Navigation Satellite System (GNSS). Tachymetric measurement utilizes total stations in geodetic surveying. Reference points are placed in stable areas to ensure the accurate determination of absolute displacements [13], [18]. The total station is used to measure the angle and distance between the instrument and the prism, based on which 3D coordinates of the measured points are obtained [15]. Terrestrial Laser Scanning (TLS) system generates a dense point cloud with high accuracy within a local coordinate system. Accuracy decreases as the distance between the sensor and the object increases. The GNSS is a method that can provide 3D coordinate time series of landslide surface displacements at discrete points [19]. A comparative overview of the characteristics of different geodetic instruments for landslide monitoring is provided in Table 1.

Table 1 - Comparison of geodetic sensors for landslide monitoring

Technique	Typical accuracy	Advantages	Disadvantages
Total station	0.5-3 mm [14], [18], [19]	High accuracy [15], [18], [19]	Weather sensitivity, limited range, installation challenges, requires skilled workers [15], [19]
TLS	less than ± 10 mm at a range of 100 m [19]	High spatial resolution, large coverage, good accuracy and 3D capabilities, fast [20], [21]	Difficult to operate in fog or rain, expert staff required for data processing [15], [21]
GNSS	$\pm 2 - 3$ mm (horizontal), $\pm 5 - 10$ mm (vertical) [16], [17]	Deploying monitoring units in inaccessible locations, continuously monitoring with real-time data transfer, visibility among stations is not necessary, automated [14], [24]	Limited to locations with open sky, restricted to observing only a certain number of ground points, depends on differential correction data for higher accuracy, accuracy degrades under dense vegetation [24]

The application of geotechnical sensors enables the determination of the depth of the sliding surface and the rate of terrain movement by monitoring parameters such as angle, displacement, ground vibration, and pore-water pressure [25]. The primary geotechnical sensors employed for monitoring deformations are inclinometers, extensometers, piezometers and tiltmeter [14]. Inclinometers are devices that measure deformations perpendicular to the casing axis, providing a profile of horizontal subsurface displacements. They are the most commonly used devices for measuring small levels of movement along the shear zone [26]. Extensometers are geotechnical devices used to measure axial displacement between two reference points and can be installed within boreholes or on the surface of landslides [27]. With this instrument, displacement can be monitored continuously at regular time intervals [15]. Tilt-meters are highly sensitive instruments used to measure the angle between the instrument body and the plumb line in two horizontally perpendicular directions [28]. They are most suitable for monitoring landslides characterized by rotational movements, as translational movements are unlikely to be detected [13]. Piezometers measure the pore pressure of ground-water within a geological structure, thus giving an indication of the build up of stresses and strains within the rock mass [14]. A comparative overview of the characteristics of different geotechnical sensors for landslide monitoring is provided in Table 2.

Table 2 - Comparison of geotechnical instruments for landslide monitoring

Sensors	Typical accuracy	Advantages	Disadvantages
Inclinometers	± 0.02 mm over a reference length of 3 m [14], [26]	Real-time monitoring [15], [26]	High complexity, curvature can only be observed in one axis [15], [26]
Extensometers	± 0.3 mm over 30 m [14]	Continuous surveying, high accuracy, easy installation [15], [27]	Need for specialized technical personnel for the installation, sensitive to the temperature changes [14], [15], [27]
Tilt-meters	between $1 \mu\text{rad}$ ($\approx 1 \mu\text{m/m}$) and 1 nrad ($\approx 1 \text{ nm/m}$) [27]	Easy to use, simple, suitable for monitoring landslides characterized by rotational movements [13], [15], [28]	Required protection for external frames, manual measurements, translational movements are unlikely to be detected [13], [15], [28]
Piezometers	/	High reliability [15]	Unable to measure too small and very large pressure [15]

Remote sensing techniques gather information about an area or an object by measuring reflected and emitted radiation from a distance [13], [15]. Given the high cost and the requirement for expert data processing, this type of sensor is not considered essential for real-time landslide monitoring, but is rather employed primarily for post-event damage assessment. Consequently, it is not discussed in detail within this paper.

4. GEONETSEE PROJECT

The GeoNetSee system can respond to critical needs for real-time monitoring and management of geohazards such as unstable terrain and artificial structures. The overall goal is to create a robust and scalable solution that facilitates the detection, analysis, and response to geotechnical instabilities. Using sensors and cloud-based analytics, the system provides actionable insights for mitigating risks associated with landslides, structural collapses, and other terrain-related hazards. GeoNetSee's vision is to establish a reliable, scalable, transnational monitoring platform that supports informed decision-making and proactive management of geohazards in diverse environments, called the Danube Cooperation Center (DCC). The implementation of the geonetsee modular architecture is capable of integrating multiple data streams, such as GNSS, accelerometer readings and environmental parameters, into a centralized platform. The system architecture is designed to adapt to different levels of infrastructure and resources. GeoNetSee improves the efficiency of geotechnical monitoring by

combining sensors and predictive modelling based on artificial intelligence and cloud computing. The platform will also provide open APIs to facilitate integration with existing monitoring systems, such as EPOS (European Plate Observing System), and enable stakeholder collaboration. In addition, the scope of the project includes testing and validation through pilot implementations in high-risk areas in three countries: Serbia, Montenegro and Bosnia and Herzegovina, ensuring the reliability and effectiveness of the system before large-scale implementation.

The system architecture is divided into three layers: field level, communication layer and central cloud-based platform. The layers define the sensor deployment, data transmission, visualization, and analysis tools (Figure 1). The design ensures scalability, interoperability, and efficient data flow. The platform uses predictive models based on artificial intelligence. Using the described architecture and trained models, the system can provide early warnings about potential geohazards. Project participants can react proactively based on the results obtained. The platform contains user-friendly interfaces and open APIs for collaboration and data sharing across multiple organizations and regions.

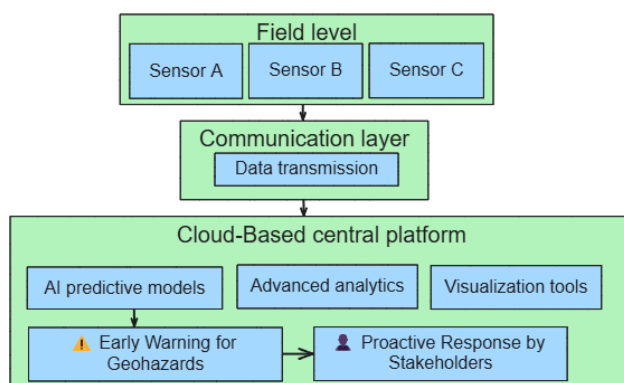


Figure 1 - The system architecture of GeoNetSee

5. CONCLUSION

The paper presents the current state of landslide monitoring - an analysis of the state in this area in the Republic of Serbia is provided in terms of the landslide territorial coverage, existing regulations in this area, as well as the ways in which the state is trying to further improve the situation in this area. After that, an overview of the sensors and technologies currently available in the field of landslide monitoring is provided. The GeoNetSee project, which is specifically concerned with improving the state of landslide monitoring in the Danube region, is also presented. In accordance with everything stated in the paper, it can be concluded that the field of landslide monitoring is suitable for additional and further development through the application of modern technologies, smart sensors, the IoT concept and artificial intelligence. This is precisely the topic of the GeoNetSee project, which makes its financing and implementation absolutely justified. The integration of these concepts and technologies into the field of landslide monitoring will significantly improve the quality of monitoring, sensor data and information will be available in near real time, which will enable the creation of alarm notifications and the taking of adequate actions in a timely manner to reduce damage and save human lives.

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6. LITERATURE

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