Algorithm for Automatic Path Routing in Mountain Areas

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The main purpose of the research is to achieve a fully automated technique for calculation of new trails in the mountain areas. The main idea is to provide the user with a possibility to move around the area regardless of the existing routes, which can make the user independent of using trails. Such a concept is nowadays getting a lot of attention due to the growing need for revitalisation and enabling new areas to be used for tourism and educational purposes. Moreover, the proposed solution can become a useful tool for emergency services, foresters or park employees. The main project assumption was to create a tool able to find a new path between two locations given a set of input parameters provided by the user. The new path had to be distinct from any existing paths in the area. The algorithm was designed to be a solution for path routing in poorly recognised areas or within big acreage as it can take a long time to explore the area in enough detail manually create a plan of the new path. The result of the project is the new ArcMap toolbox, built with a help of spatial analysis tools of the ArcGIS platform. The project uses GIS methods, taking advantage of remote sensing, spatial analyses and Python scripting. This makes it possible to create an automatic tool that is able to process various data in a relatively short time (comparing to manual work on planning new paths). As the end result algorithm generates a map with least cost path, which after conversion to GPX file is ready to use with supporting devices, e.g. smartphones. The project has been verified in the surroundings of Gorczański National Park in southern Poland. Performed tests allowed to find optimal settings and proved that an algorithm works correctly.

1. Introduction

There is no clear definition of a “walking trail” even though it is a widely discussed matter in technical literature [1]. There are very few examples of studies of this subject in the context of a GIS based algorithm for generating new trails. That can be related to the fact that this is a highly complicated problem that needs to take into consideration many aspects that are dependent on each other. For example, the process of designing a new touristic path in Poland has no clear law regulations [2]. Moreover, planning new paths in mountainous areas is rarely discussed in the context of searching for routes completely independent of the existing roads. Plans of short paths (e.g. for educational purposes) can be created relatively easy without any special spatial algorithms or tools. In such cases it is usually enough to base them on the knowledge of people who know the area by themselves. Complexity of the problem grows respectively to expanding the research area or when designing trails in poorly or totally unrecognized fields or in the case of the need to carry out the whole process in a critically short time.

Using GIS as a support in selecting an optimal path from a database is a widely applied practice in many regions and sectors as described e.g. by Dye & Shaw [3]. GIS systems are also used to manage the existing trails and monitor the condition of the geographical environment due to trail exploitation.
Spatial analyses are also used in tourism sectors as a support for tourists and designers as described by Chiou et al [5] or by Xiang [6]. Applying the Least Cost Path algorithm for finding an optimal way is widely known, as has been shown e.g. by Douglas [7]. Using least cost path analysis to generate new walking trails in the mountains was described by Kokkinidis et al. [8]. In this case the goal was to look for a new path in predefined and unchangeable for the user area. Authors built a tool for generating new trails for scouts’ needs without using existing trails. The least cost path algorithm way was also used by Petrasova [9] for designing new trails for Lake Raleigh Woods, USA.

2. Purpose

The algorithm was created for a wide range of applications, but mostly for being useful in tourism during the process of creating and modernising trails. So far this process has been dependent solely on the knowledge and experience of the people designing the path. The algorithm was designed to be a solution for path routing in poorly recognised areas or within big acreage as it can take a long time to explore the area in enough detail to manually create a plan of the new path. Developing walking a tourism sector is important for local economics, popularizing healthy activities and providing access to nature for all who may need it.

Furthermore, the algorithm brought solutions that can be adapted to support the work of foresters as well as emergency services. The described tool can be also helpful during rescue operations as it can facilitate making decisions related to determining the search route to ensure safety. What is important is that the algorithm is not dedicated to a single area but can be freely applied to any area with similar morphology.

The main task of the algorithm was to generate new, independent paths which can be walkable in the area likely unknown to the user.

3. Algorithm & Data

The very first version of a project was a new toolbox for ArcMap. It was built by using Python 2.7, as Python scripting allows new geoprocessing tools to be executed inside ArcMap. What is more, this solution made the algorithm an automatic process - the role of the user was only to upload the data.

The whole tool was built up from two modules. First one was responsible for analyzing all the information about the chosen area. This step involves more complicated operations and usually takes a few minutes (this depends strictly on available computing power and the size of the area). The second module was responsible for generating a new path.

The algorithm takes into consideration basic difficulties that a potential user might face. These were the angle of the slope, density of the vegetation, appearance of streams, rivers, bare soils and buildings. To achieve that, plenty of data were analysed:

- Classified LIDAR point cloud. The first version algorithm used point cloud from the ISOK project, a Polish national program using classes 2, 4 and 6 which respectively describe Ground, Medium Vegetation and Buildings. During processing, information about density of vegetation was extracted as well as the location of the buildings. Only plants with a height between 0.4 m and 2 m were taken into consideration as they can possibly cause problems for a user walking along the footpath.
- DEM - Digital elevation model allowed to create raster map with information about slopes.
- Vector maps of rivers, streams and existing paths. This data was used to obtain information about places where the watercourse can be crossed safely and about the possibility of appearance of wetlands.
- Images delivered by Sentinel-2 satellite. Based on satellite products the Normalized Difference Vegetation Index was calculated. This operation allowed predicting areas with bare soil or dense green vegetation occurrence. This step was used to avoid leading paths through farmlands and possibly muddy places.
Test LIDAR dataset was obtained from the Geodesic and Cartographic Documentation Center (Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej) and vector data has been shared by Gorczański National Park.

4. From rare data to ready-to-go path

Toolbox was built up from two separate tools. The first one was responsible for analyses of the given area. All information obtained during these analyses led to the creation of two general raster cost maps. One about vegetation density and one about slopes. As mentioned beforehand, density of vegetation was also taken into consideration. As a result of processing LiDAR las files, a density map was created with spatial resolution of 4 meters. All pixels were assigned to a value in the range 0-1 (where 0 was assigned to pixels without any vegetation). A spatial resolution of 4 meters was chosen as the best during field tests. Lower ones (e.g. 1 m) were used to find small gaps between branches or bushes that were not comfortable to follow through. Additionally, using class 6 of the LiDAR dataset, information about building presence was extracted. Based on this, another raster map was created using pixels with value NODATA, describing buildings and any other pixels with a value of 1. In the second step the algorithm processed vector data. The vector map describing streams was converted into raster one with 5 m spatial resolution. Low resolution in this case was treated as a safety buffer due to low data accuracy. Pixels describing water were given a value of 2. All other pixels were assigned with a value of 0, including those pixels where safe crossings were detected (intersection of streams and official paths or roads). In this step the location of springs was predicted. As a result, the algorithm generated another raster map, where pixels describing streams and the closest areas (10 m buffer) were given a value of 1 and any other were given a value of 0. One of the last steps was to calculate DEM raster with Slope tool from ArcMap built-in toolbox. Raster with 1 m resolution was being reclassified. 10 classes total were assigned, where classes 1 to 9 described slopes with an angle from 0° to 47°, and class 10 was reserved for steeper slopes. The last calculated feature was NDVI ratio from Sentinel-2 for the purpose of detection of bare soil. The output raster with binary values was created, where value 1 described pixels where bare soil was recognised. This step allowed the algorithm to avoid calculating paths through farm fields or muddy areas. The value of pixels was subsequently increased where any kind of inconvenience was recognised (Figure 1). Moreover, pixels representing buildings were marked as NODATA and excluded from the analysis.
Figure 1. Logic of the cost map

The main calculations were carried out using the least cost path algorithm, which allows the algorithm to find “the cheapest” path (the most optimal path of all variants). At the first stage, the user decides on what weights to assign to the slope map and what to the vegetation density map. This allows the algorithm to match paths to the user’s skills or preferences. Then, the user has to input start and end point coordinates (WGS 84 coordinate system). What is more, the algorithm finds previously saved maps and cuts them with a mask built on given start and end points with a 500 m buffer. This makes analysis faster and more efficient. In the next step, the Weighted Overlay tool (Spatial Analyst ArcGIS) is used to create the final cost map. The weights are assigned according to the user's specification. After that, the algorithm executes the Cost Distance (Spatial Analyst ArcGIS) tool which creates a map where each pixel contains information about the cost of moving from or to the cell described as a source (in this case the starting point), based on the one created on the previous final cost map. In this step, the backlink map is also being created, defining direction of movement for each raster cell. Finally, the Cost Path Tool is used, as a core for least cost path analysis. Raster map with a new path is generated. Then, it is converted to a vector map and exported to a GPX file using the Feature to GPX tool. As an output, a GPX file is generated, which can be easily imported e.g. to a smartphone. The next and final step is to go out to the field and check the results empirically. Wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations is in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

5. Tests and results
The algorithm was verified by the authors (Figure 2) in Ochotnica Górna village, which is located in southern Poland at Gorce Mountains.
Figure 2. Ochotnica Górna, the field test area.

The first step was to find optimal settings including the selection of the best resolution and parameters for components maps. This prevented analyses from being distorted and allowed us to replicate the field conditions. On the first attempt the limit level of acceptable density of vegetation was too tolerant. As the result it was hard to keep going along the new path, because of the density of bushes and trees. On the next attempts parameters were adapted to requirements resulting in superior paths. During one of the tests, trained mountain guides were present to evaluate the algorithm, which brought important feedback. A little private shelter in mountains was set up as the start point and the main road in Ochotnica Górna as the end point. The generated path was completely different from the official one (Figure 3), but it was possible to freely walk along it. During movement from one point to another some difficulties like wetlands were faced. Therefore, in subsequent versions of the algorithm, their presence was taken into consideration. Field tests also allowed us to verify the quality and accuracy of the obtained data.
6. Conclusions
In the first version only basic parameters were included, and not enough of them to call it a full-fledged tool. In the future also seasons and snow issues need to be included along with local law regulations, safety of users and many other factors. Also many suggestions given by a wide range of the specialists from diverse fields will be applied. Another problem is the lack of a possibility to obtain actual vector data which was crucial for getting correct results. As remote sensing and related fields are developing quickly there is a possibility to make the algorithm independent from vector data. During a field test with professional mountain guides it was said that the algorithm does a job that is unlikely to be done by humans. Even a very experienced person left in an unknown area has very few chances to figure out a convenient path at the first attempt. Finding optimal paths is almost impossible in this case. This project has gained interest also among tourism enthusiasts as it is the first tool of its kind. These conclusions provide a reason to continue work on the algorithm and development of its functionality as it can become a useful tool in the future.

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