GeoTerrace-2026-050

Geospatial Modelling of Routes for Navigation across Unfamiliar Terrain

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SUMMARY

This study investigates the effectiveness of integrating geographic information system (GIS) tools, unmanned aerial vehicle (UAV) data, and traditional navigation techniques for route modelling and movement across unfamiliar terrain. Navigation in areas with limited visibility, complex terrain, and insufficient landmarks requires reliable spatial information and preliminary analysis of the intended route. The study aims to assess whether preliminary geospatial route modelling combined with UAV-derived information can improve navigation efficiency compared with conventional map-and-compass techniques. A pilot field experiment was conducted with 17 participants who completed two comparable 3 km routes containing six control points. The conventional approach relied on a topographic map, compass, and terrain landmarks, whereas the integrated approach additionally involved preliminary GIS-based route modelling, electronic maps, and UAV imagery. Navigation effectiveness was assessed using route completion time, deviation from the planned route, number of navigation errors, requests for assistance, correctly reached control points, and independent route completion. The integrated approach reduced the average route completion time from 62 to 43 minutes and route deviation from 51 to 19 m. Navigation errors decreased from 3.6 to 1.6 per route, while correctly reached control points increased from 77% to 94%. The proportion of participants who completed the route independently increased from 62% to 88%. The results demonstrate the potential of combining GIS-based route modelling and UAV data with traditional navigation techniques to improve route planning and navigation across unfamiliar terrain.

Keywords: GIS; UAV data; Route modelling; Navigation; Unfamiliar terrain; Geospatial analysis; Electronic maps; Military operations.

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Introduction

Reliable navigation across unfamiliar terrain remains an important task in military operations, particularly under conditions of limited visibility, complex terrain, insufficient landmarks, and restricted access to satellite navigation. Traditional navigation based on topographic maps, a compass, and terrain landmarks remains essential; however, modern geographic information system (GIS) technologies, electronic maps, and unmanned aerial vehicle (UAV) data provide additional opportunities for preliminary route analysis and spatial decision-making. Their combined use enables terrain characteristics, control points, potentially difficult sections, and alternative directions of movement to be assessed before entering an unfamiliar area.

The purpose of this work is to assess the effectiveness of integrating GIS-based route modelling and UAV data with traditional navigation techniques for movement across unfamiliar terrain. The study compares a conventional map-and-compass approach with an integrated approach involving preliminary geospatial route modelling, electronic maps, and UAV-derived information. The effectiveness of both approaches is evaluated using route completion time, deviation from the planned route, navigation errors, requests for assistance, correctly reached control points, and independent route completion. The research aims to determine whether preliminary geospatial analysis can improve the efficiency and reliability of navigation while maintaining traditional navigation skills as an essential backup capability.

Method

The research was based on a field experiment comparing conventional navigation with an integrated approach combining GIS-based route modelling, UAV data, electronic maps, and traditional navigation techniques. The field evaluation involved 17 participants who completed two comparable routes, each 3 km long and containing six control points. Automatic positioning was disabled during both trials to ensure that route traversal depended on spatial analysis, map reading, landmark recognition, and compass-based navigation. The overall GIS-based route modelling and field verification workflow is presented in Figure 1.

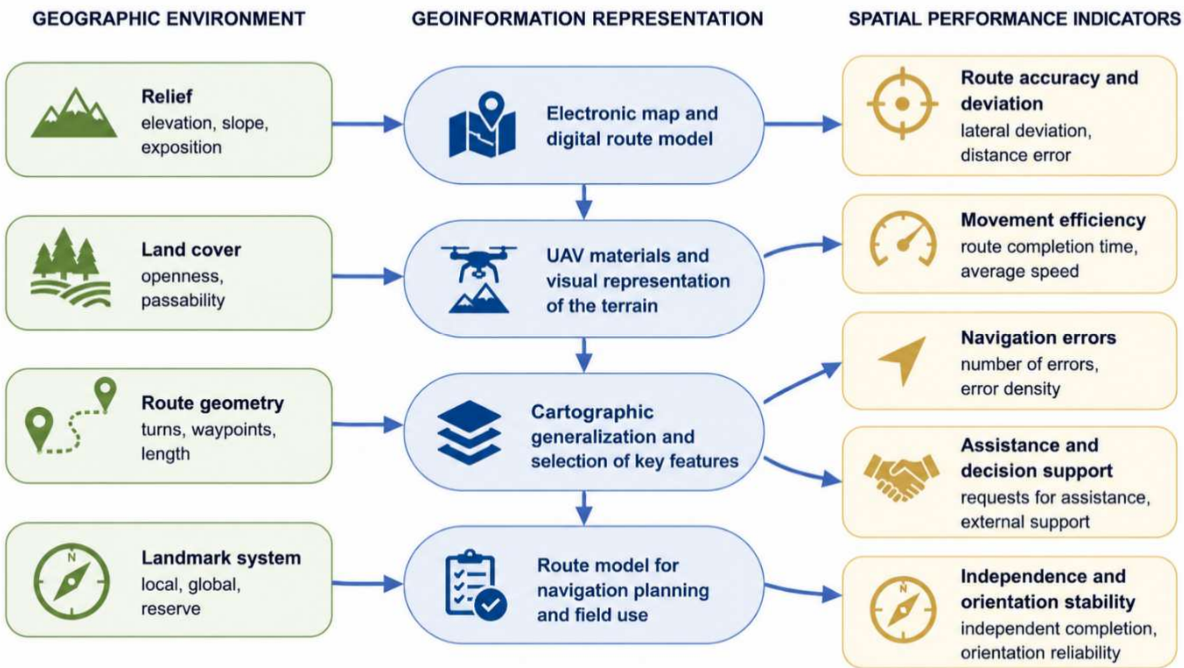

Figure 1. *GIS-based route modelling and field verification workflow*

The first stage involved baseline route traversal. Participants received standard preliminary information about the route, movement directions, and control points and navigated using an electronic map, compass, terrain landmarks, and radio communication. Movement was performed by azimuth along straight segments between successive landmarks.

The second stage involved preliminary geospatial route modelling. Before entering the terrain, the route was analysed using electronic maps and UAV imagery. Particular attention was paid to terrain characteristics, difficult route segments, control points, primary and alternative landmarks, and possible movement directions. UAV-based spatial observation was conducted at an altitude of 100–150 m using a DJI Mavic 3 integrated with FireFly and Kropyva software.

The effectiveness of both approaches was evaluated using the following indicators: route completion time, deviation from the planned route, number of navigation errors, requests for assistance, percentage of correctly reached control points, and percentage of participants who completed the route independently. Lateral deviations were recorded when a participant moved more than 10 m beyond the planned straight route segment. The comparison of these indicators made it possible to assess the practical effect of preliminary GIS-based modelling and UAV-derived spatial information on navigation efficiency across unfamiliar terrain.

Results

The proposed approach treats route traversal as a spatial process determined by the interaction between terrain characteristics, route geometry, the system of landmarks, available cartographic information, and the navigation tools used by the participant. Preliminary geospatial modelling makes it possible to analyse the intended route before entering unfamiliar terrain and to identify control points, difficult segments, primary and alternative landmarks, and possible directions of movement. The sequence of GIS-based analysis and field verification used in the study is presented in Figure 2.

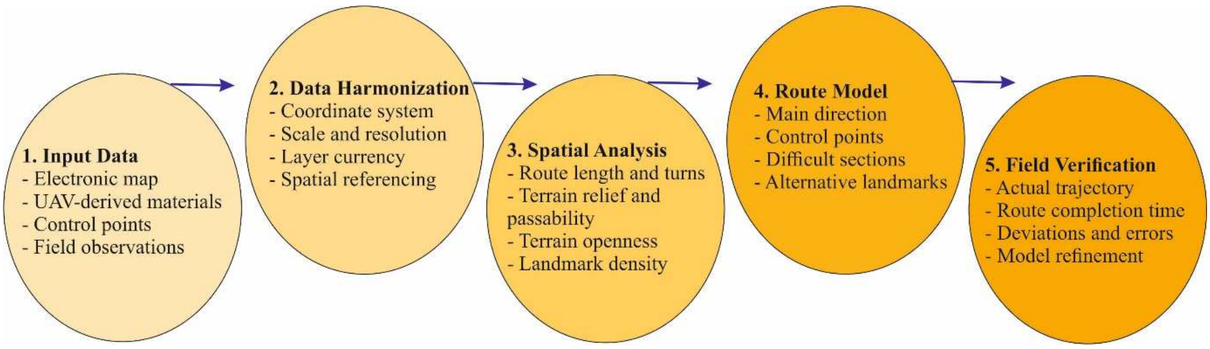

Figure 2. *GIS-based route modelling and field verification workflow*

The practical implementation of the approach was based on the sequential analysis of electronic maps and UAV-derived information. The route was divided into individual segments between successive control points, and each segment was analysed with regard to terrain features, visibility of landmarks, possible navigation difficulties, and alternative movement directions. The anonymized spatial arrangement of the planned route and its control points is illustrated in Figure 3. The map is used only to demonstrate the spatial logic of route construction and does not disclose actual coordinates.

The field evaluation demonstrated consistent improvements in all analysed navigation indicators after preliminary geospatial modelling. The average route completion time decreased from 62 to 43 min (30.6%), while the average recorded deviation greater than 10 m decreased from 51 to 19 m (62.7%). Navigation errors decreased from 3.6 to 1.6 per participant, and requests for assistance decreased from 2.6 to 1.3. The proportion of correctly reached control points increased from 77% to 94%, while independent route completion increased from 62% to 88% (Table 1).

The graphical comparison in Figure 4 shows that the largest relative improvement was observed in route deviation, followed by navigation errors and requests for assistance. The results suggest that preliminary familiarization with route geometry, terrain characteristics, and the landmark system primarily improved the ability to maintain the planned direction of movement and reduced the need for external assistance.

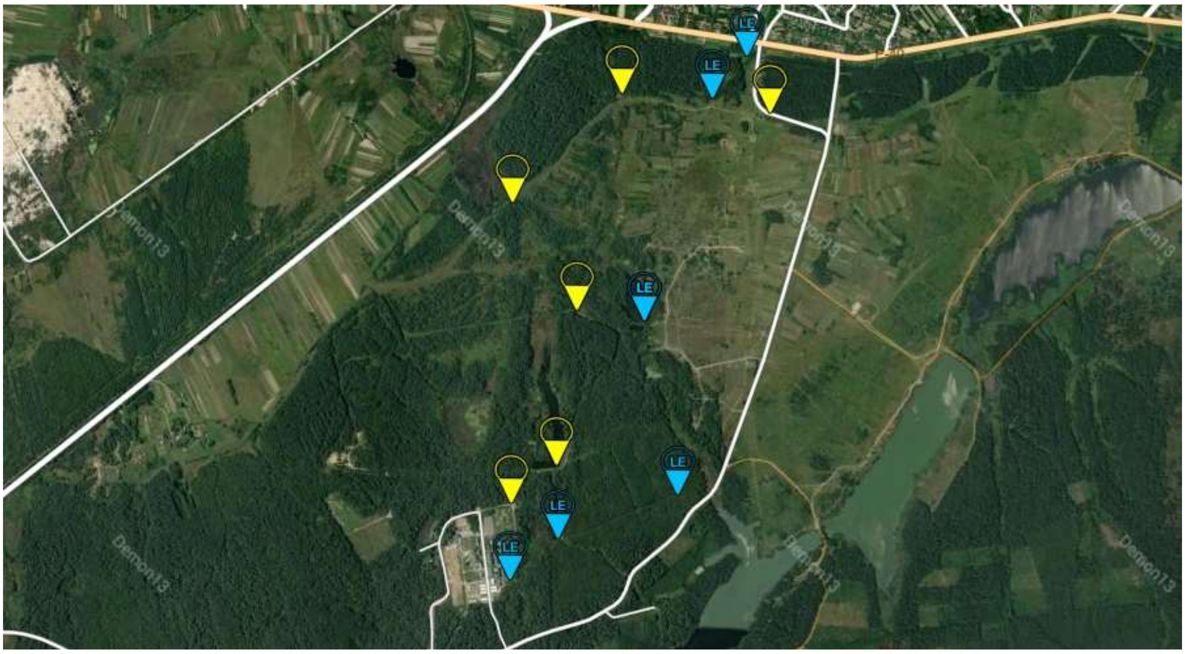

Figure 3. *Anonymized spatial representation of the planned route and control points*

Table 1. *Comparison of navigation performance indicators*

Indicator	Baseline approach	GIS-based approach	Change
Route completion time, min	62	43	-30.6%
Recorded deviation (>10 m), m	51	19	-62.7%
Navigation errors per participant	3.6	1.6	-55.6%
Requests for assistance per participant	2.6	1.3	-50.0%
Correctly reached control points, %	77	94	+17 p.p.
Independent route completion, %	62	88	+26 p.p.

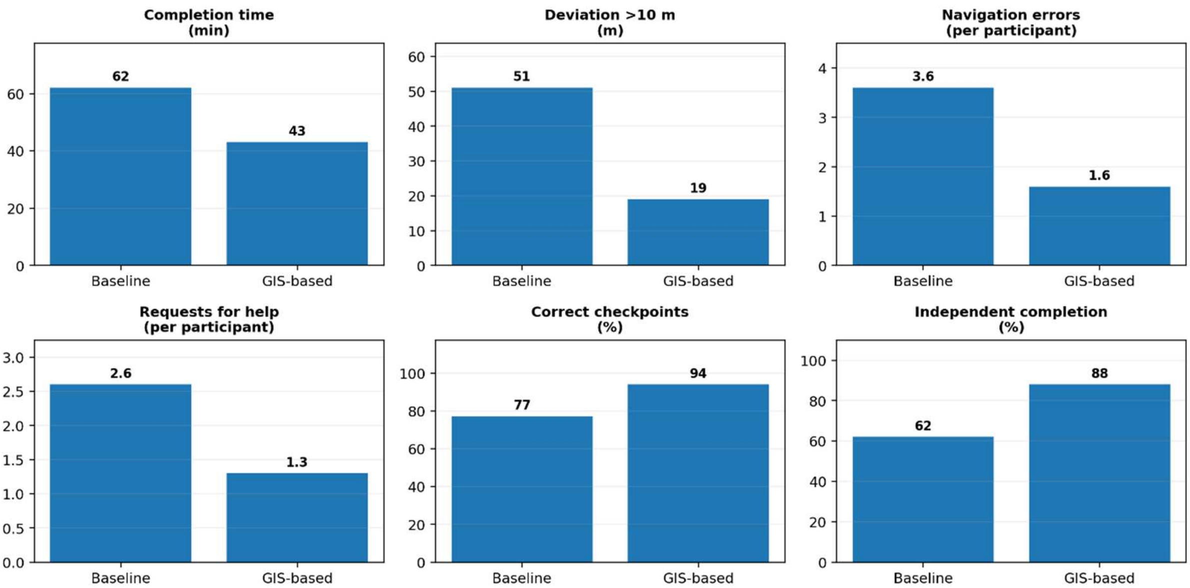

Figure 4. *Comparison of navigation performance indicators for baseline and GIS-based approaches*

Overall, the pilot results indicate that the integration of electronic maps, UAV-derived spatial information, and preliminary GIS-based route modelling can improve the efficiency and spatial reliability of movement across unfamiliar terrain. Because the available dataset contains aggregated results for a limited sample, these findings should be interpreted as preliminary and require further verification using individual trajectories and a larger number of participants.

Conclusion

This study demonstrates the effectiveness of integrating GIS-based route modelling, UAV-derived spatial information, electronic maps, and traditional navigation techniques for movement across unfamiliar terrain. The proposed approach enables preliminary analysis of terrain characteristics, route geometry, difficult sections, control points, and primary and alternative landmarks, providing a more comprehensive spatial representation of the planned route before field navigation. The field evaluation showed that preliminary geospatial modelling improved all analysed navigation performance indicators. The average route completion time decreased from 62 to 43 min, while the average recorded deviation from the planned route decreased from 51 to 19 m. The number of navigation errors was reduced from 3.6 to 1.6 per participant, and requests for assistance decreased from 2.6 to 1.3. The proportion of correctly reached control points increased from 77% to 94%, while independent route completion increased from 62% to 88%. The results confirm that the integration of GIS technologies and UAV-derived data with conventional map-and-compass navigation can improve both the efficiency and spatial reliability of route traversal. At the same time, traditional navigation techniques remain an essential component of the proposed approach, particularly when automatic positioning is unavailable or restricted. Thus, preliminary geospatial route modelling can be considered a promising tool for planning and supporting navigation across unfamiliar terrain. Further research should involve larger samples, routes with different terrain and land-cover characteristics, and individual trajectory recording to assess the statistical significance of the observed improvements and determine the influence of specific geospatial factors on navigation performance.

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