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CREATING VECTOR PROFILE GRAPH IN ARCGIS PRO BASED ON HIKING TRAIL TRACKING WITH ALLTRAILS APP

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Abstract

This paper proposes a model for creating a vector profile graph in ArcGIS Pro based on AllTrails tracking. The vector profile graph is important for route's geometric measurements and spatial analysis in GIS. The model was created in an Excel table, based on the AllTrails output Excel data, and implemented in ArcGIS Pro. A model needed to be equipped with several attributes, including the coordinates of the initial and all other points of the vector profile graph. The same Excel model was also used to create a vector profile graph based on the output of the *Stack Profile* tool. The two vector profile graphs were compared with each other. Comparison showed significant differences in elevation and surface distance between them. In general, the profile graph created using the *Stack Profile* tool shows lower elevations and shorter surface distance. This study also points out the issues of positional error that can occur when tracking routes with smartphones, and the discrepancies in creating vector profile graphs using different approaches.

Keywords: vector profile graph, hiking route, distance, elevation, AllTrails

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USTVARJANJE VEKTORSKEGA PROFILNEGA GRAFIKONA V PROGRAMSKEM ORODJU ARCGIS PRO NA OSNOVI SLEDENJA POHODNIŠKE POTI Z APLIKACIJO ALLTRAILS

Izvleček

Ta članek predlaga model za ustvarjanje vektorskega profilnega grafikona v programskem orodju ArcGIS Pro na podlagi sledenja poti z aplikacijo AllTrails. Vektorski profilni grafikon je pomemben za geometrijske meritve sledi in prostorsko analizo v GIS. Model je bil ustvarjen v Excelovi tabeli na osnovi izhodnih Excelovih podatkov sledenja poti z aplikacijo AllTrails in implementiran v programu ArcGIS Pro. Model je bilo treba opremiti z več atributi, vključno s koordinatami začetne in vseh drugih točk vektorskega profilnega grafikona. Isti Excelov model je bil uporabljen tudi za ustvarjanje vektorskega profilnega grafikona na podlagi rezultatov orodja *Stack Profile*. Oba vektorska profilna grafikona sta bila med seboj primerjana. Primerjava je pokazala pomembne razlike v nadmorski višini in trirazsežni razdalji. V splošnem prikazuje profilni grafikon, ki je bil ustvarjen s pomočjo orodja *Stack Profile*, nižje nadmorske višine in krajšo trirazsežno razdaljo. Raziskava tudi izpostavlja vprašanji pozicijske točnosti pri sledenju poti s pametnim telefonom ter neskladnosti pri ustvarjanju vektorskega profilnega grafikona z različnima pristopoma.

Ključne besede: vektorski profilni grafikon, pohodniška pot, razdalja, nadmorska višina, AllTrails

1 INTRODUCTION

Many smart phone apps have been developed to track routes along hiking trails. Such hiking apps include Topo GPS, Outdooractive, Gaia GPS, FATMAP, HiiKER, AllTrails and others. They differ in terms of cost, platforms, maps, functions and other features.

Hiking, especially mountain hiking, is defined as walking in a mountainous environment, mainly on official hiking trails, but also off official hiking trails on paths or in loose terrain (Faulhaber et al., 2017). In practice, hiking is mainly a network of marked hiking trails with accommodation and catering bases located in attractive places for tourists (Molokáč et al., 2022). Hiking trails are defined as routes of a few kilometers to several tens of kilometers making territories with rich natural, cultural or historical features or monuments accessible (Matlovičová, Klamár, Mika, 2015).

Tracking routes on hiking trails has several purposes: measuring the distance and time travelled, the elevation gain, displaying the elevation profile of the route and much more. The application that makes this possible, and which is the subject of our research is AllTrails (AllTrails, 2024). It is a fitness and travel mobile app used in outdoor recreational activities such as hiking, mountain biking, climbing and snow sports. AllTrails is accessible through a mobile app or a web browser for computers. Users can search and explore trails, as well as read reviews about these trails. Upon arriving at a trail, users are able to see information about the trail, track their activity, and add new trails to the service. There are also additional features available, such as using hiking maps in offline mode, accessing more details on the maps by adding "filters", and a 3D visualisation of the route (Fabienne, 2023). For these additional functions, users must purchase an AllTrails+ subscription service.

Some disadvantages of the AllTrails app were also identified, which are described below (Thompson, 2021). As AllTrails is a community-driven project, the data they provide is crowdsourced, which can lead to inaccurate information. Also, there is no distinction between official and unofficial trails, which can lead to people venturing into areas that are beyond their skill level. And there is a risk that a huge influx of visitors will have an impact on areas where no hiking trail has yet been created for visitors.

The AllTrails app generates an interactive profile of the tracked route. For advanced analysis in GIS, a vector profile graph of the tracked route is needed. An example of such analysis is box-counting when calculating the vertical complexity of a hiking trail. In the existing literature, it can be found that the vertical fractal dimension of roads on a vector profile graph has been studied using the box-counting method (Prah, Shortridge, 2023). To study the vertical fractal dimension of a hiking trail, its vector profile graph is needed.

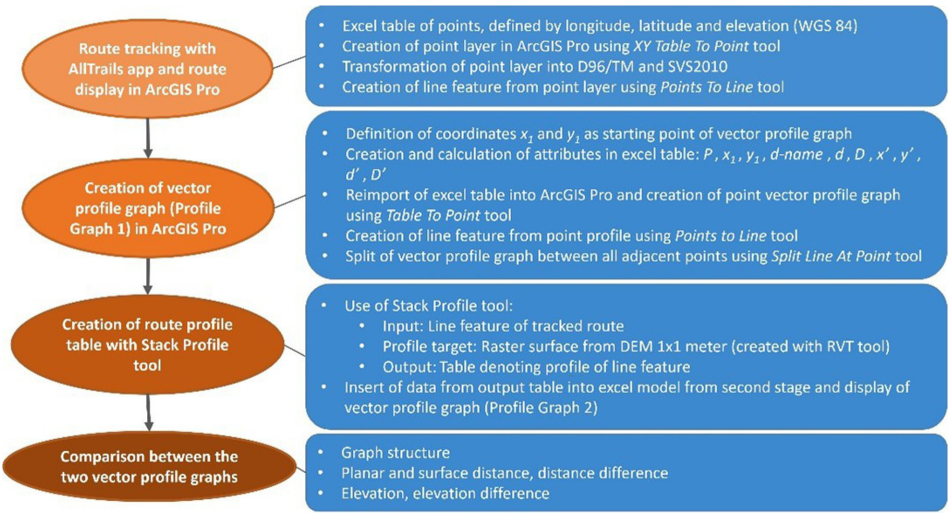
This article focuses on the process of creating a vector profile graph in ArcGIS Pro (Esri, 2024) based on the output of AllTrails. ArcGIS Pro is a full-featured professional desktop GIS application from Esri. It includes several built-in tools for creating a profile in the form of an image or other output, but does not include a built-in tool for creating a vector profile graph in the ArcGIS Pro itself. These built-in tools are as follows. The *Profile* is a ready-to-use ArcGIS Online geoprocessing service that returns elevation profile for the input line feature. The *Profile Graph* is a tabular chart that allows to visualize elevation change over a continuous distance using 3D line geometry. The *Stack Profile* tool belongs to the *3D intersection* toolset and creates a table and optional graph denoting the profile of line features over one or more multipatch, raster, Triangulated Irregular Network (TIN), or terrain surfaces. The interactive *Elevation Profile* tool generates a graph of height values along a linear path in the view. The latter elevation profile is calculated using the ground elevation surface in a map or a 3D scene. The results can be saved as an image file, geodatabase table, CSV table, or a line feature class.

None of these tools can create a vector profile graph in the ArcGIS Pro itself. Therefore, the aim of this article is to develop and present a model that allows the conversion of output data from the AllTrails app into a vector profile graph in ArcGIS Pro. Such a vector profile graph can represent an important basis for advanced GIS analysis of a tracked route.

2 RESEARCH DESIGN

As this paper is primarily methodological, in this section we focus on presenting the research design, which was organized into four general, progressive stages (orange ellipses) and associated analysis details (blue rectangles) (Figure 1).

Figure 1: Research design, organized into four progressive stages.



Tracking the hiking route with the AllTrails app generates outputs in different formats such as gpx, js, kml, sql, xml, csv, xls and others. For our research, the most important was xls, as the Excel table contained the data about longitude, latitude and elevation of each point of the tracked route. The values were in WGS 84, i.e. longitude and latitude in decimal degrees and elevation in meters. The latter was rounded to whole numbers. Based on that table, a point vector layer was created and displayed in ArcGIS Pro, using the tool *XY Table to Point* (XY Table To Point, 2024). The point layer was then transformed into Slovene coordinate system D96/TM in order to enable planar geometric measurements.

Above method allowed us to create a map of a tracked route in ArcGIS Pro. As mentioned in introduction section, ArcGIS Pro contains several built-in tools to create a profile graph of a 3D line with different result options, but not a vector profile graph in ArcGIS Pro itself. Since ArcGIS Pro does not contain a built-in tool to create a vector profile graph from a point layer that already has defined elevation values, we developed our procedure. The procedure is presented in detail in section 3. The result of that procedure was a vector profile graph of a tracked route, i.e. the Profile Graph 1.

In our case study we focused geographically on the Pohorje Hills, where we performed a route tracking with an AllTrails app in January 2024. The route runs from Rogla to the Lovrenc Lakes (Lovrenška jezera) and back. The return part of the route largely follows different path than the approach part and overlaps only partially with the approach part (Figure 2). Main disadvantage, irrelevant in our opinion, is that there are no big and impressive differences in elevation along the whole route, as the route mainly follows the top of the Pohorje Hills.

To compare two different approaches to creating a vector profile graph, the linear feature representing the tracked route from AllTrails was then overlaid on a raster

Figure 2: Hiking route (red line) from Rogla (bottom of image) to the Lovrenc Lakes (top of image) and back displayed in Google Earth Pro browser. The route was tracked by the AllTrails app in January 2024 and displayed in Google Earth Pro based on a KML file. The snow cover is not realistic for the tracking period.

surface using the *Stack Profile* tool in ArcGIS Pro (Stack Profile, 2024). The raster surface was created from the Digital Elevation Model (DEM) data of 1-meter horizontal resolution (Ministrstvo za okolje in prostor, 2015) using the *Relief Visualization Toolbox* (RVT) (Kokalj et al., 2013). The 1 m × 1 m DEM grid was based on the Laser Scanning of Slovenia project (Mongus et al., 2013). Inserting the data from the output table from the *Stack Profile* procedure into the aforementioned Excel model for creating a vector profile graph resulted in a Profile Graph 2.

Finally, we compared the two vector profile graphs with respect to a set of parameters. These parameters relate to the structure of the graph, the planar and surface distance, the distance difference, and the elevation difference.

3 PROCEDURE FOR CREATING VECTOR PROFILE GRAPH IN ARCGIS PRO BASED ON ALLTRAILS HIKING ROUTE DATA

3.1 Map of hiking route in ArcGIS Pro

First, the AllTrails mobile app was used to track the hiking route. The result of the tracking was a record of the route in various formats and was also available in the AllTrails web browser. One of the results was an Excel table with a record of points defined by longitude, latitude and elevation, the latter in whole numbers. The numeric values in the Excel table were written in the general format, which is the default number format that Excel applies when a number is entered (Available Number Formats, 2024). An excerpt from the Excel table for the first twelve points is presented in Table 1. The coordinates are given in WGS 84 and are written in decimal degrees, while the elevation is given in meters. For our example route from Rogla to Lovrenška Lakes and back, the total number of points was 2701. To display points on an ArcGIS Pro map (Figure 3) using the *XY Table To Point* tool, we first had to convert the coordinate values into a number format in an Excel table.

As the WGS 84 coordinate system does not allow planar geometric measurements, the route point data had to be converted to the Slovenian D96/TM coordinate system and the SVS2010 vertical coordinate system. For that purpose, a new map was created in ArcGIS Pro in the D96/TM and SVS2010 coordinate systems. Three additional columns were added in the route points table, namely x, y and z. Using the *Calculate Geometry* function, all three columns were converted to the aforementioned coordinate system (Table 2). Using the *XY Table To Point* tool, a new point layer was created and displayed according to the x, y and z values.

Table 1: Excerpt from the Excel output table of the AllTrails tracking from Rogla to Lovrenc Lakes and back. The figure represents the records for the first twelve of the 2701 points. Each point is defined by longitude, latitude and elevation. The coordinate system is WGS 84. Latitude and longitude are shown in decimal degrees, while elevation is given in whole numbers in meters.

Latitude	Longitude	Elevation
46.45155000	15.32847000	1466
46.45155000	15.32853000	1466
46.45154000	15.32857000	1467
46.45153000	15.32860000	1467
46.45151000	15.32864000	1467
46.45150000	15.32867000	1467
46.45148000	15.32871000	1467
46.45147000	15.32876000	1467
46.45145000	15.32881000	1467
46.45144000	15.32885000	1467
46.45144000	15.32890000	1467

Figure 3: An excerpt of the tracked route in ArcGIS Pro on the way to the Lovrenc Lakes. The base map is World Imagery and is one of the in-built base map options in ArcGIS Pro.

Table 2: The first twelve records from the table in ArcGIS Pro, where the x, y and z coordinates of the points were calculated in the Slovenian coordinate system D96/TM and the SVS2010 vertical coordinate system using the Calculate Geometry function.

Latitude	Longitude	Elevation	x	y	z
46.45155	15.32847	1466	525234.066032	145816.093749	1466
46.45155	15.32853	1466	525238.675413	145816.112904	1466
46.45154	15.32857	1467	525241.752953	145815.014186	1467
46.45153	15.32860	1467	525244.062264	145813.912276	1467
46.45151	15.32864	1467	525247.144427	145811.702072	1467
46.45150	15.32867	1467	525249.453740	145810.600165	1467
46.45148	15.32871	1467	525252.535906	145808.389963	1467
46.45147	15.32876	1467	525256.381684	145807.294447	1467
46.45145	15.32881	1467	525260.232086	145805.087445	1467
46.45144	15.32885	1467	525263.309636	145803.988738	1467
46.45144	15.32890	1467	525267.150794	145804.004719	1467
46.45145	15.32894	1468	525270.219095	145805.128994	1468

3.2 Creating vector profile graph in ArcGIS Pro

To begin with the creation of the vector profile graph, a new map in the D96/TM coordinate system was created in ArcGIS Pro. The coordinate values x_1 and y_1, representing the starting point of the vector profile graph, were defined. They were defined by the x and y coordinates of the first route point, i.e. x_1 and y_1. They represent the coordinates for determining the coordinates of all other points of the vector profile graph. The specific location of these two initial coordinates on the map is irrelevant as they represent the starting point of the vector profile graph. In our case, the coordinates x_1 and y_1 represent the starting point of our route at the Rogla car park. Therefore, our initial coordinates were:

$$(x_1, y_1) = (525234.07, 145816.09)$$

In the next step, we exported the attribute table of a route point layer as a dbf format and converted it to xlsx format. We created the following new attributes in that table (Table 3): P, x_1, y_1, *d-name*, d, D, x', y', d' and D', where:

P is the name of the route's points, for example: P_1, P_2, P_3

x_1 and y_1 are the coordinates of the initial point of the route's vector profile graph

d-name is the name of a segment representing the planar distance between two adjacent points P_n for example: d_1, d_2, d_3

d represents the planar distance between two adjacent points P_n and is defined by the Pythagorean theorem as follows

$$d_n = \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2}$$

D is the sum of all d_n up to a point P_n and is defined as $D_n = x_1 + \sum_{i=1}^{n} d_{i-1}$

x' is the coordinate of the vector profile graph's points on the horizontal axis and is defined as $x_n' = x_1 + D_n$

y' is the coordinate of the vector profile graph's points on the vertical axis and therefore represents the elevation; it is defined as $y_n' = y_1 + z_n$

z is the elevation of the points P_n

d' is the surface (three-dimensional) distance between two adjacent points P_n

D' is the surface distance from the initial point of the profile (x_1, y_1) to any point P_n of the profile.

The Excel table thus completed was then re-imported into ArcGIS Pro and the *XY Table To Point* tool was used to create a point profile graph according to the *x'* and *y'* coordinates. The number of points P_n in the graph was 2701. Using the *Points To Line* tool (Points To Line, 2024), a single polyline feature was created from these points, representing the vector profile graph. Using the *Split Line At Point* tool (Split Line At Point, 2024), a polyline was split into individual line features between all adjacent points. The result was 2700-line features *d'* (Figure 4). The distance of the line features *d'* is the surface- or three-dimensional distance between all adjacent points P_n. Their sum represents the route's total surface distance. In order to cross-check the values representing the surface distance d_n' and D_n' from ArcGIS Pro, these variables were also calculated in an Excel table using the Pythagorean theorem:

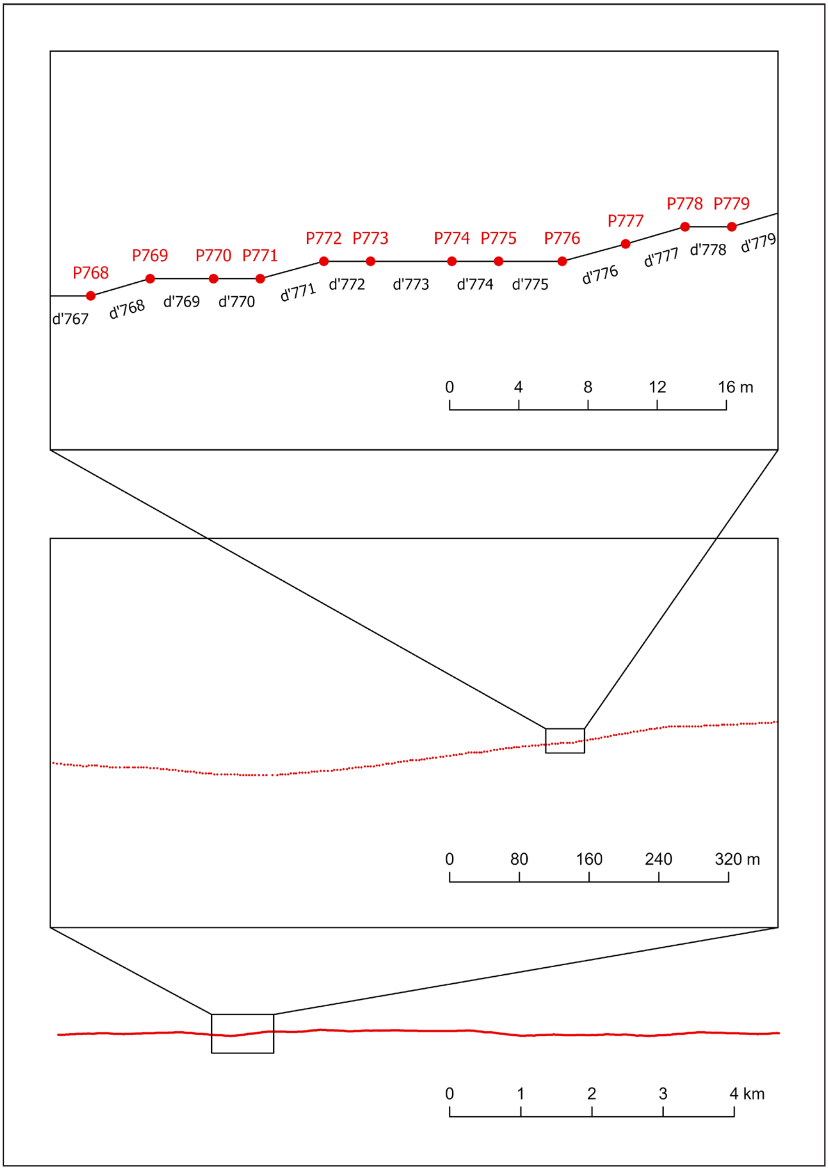
$$d_n' = \sqrt{(d_n)^2 + (z_{n+1} - z_n)^2}$$

The attribute *D'* in the Excel table represents the surface distance from the initial point of the profile (x_1, y_1) to any point P_n of the profile (Table 3). The calculations for d_n' and D_n' in ArcGIS Pro and in the Excel table match perfectly.

Table 3: Excerpt from Excel table for the first twelve points P_n with the attributes needed to draw the vector profile graph in ArcGIS Pro, plus two additional attributes d′ and D′. The latter two were used to cross-check the surface distance values calculated in ArcGIS Pro with the Excel results.

P	*x*	*y*	*z*	x_1	y_1	*d-name*	*d*	*D*	*x'*	*y'*	*d'*	*D'*
P1	525234.07	145816.09	1466	525234.07	145816.09	d0	0.0000	0.0000	525234.07	147282.09	0.0000	0.0000
P2	525238.68	145816.11	1466	525234.07	145816.09	d1	4.6094	4.6094	525238.68	147282.09	4.6094	4.6094
P3	525241.75	145815.01	1467	525234.07	145816.09	d2	3.2678	7.8772	525241.94	147283.09	3.4174	8.0268
P4	525244.06	145813.91	1467	525234.07	145816.09	d3	2.5587	10.4359	525244.50	147283.09	2.5587	10.5855
P5	525247.14	145811.70	1467	525234.07	145816.09	d4	3.7927	14.2287	525248.29	147283.09	3.7927	14.3782
P6	525249.45	145810.60	1467	525234.07	145816.09	d5	2.5587	16.7874	525250.85	147283.09	2.5587	16.9370
P7	525252.54	145808.39	1467	525234.07	145816.09	d6	3.7927	20.5801	525254.65	147283.09	3.7927	20.7297
P8	525256.38	145807.29	1467	525234.07	145816.09	d7	3.9988	24.5789	525258.64	147283.09	3.9988	24.7285
P9	525260.23	145805.09	1467	525234.07	145816.09	d8	4.4381	29.0170	525263.08	147283.09	4.4381	29.1665
P10	525263.31	145803.99	1467	525234.07	145816.09	d9	3.2678	32.2848	525266.35	147283.09	3.2678	32.4343
P11	525267.15	145804.00	1467	525234.07	145816.09	d10	3.8412	36.1259	525270.19	147283.09	3.8412	36.2755
P12	525270.22	145805.13	1468	525234.07	145816.09	d11	3.2678	39.3937	525273.46	147284.09	3.4174	39.6929

Figure 4: Vector profile graph of the tracked route from Rogla to the Lovrenc Lakes and back. The full profile is presented at the bottom of the figure. In the middle of the figure, a section of the profile of just over 830 meters (planar distance) is presented. The red points forming the profile are clearly identifiable. In the upper part of the figure, a profile section of just over 42 meters in length (planar distance) is presented. The numbered points (P_n) are linked to the numbered segments (d_n'), which are characterized by their surface distance.



4 CREATING ROUTE PROFILE TABLE WITH STACK PROFILE TOOL

The line feature representing a tracked route from AllTrails was overlaid on a raster surface using the *Stack Profile* tool in ArcGIS Pro. The raster surface was created from a DEM with a horizontal resolution of 1 m, as presented above. The result was a table of 11,574 segments representing a profile graph. The first fifteen segments are presented in Table 4. Each segment is defined by the distance to the first vertex in the profile segment in meters, i.e. FIRST_DIST. Each segment is also defined by the elevation of the first vertex in the profile segment in meters, i.e. FIRST_Z. The LINE_ID column indicates that the input data was a single line of the tracked route, and the SRC_TYPE column indicates that the data type of the profile source was a raster surface.

The data from the output table of the Stack Profile procedure was then used as an input data for our Excel model, presented in Section 3.2. The final result was a second vector profile graph, i.e. Profile Graph 2 of the same tracked route on the Pohorje hills. The two vector profile graphs were compared in the next section.

Table 4: Excerpt from a table resulting from the Stack Profile tool. The first fifteen records, i.e. profile segments, are presented in the table.

OBJECT_ID	FIRST_DIST	FIRST_Z	LINE_ID	SRC_TYPE
1	0.00000000000	1462.5828	1	Surface
2	0.92190783205	1462.6482	1	Surface
3	1.84381608076	1462.7190	1	Surface
4	2.76562391383	1462.7490	1	Surface
5	3.68753216255	1462.7744	1	Surface
6	4.60943999459	1462.8080	1	Surface
7	5.42640783358	1462.8635	1	Surface
8	6.24334205396	1462.9161	1	Surface
9	7.06030989294	1462.9507	1	Surface
10	7.87727773130	1462.9972	1	Surface
11	8.73021461718	1463.0348	1	Surface
12	9.58306125060	1463.0693	1	Surface
13	10.43599813560	1463.0846	1	Surface
14	11.38411548050	1463.1349	1	Surface
15	12.33237236590	1463.2197	1	Surface

5 COMPARISON BETWEEN THE TWO VECTOR PROFILE GRAPHS

In this section, we compare the two vector profile graphs from the above sections. The first graph (Profile Graph 1) was created from the results of route tracking with the AllTrails app, as presented in sections 3.1 and 3.2. For the second graph (Profile Graph 2), the AllTrails tracking result was used with the *Stack Profile* tool, as presented in section 4.

The two profile graphs were compared using a set of parameters, as shown in Table 5. Profile Graph 2 is more densely defined by points than Profile Graph 1. Therefore, the average planar distance between adjacent points in Profile Graph 2 is 0.88 meters, compared to 3.75 meters in Profile Graph 1. The number of segments is correspondingly high, given the number of points that make up the graph. The planar distance of the two graphs is the same, i.e. 10,128.33 meters, as they start and end at the same points. However, the graphs differ in their surface distance. This is 23.84 meters greater in the Profile Graph 1, where it is 10,209.08 meters. The difference between the surface distance and the planar distance is 80.75 meters in Profile Graph 1 and 56.91 meters in Profile Graph 2. Given the considerable total length of the profile and the density of the points that make up the profile, there cannot be much difference when comparing the average planar distance and the average surface distance between two adjacent points. In the case of the Profile Graph 2, this is not noticeable when rounding the values to two decimal places. It is only insignificant in the case of the Profile Graph 1, which consists of slightly longer segments. The difference between the average planar distance and the average surface distance is therefore 0.03 meters.

Comparison of the two profiles shows a difference in elevation (Table 5). The elevation values in the Profile Graph 1 are presented in rounded values as this was the result of route tracking. In contrast, the elevation values in the Profile Graph 2 are presented in decimal numbers, as they are the result of overlaying the tracked route feature layer over the DEM layer. The Profile Graph 2 has a 15.24 m lower minimum elevation than the Profile Graph 1. The maximum elevation in the Profile Graph 1 is 4.2 m higher than in the Profile Graph 2. Therefore, the difference between the minimum and maximum elevation is larger for Profile Graph 2, 96.04 m compared to 85 m for the Profile Graph 1.

Table 5: Comparison between the two vector profile graphs – Profile Graph 1 and Profile Graph 2.

	Profile Graph 1	Profile Graph 2
Number of points	2701	11574
Average planar distance between adjacent points	3.75 m	0.88 m
Number of segments	2700	11573
Planar distance	10,128.33 m	10,128.33 m
Surface distance	10,209.08 m	10,185.24 m
Difference between surface and planar distance	80.75 m	56.91 m
Average surface distance of a segment	3.78 m	0.88 m
Minimum elevation	1450 m	1434.76 m
Maximum elevation	1535 m	1530.8 m
Difference between lowest and highest elevation	85 m	96.04 m

The Figure 5 shows the two profile graphs. The Profile Graph 1 is marked with red dots and Profile Graph 2 with green dots. In the lowest part of Figure 5, both profiles are shown in full scale. It can be noticed that the two profiles overlap only in general. In the middle of Figure 5 there is a section of just over 800 m of horizontal length. It is obvious that the two profiles are distinct and that the Profile Graph 1 is above the Profile Graph 2. In the upper part of Figure 5 there is a section of just over 40 m of horizontal length. It can be noticed, that the two profiles, of which Profile Graph 2 has a higher density of points, differ in elevation.

To present the section of the two profile graphs where the elevation difference between them is the largest, 20.15 m, Figure 6 was created. The elevation difference of 20.15 m is the difference between the point of the tracked route marked as *P1825* on the Profile Graph 1 and the elevation on the Profile Graph 2. It was calculated using the *Extract Values To Points* tool in ArcGIS Pro. The tool extracted the values of the elevation raster cells based on the set of point features from the tracked route and recorded the values in the attribute table of the output feature class. The raster surface used was the same as for the *Stack Profile* tool, i.e. created from a DEM with a horizontal resolution of 1 m. The difference in elevation was also manually verified by measuring between the two profile graphs on the ArcGIS Pro map, namely the measurement from point P_{1825} in the Profile Graph 1 and the vertical distance from that point to the Profile Graph 2. The equality of the two measurements confirms the accuracy of the model for creating the vector profile graph presented in section 3.2.

Figure 5: Presentation and comparison of the two profile graphs. The Profile Graph 1 is presented in red and the Profile Graph 2 in green. Both full profiles are shown at the bottom of the figure. The middle of the figure shows a section with a horizontal distance of just over 800 meters. The upper part of the figure shows a section with a horizontal distance of just over 40 meters. The numbered points (P_n) and numbered segments (d_n') are labeled.

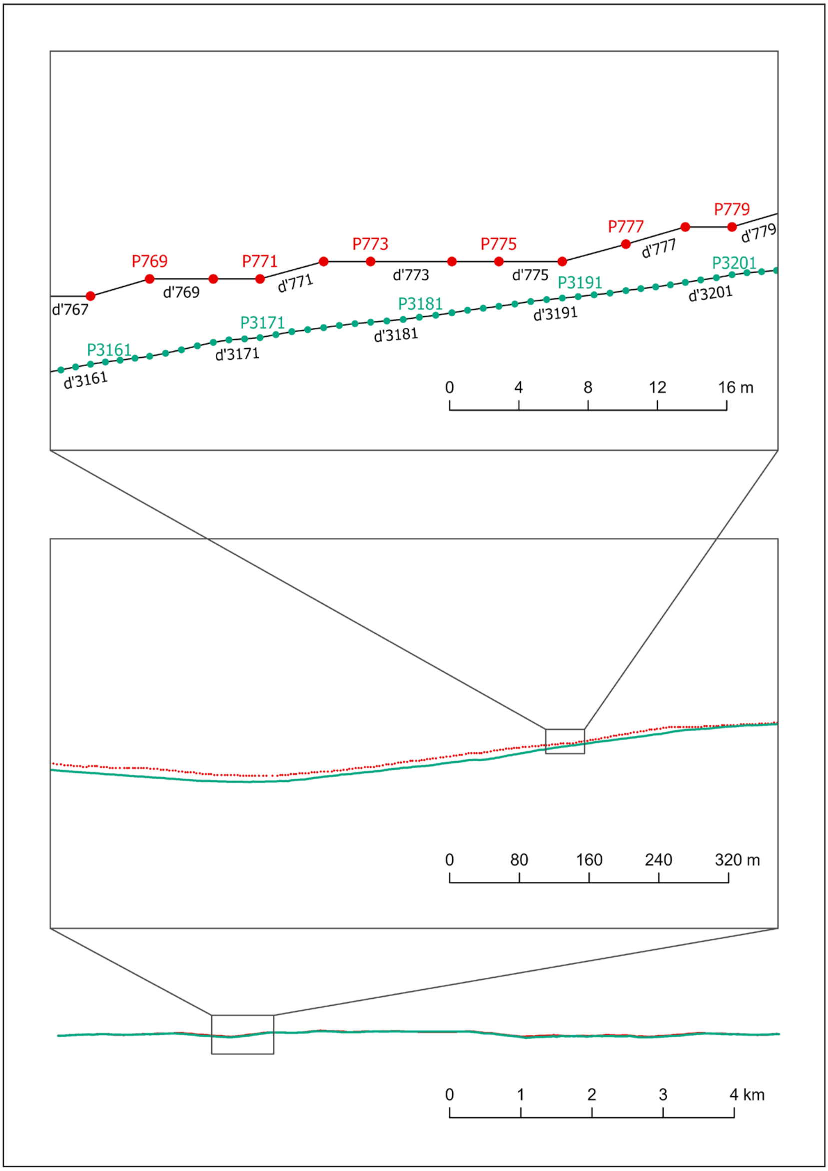
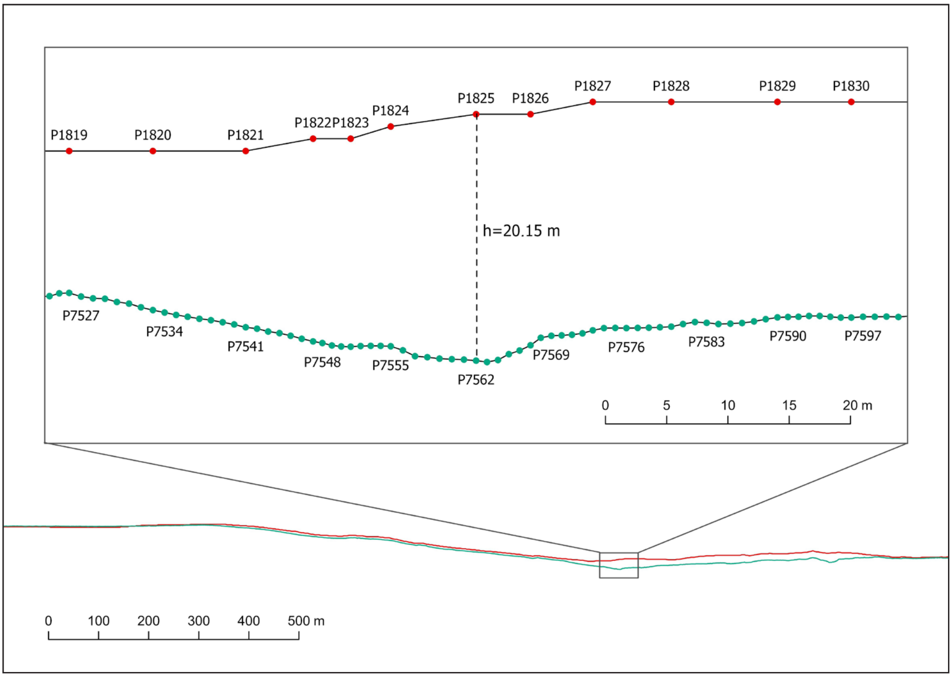


Figure 6: The section of the two profile graphs where the elevation difference between them is the largest. The red points form the Profile Graph 1 and the green points form the Profile Graph 2. The numbered points (P_n) of the two profile graphs are labeled. The maximum elevation difference between a point on the Profile Graph 1 and the vertical distance to the Profile Graph 2 is for point P_{1825} and is 20.15 m.



6 DISCUSSION AND CONCLUSION

The model presented in this study allowed us to create a vector profile graph in ArcGIS Pro based on the AllTrails app tracking data. The model was also used in combination with the *Stack Profile* tool of ArcGIS Pro to create and present a DEM-based vector profile graph of the tracked route. The two vector profile graphs were compared on a range of parameters, including surface distance and elevation difference. The model is important for advanced GIS analysis of a hiking route.

When comparing the two profile graphs, we did not expect such significant difference in elevation between one graph and the other. The result showed that the AllTrails app generally assigned higher elevations to the tracked route than the *Stack Profile* tool, at which the track was overlaid over a DEM. One reason might be carrying the phone in the backpack during the tracking, i.e. more than one meter above the ground. The snow cover raised the phone even further above the ground. The thickness of the snow cover was not measured, but it varied along the route. In general, it was thicker in shady, forested areas than in open, sunny areas. The snow cover also made it difficult to follow the exact trail in some sections.

A limitation encountered during the research was the horizontal offset of the track from the existing trail followed in certain sections. An example can be noticed in lower half of Figure 3, where the track is overlaid over the World Imagery cartographic base in ArcGIS Pro. The phenomenon indicates a discrepancy between the two types of data and addresses the question about the positional accuracy of the track on one side and the cartographic base on another side. The following limitation comes from the use of the *Stack Profile* tool. Namely, the track overlaid over the DEM was horizontally offset from the trail route discerned on the DEM in some sections. That was particularly noticeable in the eastern part of the trail loop (for orientation see upper half of Figure 2), where the terrain is steeper, in some places rugged, and the surface is covered by forest. In that area, the maximum elevation difference of 20.15 meters between the two profiles occurred. The phenomenon addresses the questions about the accuracy of tracking a hiking trail by phone, especially in steeper, forested terrain, as well as the need for critical evaluation of the accuracy of the DEM.

This study proposes a critical perspective on the creation of a vector profile graph of a hiking route. Namely, two different approaches generated graphs that differ significantly in terms of their structure, surface distance and especially elevation. The results also highlight opportunities for critically evaluating the captured tracks of a walking route in both the horizontal and vertical dimensions, as well as for critically evaluating the surface model over which we overlay the tracks. Next steps include automating the presented model using the *Model Builder* tool in ArcGIS Pro and the Python programming language. This will allow us to process a large number of hiking trails.

This study is important because it deals with the creation of a vector profile graph of hiking trails with GIS, which can provide an important basis for further study of hiking trails with GIS, in particular the relationship between their horizontal and vertical complexity, surface length, and spatial error associated with tracking. Finally, the study addresses the accuracy of route tracking with smartphones and apps and the discrepancy that can arise when the results are combined with a digital surface model. To this end, an ongoing Citizen Science project will engage with Alpine clubs in Slovenia by involving them in tracking mountain trails with smartphones. This will enable tracking of a larger number of hiking trails and multiple repetitions of tracking of the same hiking trails. The findings may also be useful for Alpine clubs.

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USTVARJANJE VEKTORSKEGA PROFILNEGA GRAFIKONA V PROGRAMSKEM ORODJU ARCGIS PRO NA OSNOVI SLEDENJA POHODNIŠKE POTI Z APLIKACIJO ALLTRAILS

Povzetek

Ob poplavi aplikacij za telefone so bile med drugim razvite aplikacije za sledenje pohodniških poti. Primer takšne aplikacije, ki je hkrati v središču naše raziskave, je AllTrails. Gre za mobilno aplikacijo, ki se uporablja pri rekreacijskih dejavnostih na prostem, kot so pohodništvo, gorsko kolesarjenje, plezanje in športi na snegu. Eden od rezultatov aplikacije AllTrails je interaktivni profil sledi. Z vidika naših potreb je pomanjkljivost aplikacije ta, da neposredno ne ustvari vektorskega profilnega grafikona sledi. Za nekatere napredne analize z GIS-i, kot je na primer ugotavljanje vertikalne fraktalne dimenzije pohodniških poti, je takšen grafikon potreben. Zaradi tega smo razvili lasten postopek za ustvarjanje vektorskega profilnega grafikona sledi v programu ArcGIS Pro na osnovi rezultata sledenja pohodniške poti z aplikacijo AllTrails. V članku predstavljamo ta postopek.

Za primerjavo dveh različnih postopkov ustvarjanja vektorskega profilnega grafikona pohodniške sledi smo linijski element, ki predstavlja pohodniško sled iz aplikacije AllTrails, v programu ArcGIS Pro prekrili preko rastrskega površja. Pri tem smo uporabili orodje *Stack Profile*, rastrsko površje pa smo pridobili iz podatkov Digitalnega modela reliefa (DMR) vodoravne ločljivosti 1 meter. Nato smo oba vektorska profilna grafikona, torej profilni grafikon 1 in profilni grafikon 2 primerjali glede na niz parametrov. Ti parametri se nanašajo na zgradbo grafikona, na ravninsko in trirazsežno razdaljo ter na razliko v nadmorski višini.

Geografsko smo se osredotočili na del Pohorja, kjer smo januarja 2024 z aplikacijo AllTrails sledili pohodniško pot od Rogle do Lovrenških jezer in nazaj. Pri tem je povratek v veliki meri potekal po drugi poti kot pristop.

Sledenje poti z aplikacijo AllTrails ustvari podatke v različnih formatih. Od teh je bila za nas najpomembnejša Excelova preglednica, v kateri je bila sled zajeta v obliki točk, opredeljenih z geografsko dolžino in širino ter nadmorsko višino. Sled je bila opredeljena z 2701 točkami. Vrednosti koordinat so bile podane v sistemu WGS 84, torej geografska dolžina in širina v decimalnih stopinjah, nadmorska višina pa

v metrih. Na osnovi omenjene Excelove preglednice smo v programu ArcGIS Pro ustvarili vektorski točkovni sloj, pri čemer smo uporabili orodje *XY Table To Point*. Nato smo točkovni sloj pretvorili v slovenski koordinatni sistem D96/TM, s čimer smo omogočili izvajanje ravninskih geometrijskih meritev. Karta nam je omogočila pogled na pohodniško sled s ptičje perspektive.

V postopku ustvarjanja vektorskega profilnega grafikona sledi smo v programu ArcGIS Pro ustvarili novo karto v koordinatnem sistemu D96/TM. Določili smo koordinati x_1 in y_1, ki opredeljujeta izhodiščno točko vektorskega profilnega grafikona. Za koordinati x_1 in y_1 smo uporabili koordinati prve od vseh 2701 točk sledi. Koordinati x_1 in y_1 predstavljata izhodišče za določitev koordinat vseh ostalih 2700 točk grafikona. Dejanska lokacija izhodiščnih koordinat x_1 in y_1 je pravzaprav nepomembna, saj ti koordinati predstavljata le izhodiščno točko vektorskega profilnega grafikona.

Atributno preglednico točkovnega sloja poti smo izvozili v formatu dbf in jo pretvorili v Excelovo preglednico. To preglednico smo opremili z naslednjimi novimi atributi: *P*, x_1, y_1, *d-name*, *d*, *D*, *x*‘, *y*‘, *d*‘ in *D*‘. Ti atributi pomenijo:

P je poimenovanje točk sledi, na primer: P_1, P_2, P_3.

x_1 in y_1 sta koordinati izhodiščne točke vektorskega profilnega grafikona.

d-name je ime segmenta, ki predstavlja razdaljo med dvema sosednjima točkama P_n, na primer: d_1, d_2, d_3.

d predstavlja ravninsko razdaljo med dvema sosednjima točkama P_n.

D je vsota razdalj d_n od izhodiščne točke P_1 do katerekoli druge točke P_n.

x‘ je koordinata točke vektorskega profilnega grafikona na vodoravni osi.

y‘ je koordinata točke vektorskega profilnega grafikona na navpični osi.

d‘ je trirazsežna razdalja med dvema sosednjima točkama P_n na vektorskem profilnem grafikonu.

D‘ je trirazsežna razdalja od izhodiščne točke profilnega grafikona (x_1, y_1) do katerekoli točke P_n profilnega grafikona.

Tako opremljeno Excelovo preglednico smo nato ponovno uvozili v program ArcGIS Pro in z orodjem *XY Table To Point* ustvarili točkovni vektorski profilni grafikon. Pri tem smo uporabili koordinatne vrednosti *x*‘ in *y*‘. Število točk P_n profilnega grafikona je 2701. Z orodjem *Points to Line* smo te točke povezali z vektorskim polilinijskim elementom in ga nato z orodjem *Split Line At Point* razdelili na posamezne linijske elemente med vsemi sosednjimi točkami. Rezultat je bil 2700 linijskih elementov d_n‘. Razdalja linijskih elementov *d*‘ pomeni trirazsežno razdaljo. Njihova vsota predstavlja skupno trirazsežno razdaljo obravnavane sledi. Da bi navzkrižno preverili vrednosti trirazsežne razdalje linijskih elementov, izračunanih s programom ArcGIS Pro, smo izračune izvedli še v Excelovi preglednici. Izračuni iz programa ArcGIS Pro in iz Excelove preglednice se natančno ujemajo.

V postopku ustvarjanja vertikalnega profilnega grafikona sledi z orodjem *Stack Profile* smo linijski element sledi prekrili preko rastrskega površja. Podatke iz izhodne preglednice smo nato uporabili kot vhodne podatke za zgoraj predstavljen Excelov model. Rezultat postopka je bil profilni grafikon 2. Slednji je gosteje opredeljen s točkami kot profilni grafikon 1, zato povprečna ravninska razdalja med sosednjimi točkami pri profilnem grafikonu 2 znaša 0,88 metra, pri profilnem grafikonu 1 pa 3,75 metra. Ravninska razdalja je pri obeh grafikonih enaka, tj. 10.128,33 metra, saj se oba začneta in končata v istih točkah. Se pa grafikona razlikujeta glede trirazsežne razdalje. Ta je za 23,84 metra večja pri profilnem grafikonu 1, kjer znaša 10.209,08 metra. Razlika med trirazsežno in ravninsko razdaljo znaša 80,75 metra pri profilnem grafikonu 1 in 56,91 metra pri profilnem grafikonu 2.

Oba grafikona se razlikujeta po nadmorski višini. Na splošno profilni grafikon 2 prikazuje nižje nadmorske višine. Pri tem grafikonu je najnižja nadmorska višina za 15,24 metra nižja kot pri profilnem grafikonu 1. Najvišja nadmorska višina pri profilnem grafikonu 1 je za 4,2 metra višja kot pri profilnem grafikonu 2. Zato je razlika med najnižjo in najvišjo nadmorsko višino večja pri profilnem grafikonu 2, kjer znaša 96,04 metra v primerjavi s 85 metri pri profilnem grafikonu 1.

Maksimalna višinska razlika med obema profilnima grafikonoma na isti lokaciji, torej na isti ravninski razdalji od njune skupne izhodiščne točke x_1 in y_1, znaša 20,15 metra. Gre za višinsko razliko med točko P_{1825} profilnega grafikona 1 in nadmorsko višino na profilnem grafikonu 2. Izračunana je bila z orodjem *Extract Values To Points* v programu ArcGIS Pro, pri čemer je bilo uporabljeno isto rastrsko površje kot pri orodju *Stack Profile*. Razlika v nadmorski višini je bila preverjena tudi ročno z merjenjem med dvema profilnima grafoma na karti ArcGIS Pro od točke P_{1825} na profilnem grafikonu 1 in navpično razdaljo do profilnega grafikona 2. Enakost obeh meritev potrjuje točnost modela za ustvarjanje vektorskega profilnega grafikona pohodniške sledi. Pri primerjavi obeh profilnih grafikonov nismo pričakovali tako velikih višinskih razlik. Menimo, da je k višinskim razlikam dodatno prispevala nošnja telefona v nahrbtniku med sledenjem, torej več kot en meter nad tlemi. Zaradi snežne odeje pa je bil telefon še dodatno dvignjen nad tlemi.

Ena od omejitev, na katere smo naleteli med raziskavo, izhaja iz uporabe orodja *Stack Profile*. Namreč sled, ki je bila prekrita preko DMR, je bila na nekaterih odsekih vodoravno odmaknjena od trase poti, razpoznavne na DMR. To je prišlo še posebej do izraza na vzhodnem delu zanke poti, kjer je teren bolj strm, ponekod grapast, površje pa poraščeno z gozdom. Na tem območju je bila tudi ugotovljena največja višinska razlika med grafikonoma, in sicer 20,15 metra. Raziskava predlaga kritičen pogled na ustvarjanje vektorskega profilnega grafikona pohodniške sledi. Dva pristopa sta namreč ustvarila grafikona, ki se razlikujeta po strukturi, trirazsežni razdalji in zlasti po nadmorski višini. Naslednji koraki vključujejo avtomatizacijo predstavljenega postopka z orodjem *Model Builder* v programu ArcGIS Pro in uporabo programskega jezika Python, kar bo omogočilo obravnavo večjega števila pohodniških sledi.