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AUTOMATED EXTRACTION OF TERRAIN FEATURES USING LIDAR DATA WITHIN A GIS ENVIRONMENT

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This scientific article introduces an automated methodology for detection and classification of characteristic terrain features using high-resolution laser scanning LiDAR (Lights, Detection and Ranging) data within a GIS-based analytical framework. The study aims to optimize the recognition of topographic key points and surface structures through a rigorously designed workflow that incorporates contour-driven segmentation, localized relief modeling, and closed-surface geometric analysis. The proposed approach significantly improves the precision of microrelief feature identification, while reducing subjectivity associated with manual interpretation. Consequently, the developed methodology provides a robust and efficient means of terrain characterization, demonstrating strong applicability in complex and heterogeneous mountainous environments.

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Keywords: GIS analysis, LIDAR, GIS, DEM, topography.

Introduction. Data represented as reflection vectors form a multi-level system consisting of point, linear, and surface elements. These structural elements capture the morphological characteristics of the terrain, shaped by both endogenous processes (such as tectonic and volcanic activity) and exogenous factors (including erosion and mass-movement dynamics). This interaction of these components defines the overall structural organization and geomorphological expression of the studied area. Each surface unit produces a chain of processes reflected in its spatial associations, which together determine the functional and analytical uniqueness of the examined dataset.

The objective of the present research is to develop an automated methodology for the detection and classification of terrain features based on high-accuracy geodetic and LiDAR (Lights, Detection and Ranging) data. This goal involves a methodological framework capable of reliably distinguishing and analyzing topographically significant microforms and structurally relevant landscape units [1].

Traditional topographic maps, regardless of scale, provide a generalized representation of relief, where characteristic features may be partially omitted. When

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contour intervals are small (e.g., 0.5 *m*), subtle local forms such as minor depressions, ridges, or closed basins – may fall below the generalization threshold and, therefore, remain unrecognized through standard cartographic interpretation. However, these features can be identified through automated surface analysis, using the absolute elevation values distributed across the terrain model.

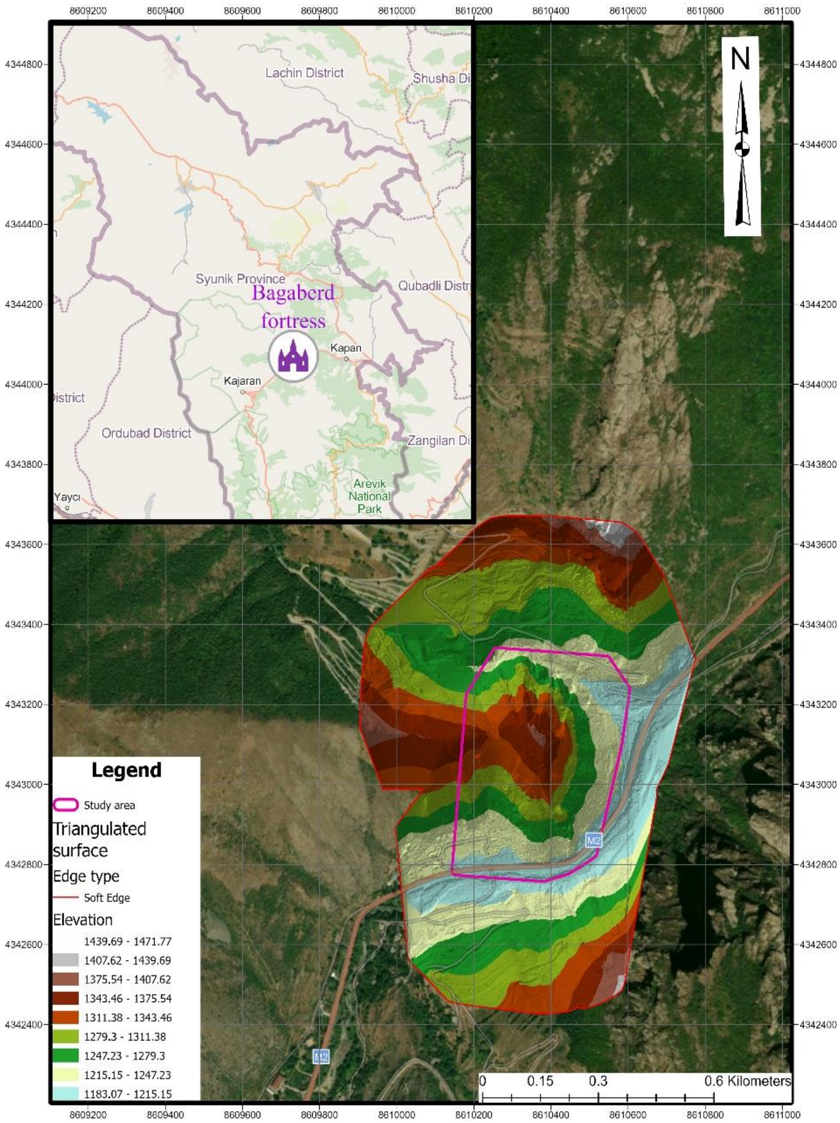


Fig. 1. Surface triangulated irregular network of Baghaberd Castle and surrounding areas.

Within this study, a closed-surface recognition algorithm was developed as part of an automated feature-extraction workflow. This methodology enables the identification of characteristic points: local maxima, minima, breaklines, and enclosed depressions – particularly in complex mountainous terrains, where manual interpretation is both time-consuming and prone to human error. The approach significantly enhances analytical reliability by reducing subjective influence and increasing processing efficiency.

Modern geodetic technologies, including three-dimensional laser scanning systems LiDAR, enable rapid acquisition of vast amounts of spatial data in the form of point clouds. Following LiDAR classification, point clouds are separated into relief components and other natural or anthropogenic features such as vegetation, buildings, or metal structures. In this research, LiDAR-based spatial data were obtained from "Centre of Geospatial Technologies" LLC as part of monitoring activities for the Kajaran community using the AU20 laser-scanning system. The acquired point cloud was used to generate triangulated irregular network (TIN) surface model (Fig. 1) [1], serving as the basis for relief element extraction and automated geomorphometric analysis.

Study Area. Within the framework of the study, the area of the Baghaberd historical and cultural fortress located in the Kajaran community of the Syunik Province of the Republic of Armenia was selected (Fig. 2). The selection of the area is justified by the need to prepare topographic maps in the processes of preservation and restoration of historical and cultural values. The studied object is a valuable cultural heritage site, which was excavated in 2024 through archaeological works and subsequently documented using laser scanning and aerial photography for the development of the fortress restoration project.

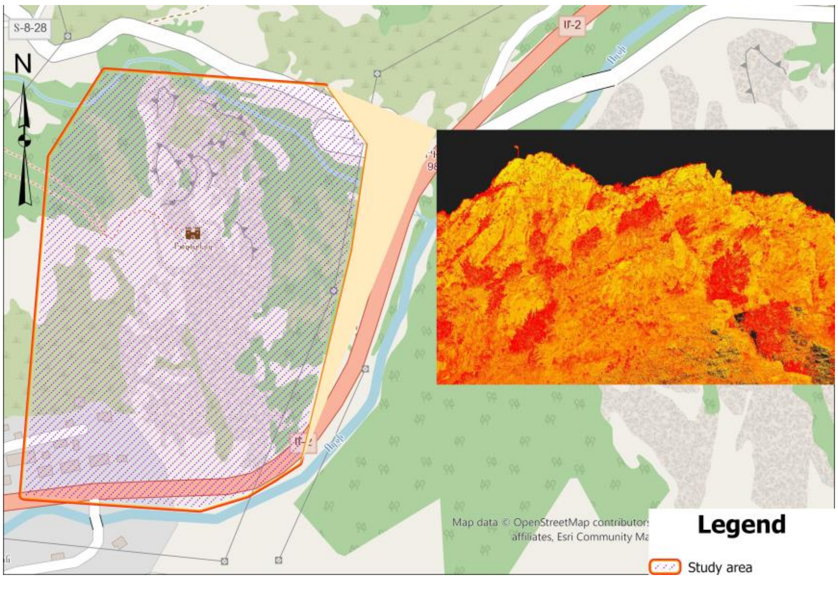


Fig. 2. Study area.

For this research, the study area attracted significant interest due to the diversity of its relief forms. The development of the research methodology is based on the concept of automated extraction of characteristic relief points in the preparation of topographic maps for complex mountainous terrains.

Materials and Method. The automated recognition of closed terrain forms and characteristic geomorphological points was implemented using advanced GIS (Geographical Information Systems) technologies, specialized software, and a structured analytical workflow. The methodology is based on the extraction of topographic macro- and micro-forms from LiDAR-derived spatial data, represented as vector and raster layers, followed by their classification through a set of geo-processing tools. This approach enables the systematic separation and interpretation of relief components with high positional accuracy. The study area (Baghaberd Castle and its surrounding terrain) was analyzed using a 0.5 *m* contour interval to ensure optimal balance between data detail and interpretability. This interval allows for the detection of local irregularities, including enclosed depressions, minor rises, and other subtle morphometric features that may not be visible in coarser datasets. Closed-contour configurations were used as diagnostic elements for identifying local maxima and minima, representing characteristic points of the terrain surface. Closed-form recognition was performed to determine the absolute elevation extremes within each enclosed contour structure, enabling the automated extraction of geomorphologically significant points. This process allowed the identification of micro-features such as small basins, hilltops, knolls, and other terrain discontinuities that play an important role in the structural interpretation of the landscape. A 0.5 *m* contour reduction interval was selected for the generation of topographic layers, as it provides an optimal ratio between surface detail and computational efficiency, supporting both visual inspection and engineering-level analysis [2] (Fig. 3). For all stages of spatial data processing, classification, and analytical modeling, ArcGIS was used as the core geospatial platform, integrating tools for LiDAR point cloud preprocessing, surface model generation TIN/DEM (Triangulated Irregular Network/Digital Elevation/Terrain Model), contour extraction, feature-class creation, closed-contour detection and elevation analysis, geomorphometric interpretation. This integrated workflow ensures a reliable and reproducible method for identifying terrain characteristics within complex mountainous environments [3].

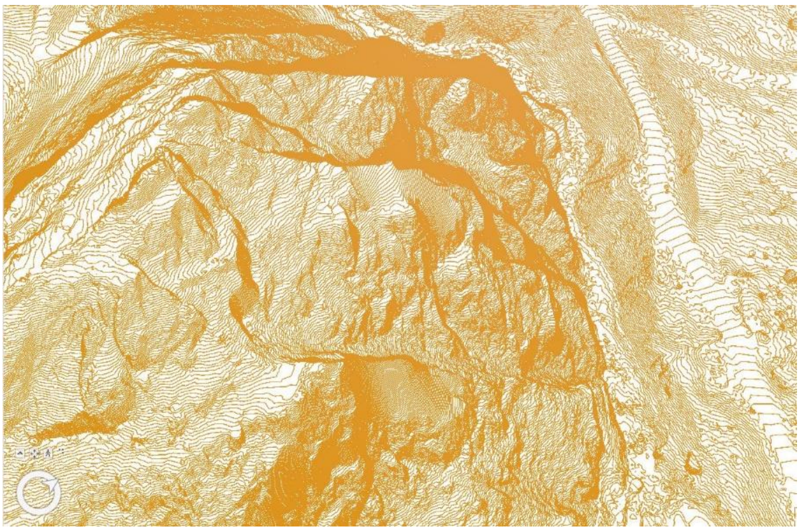


Fig. 3. Elevation contours of Baghaberd Castle and surrounding areas.

The next stage of analysis involves the geometric identification of closed contour structures, which serve as indicators of localized relief elements within the study area. This step focuses on recognizing enclosed forms that represent potential topographic features such as depressions, hilltops, or isolated microrelief units.

For this purpose, the derived contour data are transformed into polygonal representations using the "Line to Polygon Geoprocessing" tool. This transformation allows the system to detect fully enclosed shapes, enabling automated recognition of geomorphologically meaningful units for further analysis (Fig. 4) [4].

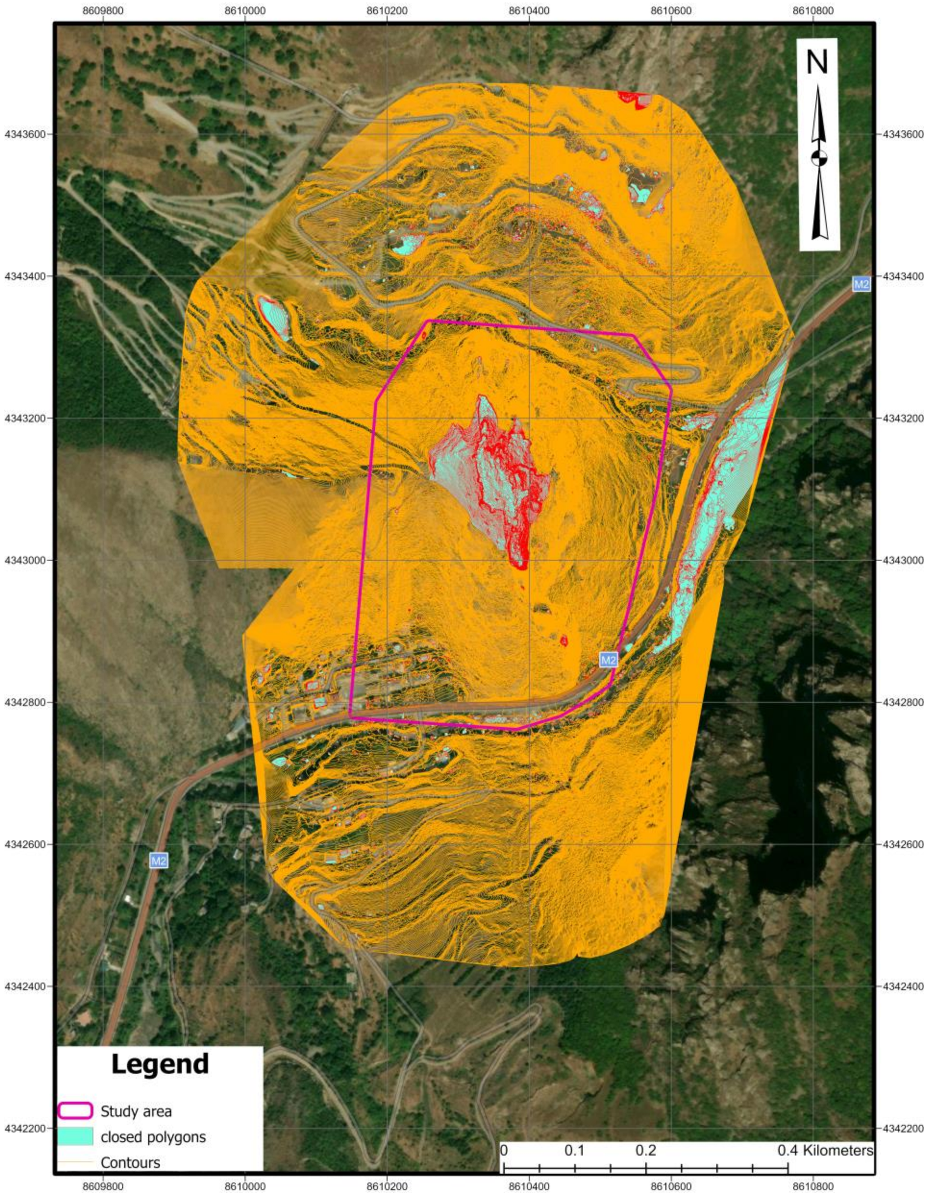
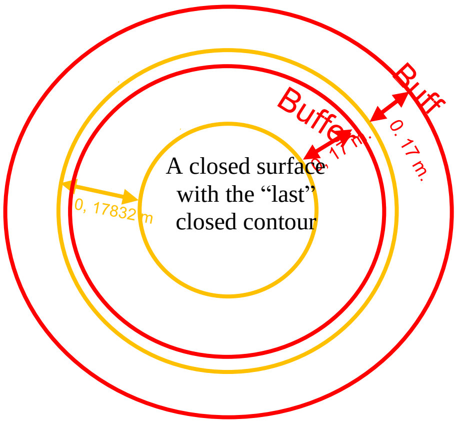


Fig. 4. Detection of closed contour features within the study area.

Following the identification of closed contour structures, the next phase focuses on *local feature extraction*, including the detection of microrelief elements and point clusters within the point cloud. Because the study area is characterized by *complex mountainous terrain*, the methodology relies on recognizing closed horizontal contours that represent significant topographic discontinuities and elevation changes typical for the Armenian landscape. The closed-contour recognition step isolates the "innermost" or final closed features, which are essential for subsequent spatial analysis. These final closed forms serve as primary indicators of localized elevation extremes and are extracted using specialized geoprocessing filters. As part of the analysis, a methodology for allocating the latest closed features was applied. *This approach integrates buffer generation around detected closed structures to identify external boundaries and assess their spatial relationships with surrounding contour-derived surfaces.* The process involves the creation of buffers around recognized features, which are then combined and compared with the contour-derived polygon surfaces to evaluate potential intersections. Buffer generation within the spatial analysis workflow is necessary for determining the minimum planned distance between extracted features. To quantify this distance, the "Generate Near Table" tool was applied, producing attribute information that characterizes the spatial proximity between each pair of target features. The minimum computed distance between features was 0.17832 *m*, indicating that although buffers derived from the external closed forms may intersect with surfaces generated from contour data, the original closed-feature geometries do not intersect spatially. This confirms the structural independence of the detected units and validates the reliability of the automated identification process (see Scheme) [5]. Local feature extraction and point cloud analysis are particularly critical for transport infrastructure planning, where accurate predictions of drainage channels, slope stability, and terrain-related impacts are required during the design stage.



Scheme. Methodology for recognizing external buffer zones.

To address these challenges, a spatial integration methodology is applied, enableng the identification of localized topographic minima and maxima across the terrain surface determining whether a selected terrain polygon exhibits a positive or negative relief form requires referencing the absolute elevation values of the terrain surface. Each object is positioned relative to the surface, and its elevation characteristics are assessed in relation to the surrounding topography. During the study, the "Point Vertex" tool was employed to extract key feature points from the terrain polygons. Although linear features are composed of multiple points, only the relevant vertex points were selected for analysis to represent localized morphometric extremes. This approach allows for precise identification of terrain characteristics critical for engineering and planning applications [6]. The identified points exhibited a *minimum separation* of up to 0.17 *m*, with the range conditioned to ensure compliance with the planned minimum distance, thereby preventing artificial linear propagation during spatial analysis. In the generated graphic buffer, peak polygons (squares) were constructed, with at least one vertex extending beyond the linear features representing the surface boundaries. To ensure the integrity of the extracted features, peaks that spatially intersected the closed-surface polygons were removed, while polygons with one or more omitted vertices were retained for further analysis. Duplicate points were eliminated using the "Delete Identical" tool, ensuring that only a single representative point remained for each identified feature. As a result of the processing workflow, point features *were generated*, *each associated with the attributes of the underlying closed polygons*. Using the "Add Surface Information" tool, *absolute elevation values were assigned to each point*, enabling a direct comparison with the terrain surface. GIS-based automated workflow for identifying local relief minima and maxima using LiDAR-derived elevation data. The methodology includes contour generation from a digital elevation model, polygon conversion of contour lines, detection of closed contour structures, and extraction of representative points along enclosed forms. The derived point features undergo spatial proximity analysis, distance computation, and duplicate removal, enabling the quantitative classification of localized depressions (negative relief forms) and elevations (positive relief forms) (Fig. 5).

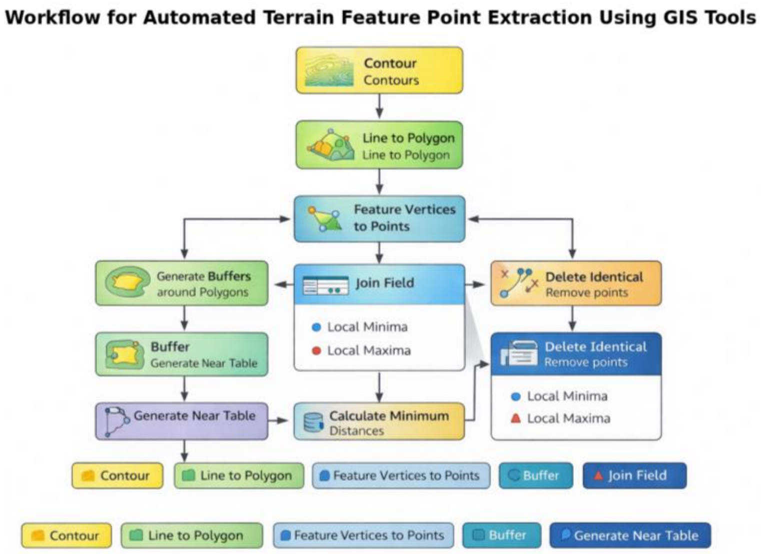


Fig. 5. Schematic representation of the proposed terrain-feature extraction methodology developed by the authors.

The resulting dataset allows the classification of points based on their elevation relative to the surrounding surface. Points with values less than 0 represent local depressions or negative microrelief features, while points with values greater than 0 correspond to local elevations or positive microrelief features. This classification provides a quantitative basis for identifying and analyzing microtopographic elements in the study area (see Table) [7].

Closed surface identification of data table attributes

ID	Shape	Contour	Polygon Z	Difference
1	Polygon	1316	1316.02417	–0.02417
2	Polygon	1296	1296.418159	–0.41816
3	Polygon	1295	1295.011841	0.988159
4	Polygon	1294	1294.10498	–0.10498
5	Polygon	1293	1293.682373	–0.68237
6	Polygon	1292	1292.377197	–0.3772
7	Polygon	1291	1291.778564	–0.77856
8	Polygon	1290	1290.616577	–0.61658
9	Polygon	1289	1289.940552	–0.94055
10	Polygon	1288	1288.540405	–0.54041
11	Polygon	1287	1287.906494	–0.90649
12	Polygon	1286	1286.011841	–0.01184
13	Polygon	1285	1285.088379	–0.08838
14	Polygon	1284	1284.095581	–0.09558
15	Polygon	1283	1283.073364	–0.07336
16	Polygon	1282	1282.050415	–0.05041
17	Polygon	1281	1281.048462	–0.04846
18	Polygon	1280	1280.065063	–0.06506
19	Polygon	1279	1279.106445	–0.10645
20	Polygon	1278	1278.176514	–0.17651

The process of identifying local irregularities is followed by the process of identifying the highest and lowest points lying on closed surfaces (Fig. 7). In the digital representation of a relief, any part of the grid of irregular triangulation, the maximum and minimum values of the absolute height of the relief are recorded at the vertices of the junction of the triangles (nodes TIN). All altimetric relief data beyond the vertices were obtained by linear interpolation. The identification of minimum and maximum values on the surfaces of local depressions and mounds separated in the framework of the study should be considered by the vertices of the triangles of the grid of irregular relief triangulation located within these surfaces, with the separation of vertices having minimum and maximum absolute height, respectively. Performing spatial data mapping (spatial connection) with depressions, hills, and vertices of an irregular triangulation grid, as a result, we generate new spatial data on the area, where each surface can correspond to the values of absolute height symbols exceeding one symbol (Fig. 6) [8].

The proposed methodology is based on the integrated application of LiDAR-derived terrain data and GIS-based spatial analysis tools. The developed workflow includes contour generation, detection of closed contour structures, extraction of enclosed terrain surfaces, evaluation of spatial relationships, and identification of local terrain minima and maxima. Following the recognition of closed contour forms, geometric analysis is performed to isolate terrain surfaces representing local relief features. Spatial analysis tools are subsequently applied to assess the positional relationships, interactions, and elevation characteristics of the extracted objects. Based on the obtained results, local positive and negative terrain forms are automatically identified and classified. The proposed workflow reduces the need for manual interpretation, accelerates spatial data processing, and provides an objective and reproducible approach for the extraction of characteristic terrain features. This is particularly important in complex mountainous environments, where conventional terrain interpretation methods are often time-consuming and highly dependent on expert judgment.

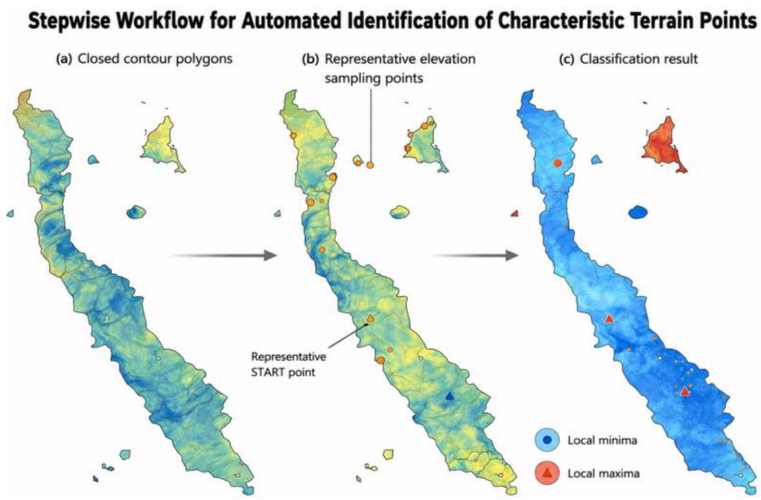


Fig. 6. Extracting of local terrain minima and maxima.

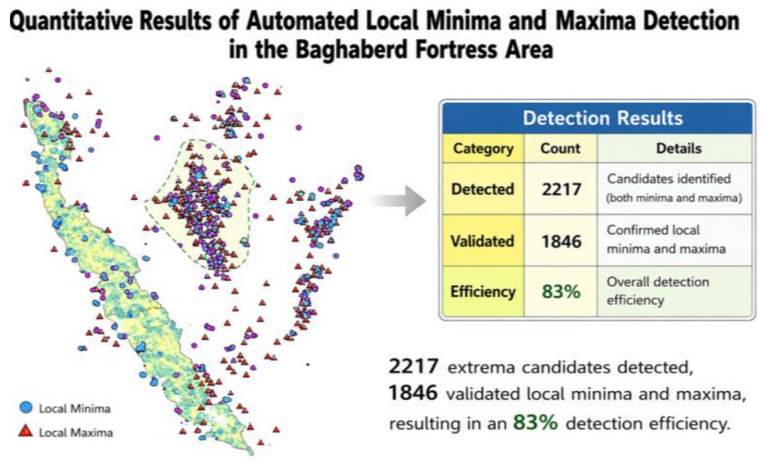


Fig. 7. Topography representation demonstrating the efficiency of the automated feature selection methodology.

Scientific Novelty. The scientific novelty of this research lies in the development of an automated methodology for the extraction of local terrain minima and maxima based on the combined analysis of closed contour geometry and high-resolution LiDAR-derived surface models. Unlike conventional approaches, which primarily rely on visual interpretation or the use of individual geomorphometric parameters derived from digital elevation models, the proposed methodology utilizes the spatial and geometric properties of closed contour structures as the principal criterion for terrain-feature identification. A distinctive aspect of the proposed approach is that the identification of local terrain extrema is performed not only through the comparison of elevation values, but also through the analysis of spatial relationships between closed contours and the surfaces derived from them. This allows for a more reliable detection of microrelief features, reduces the influence of subjective interpretation, and improves the reproducibility of terrain analysis in complex mountainous environments.

Conclusion. The developed automated methodology enables the identification and classification of local terrain micro-features without manual analytical intervention. By integrating LiDAR-derived elevation data with GIS-based geoprocessing tools, the method supports reliable analysis of complex mountainous terrain. Within the study area, a total of 2217 closed-form extrema candidates were automatically detected, of which 1846 features were validated as geomorphologically significant local relief points, corresponding to an overall detection efficiency of approximately 83%. This quantitative result demonstrates that the proposed algorithm significantly reduces subjectivity in terrain interpretation while ensuring a high level of objectivity and reproducibility in microrelief analysis, which is critical for planning and monitoring applications in mountainous environments (Fig. 7). Research has shown that open recognition based on local elements, a detection method, significantly reduces the impact of human factors, speeds up the data processing process, and improves territorial analysis accuracy.

***Recomendation*.** The proposed methodology should be further tested across a variety of terrain types to ensure its universal applicability. It is recommended to develop an algorithm capable of evaluating diverse morphological features in different landscapes, including low-lying areas, plateaus, and mountainous regions. Large-scale performance assessments should be conducted under varying spatial resolution conditions (e.g., 0.5 *m*, 1 *m*, and 2 *m* contour intervals) to determine the optimal balance between computational efficiency and feature detection accuracy for different terrain environments. Given the effectiveness of the methodology, it is advisable to integrate real-time monitoring systems for terrain changes, which can be particularly valuable for forecasting natural hazards such as landslides, rockfalls, and other geomorphological events. Finally, the results obtained from these assessments should be compared with international studies to evaluate the competitiveness and robustness of the method, providing benchmarks for performance and identifying areas for further improvement.

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Է. Մ. ՀՈՎՍԵՓՅԱՆ, Պ. Ս. ԷՖԵՆԴՅԱՆ

LiDAR ՏՎՅԱԼՆԵՐԻ ՀԻՄԱՆ ՎՐԱ ՌԵԼԻԵՖԻ ԲՆՈՐՈՇ ՏԱՐՐԵՐԻ ԱՎՏՈՄԱՏ ԱՌԱՆՁՆԱՑՈՒՄԸ ԱՏՀ ՄԻՋԱՎԱՅՐՈՒՄ

Ամփոփում

Հետազոտության շրջանակներում ուսումնասիրվել են ռելիեֆի ձևաբանական առանձնահատկությունների բացահայտման և դասակարգման գործընթացները՝ որպես հետազոտության առարկա ընտրելով բարձր ճշտության LiDAR տվյալների հիման վրա ձևավորված տեղագրական մակերևույթները: Հոդվածում առաջարկվում է ԱՏՀ (աշխարհագրական տեղեկատվական համակարգ) միջավայրում բնորոշ ռելիեֆային տարրերի ավտոմատ բաժանման և ճանաչման մեթոդաբանություն, որը հիմնված է փակ հորիզոնների վերլուծության, տեղական ռելիեֆային ձևերի մոդելավորման և եռաչափ մակերևութային տվյալների երկրաչափական վերլուծության վրա: Աշխատանքի նպատակն է ապահովել ռելիեֆի միկրոձևերի, տեղային առավելագույն և նվազագույն կետերի բացահայտումն ու գնահատումը՝ նվազեցնելով ձեռքով մեկնաբանության ազդեցությունը և բարձրացնելով տարածական վերլուծության օբյեկտիվությունը: Հետազոտության արդյունքում տարածական տվյալների մշակման և ԱՏՀ գործիքների կիրառման միջոցով ստացվել է գործնական նշանակություն ունեցող տեղեկատվություն ռելիեֆի կառուցվածքային առանձնահատկությունների վերաբերյալ, ինչը կարող է կիրառվել տեղագրական քարտեզագրման, ինժեներական նախագծման, պատմամշակութային տարածքների ուսումնասիրման և բնական գործընթացների մոնիթորինգի հետագա աշխատանքներում:

Э. М. ОВСЕПЯН, П. С. ЭФЕНДЯН

АВТОМАТИЗИРОВАННОЕ ВЫДЕЛЕНИЕ ХАРАКТЕРНЫХ ЭЛЕМЕНТОВ РЕЛЬЕФА НА ОСНОВЕ ДАННЫХ LiDAR В СРЕДЕ ГИС

Резюме

В рамках исследования были изучены процессы выявления и классификации морфологических особенностей рельефа, при этом в качестве объекта исследования были выбраны топографические поверхности, сформированные на основе высокоточных данных LiDAR. В работе предложена методология автоматизированного выделения и распознавания характерных элементов рельефа в среде ГИС (геоинформационная система), основанная на анализе замкнутых горизонталей, моделировании локальных форм рельефа и геометрическом анализе трехмерных поверхностных данных. Целью исследования является обеспечение выявления и оценки микрорельефных форм, локальных максимумов и минимумов с минимизацией влияния ручной интерпретации и повышением объективности пространственного анализа. В результате применения методов обработки пространственных данных и инструментов ГИС была получена практически значимая информация о структурных особенностях рельефа, которая может быть использована в дальнейших работах по топографическому картографированию, инженерному проектированию, исследованию историко-культурных территорий и мониторингу природных процессов.