Session 15

Geostatistics, Mapping and Spatial Data Analysis

114. Mitigating soil erosion on agricultural cropland using elevation data in a track planning algorithm

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Abstract

This work investigates integrating elevation data into a track-planning algorithm to calculate AB-lines as driving tracks with minimal slope on the field. The paper utilizes a modified version of the CONREC contouring algorithm to facilitate the calculation of level-lines (lines of constant altitude) within the field. A deviation function assesses deviations in driving directions relative to the level-lines of a field. This deviation can determine the average slope of the driving direction. Consequently, the average slopes of various driving directions are compared, allowing the ideal driving direction with the minimal slope to be identified for mitigating erosion effectively. A web application has been developed to implement and demonstrate the proposed algorithm.

Keywords: AB-line optimisation, elevation data, erosion mitigation, track planning

Introduction

Track planning is relatively straightforward in the case of flat, rectangular fields. Identifying an ideal driving track encompassing more complex field shapes can represent a significant mathematical challenge, as Bochtis and Oksanen (2009) have already shown. However, it becomes considerably more complex in steep terrain, where finding the ideal track orientation, required to minimize erosion, is even more challenging. Carvalho *et al.* (2009) showed that driving perpendicular to slopes can cut soil loss by 68.7%, and Spekken *et al.* (2016) estimated a reduction of up to 75%, highlighting the impact of track orientation. In Europe, specific slope requirements for tillage are already in place to minimize erosion. In 13 European member countries, the EU CAP GAEC 5 standard (EC, 2023) sets requirements on the direction of tillage compared to the slope.

Related work

Despite numerous algorithms for field traffic planning, these algorithms typically rely on two-dimensional data (Hameed, 2013). Recent approaches, such as those by Jin and Tang (2011) or Hameed *et al.* (2013) have begun to incorporate three-dimensional terrain data. Hameed *et al.* (2013) focussed mainly on optimizing time and fuel efficiency rather than considering soil erosion and displacement. Lindstrom (2002) emphasized that strategies neglecting tillage erosion are inadequate for effectively reducing soil loss, particularly in upper slope areas. Jin and Tang (2011) found an ideal solution within a limited set of candidates for three-dimensional terrain, limiting the search space to predefined options rather than exploring the broader solution space to approach an optimum.

Materials and methods

This research utilized an algorithm to identify the angle of an AB-line with minimal slope, based on the level-lines (lines of constant altitude) in the field. Initially, input data is required for the process. Elevation data for the selected field is obtained as a point grid. This grid data is then processed using a modified version of the CONREC algorithm, initially developed by Bourke (1987), to generate the required input for the algorithm.

Elevation data

Topographic maps are used to plan AB-lines that consider the elevation characteristics of the terrain. These maps are typically created using aerial photogrammetry, laser scanning or radar. They are digitally processed for detailed 2D or 3D topographical representations. Contour lines on these maps indicate the terrain shape; closer lines represent steeper slopes, while wider spacing outlines gentler slopes. In contrast, a digital terrain model (DTM) provides 3D surface information as raster data (Guo, 2018). For this study, a DTM with 1x1 m resolution was used. This data, available through the Voibos API (Rechenraum, 2023), provides elevation data within the Austrian borders.

Processing of elevation data

A modified version of the CONREC algorithm was implemented to process the elevation data into a format suitable for further calculations. The original algorithm processes a grid of elevation points and an array specifying a range of elevations, producing contour lines for the selected elevations. The algorithm divides the input data grid into triangles and calculates a level-line for each triangle within the specified elevations. These individual level-lines are merged to create a continuous contour line (Bourke, 1987).

In contrast, the modified CONREC algorithm returns one level-line for every planar area (triangle) of the input grid (10x10 m), as shown by the blue level-lines in Figure 1 and Figure 4. This modification is critical to the findings of this paper, as the generation of contour lines in the original algorithm often results in uneven data distribution. The distribution depends on the number of contour lines generated, which may sometimes be insufficient. In such cases, the contour lines produced by the original algorithm fail to provide a representative dataset for calculating AB-lines due to the lack of information in some regions of the field.

Track planning algorithm

An optimisation algorithm has been introduced to determine the driving direction with the minimal slope, based on the level-lines of the field, shown in Figure 1. The slope (Eq. (1)) is used to calculate the slope s_a for each driving direction α and each level-line i of a triangle. The calculation considers the direction of each level-line α_i, its weight w_i, and the area A of the field as input parameters.

$$s_\alpha = \frac{\pi}{2A} \sum_{i=0}^{n} \arcsin\left(\left|\sin(\alpha - \alpha_i)\right|\right) w_i \quad (1)$$

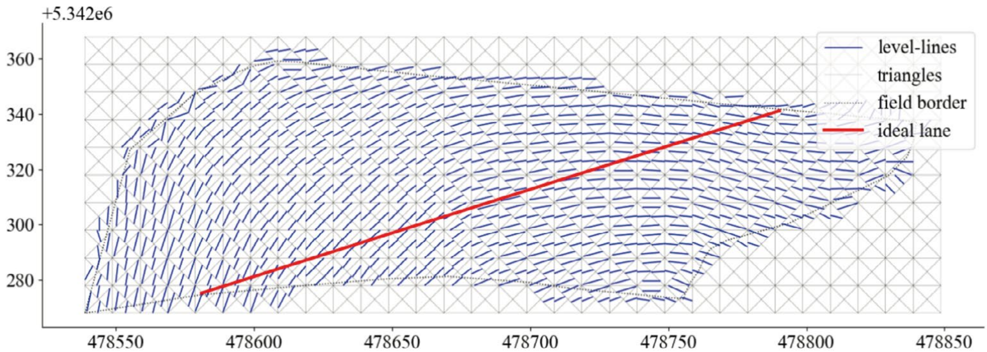

Figure 1. The blue lines show the level-lines of each part of the field. The red line indicates the ideal AB-line of the calculated minimum of Figure 3.

Eq. (1) is based on a deviation function that calculates the deviation $\Delta\alpha$ between the direction α_i of a level-line and a driving direction α, as shown in Figure 2. Since the orientation of the driving direction does not affect the deviation, the function needs to have a periodicity of π. To achieve this periodicity, the algorithm uses the absolute value of the sine function, shown in blue in Figure 2. However, the sine function does not assign proportional weight to every change in $\Delta\alpha$. To address this, the arcsine is applied, and the function is normalized. The resulting periodic triangle function is illustrated in yellow in Figure 2.

$$w_i = A_i * s_i \tag{2}$$

The deviation of each level-line is multiplied by its corresponding weight. As shown in Eq. (2), the weight w_i for each level-line i is calculated as the product of the slope of the level-line s_i and the area A_i of the level-line's triangle within the field. The level-lines and their respective areas (triangles) are illustrated in Figures 1 and 4.
To get the average slope s_a (Eq. 1) for a driving direction α, the weighted deviations of all level-lines are summed up and divided by the total field area A. This division cancels out the area component of the weight, leaving the average slope. Figure 3 displays the average slopes for all possible driving directions. The minimum on this graph (red cross) represents the driving direction with the smallest slope across the field and, consequently, the driving direction for the AB-line.

Discussion

To demonstrate the functionality of the algorithm, two fields were selected for analysis. The first field, shown in Figure 1, features a single dominant driving direction, while the second field, seen in Figure 4, includes a terrain with three dominant slope directions. These fields provided a clear basis for evaluating the algorithm's behaviour, especially in diverse conditions. In particular, the terrain in Figure 4, with multiple competing slope influences, highlights the algorithm's ability to handle complex scenarios. The graph in Figure 5 illustrates that for fields with several dominant driving

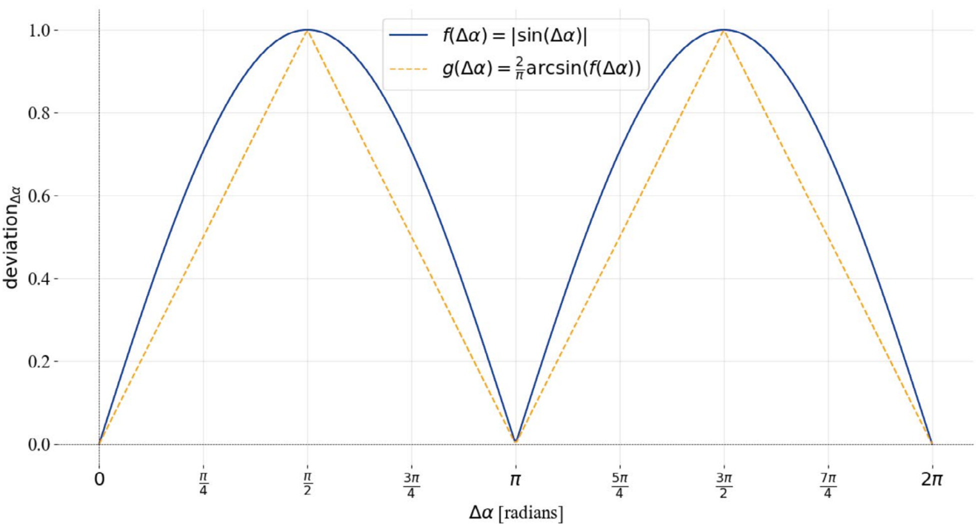

Figure 2. The deviation function evaluates the difference between a level-line and the driving direction.

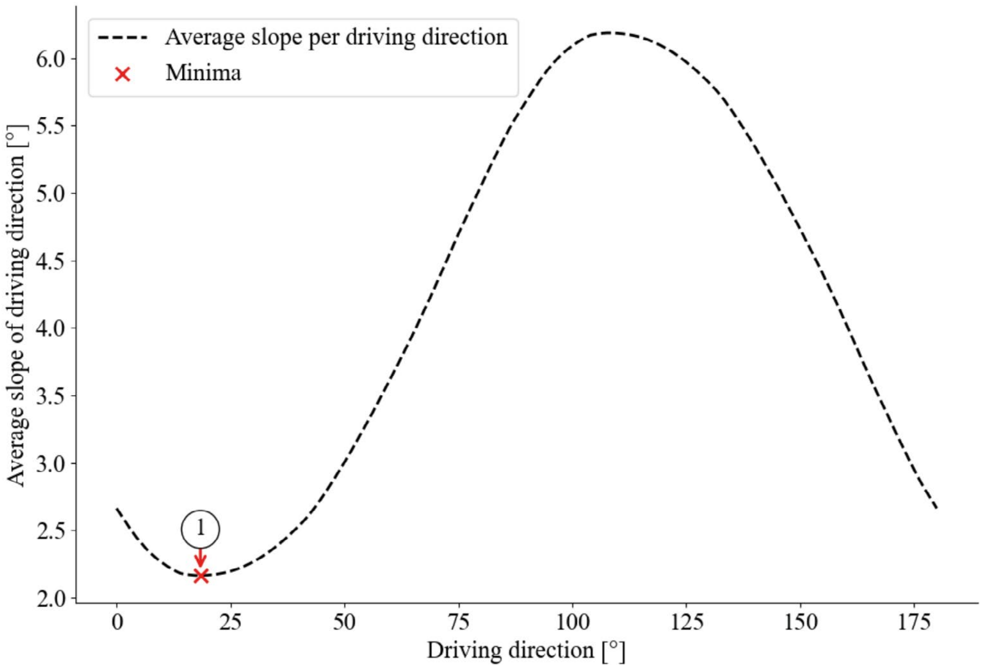

Figure 3. The average slope in relation to the driving direction across the field. The minimum indicates the driving direction with the least slope, as shown in Figure 1.

directions, multiple local minima are possible. These angles are visualized as red lines in Figure 4. This example illustrates the importance of evenly distributed data for identifying such minima. To make the terrain of Figure 4 drivable using AB-lines, the decomposing method from Jin and Tang (2011) could be adapted to divide the field based on its three driving directions.

During this research, a binary search algorithm was tested as a potential alternative. While this method offered advantages in runtime, it failed to consistently find the global minimum in cases with multiple local minima, as shown in Figure 5. In contrast, the proposed optimization algorithm consistently identified both the lowest local minimum and the global minimum, even in complex terrains. A key strength of the proposed algorithm is its adaptability. By adjusting the weight of each level-line, the algorithm can prioritize areas that are more prone to erosion, such as those with steeper slopes. Additionally, slopes below a certain threshold, where erosion is not a concern, can be assigned lower weights or ignored. This flexibility makes the algorithm suitable for diverse terrain conditions.

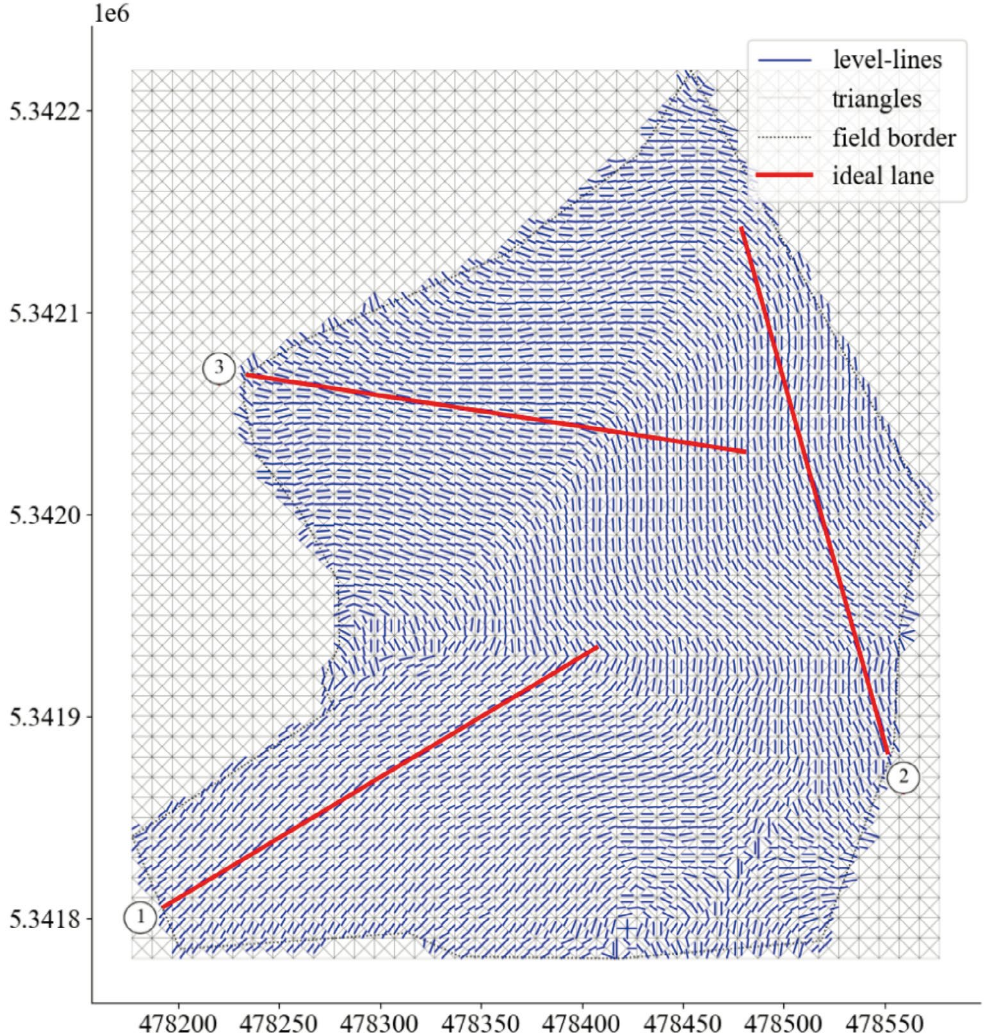

Figure 4. The blue lines show the level-lines of each part of the field. The red lines indicate the feasible AB-lines of the three calculated minima of Figure 5.

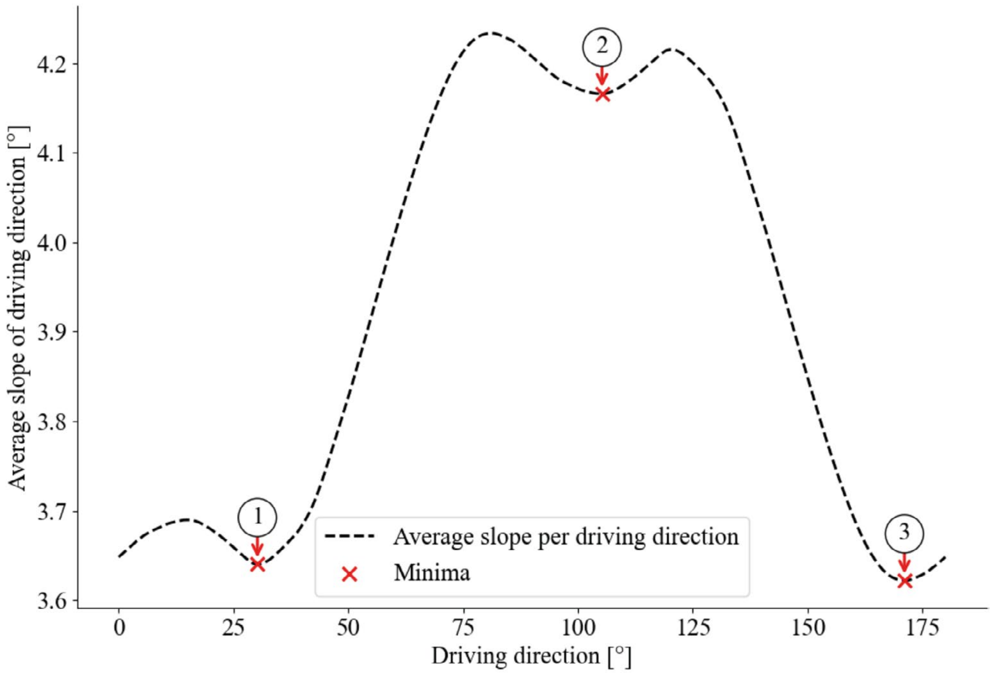

Figure 5. The average slope in relation to the driving direction across the field. The minima indicate the feasible driving directions of the field in Figure 4.

Future work

Future work will focus on continuing this research and develop an algorithm that calculates ideal contour tracks with the smallest possible slope, while considering constraints such as maintaining a minimal driving radius. Although AB-lines may not be a practical solution for all fields, this paper represents a crucial preliminary step by calculating the optimal angle for AB-lines, representing the dominant driving direction of a field, and serves as an essential foundation for further advancements in contour track planning. The next logical step is to develop an algorithm, where all triangles of Figure 1 or Figure 4 are initialized with the dominant direction. Based on the direction of each triangle's level-line, the algorithm adjusts the direction, within the constraints of neighbouring triangles, to maintain drivable radii. This will help finding the ideal contour tracks of a field.

Conclusions

This research focused on developing an algorithmic approach for AB-line planning. The goal was to calculate AB-lines that closely align with the level-lines across the field, based on the assumption minimizing deviation between the driving track and the level-line minimizes erosion. Unlike prior methods, such as those proposed by Jin and Tang (2011), which are limited to selecting the best option from a predefined set of candidates, the proposed optimization algorithm consistently determines the driving angle with the lowest possible slope, offering a more comprehensive and reliable solution. This is achieved by evenly distributed data to ensure precise and comprehensive analysis.
The algorithm was implemented in a web application (terratrack.at). This way, farmers can take advantage of its functionality to plan optimal driving tracks and reduce soil erosion.

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