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Optimizing Machine Traffic Pattern Against Slope

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ABSTRACT

In rolling surfaces it is often required for the implantation of crops to be perpendicular to slope, because this procedure is considerably effective to reduce water runoff and soil erosion. The problem that poses in such environment is that level lines across slope are often curve and rarely parallel to each other, contrasting with machinery and crop patterns that are always parallel. This work proposes a method that finds the seed curve for an optimal pattern and models this curve to keep machine steerability. The method finds a hybrid curve from two initial (non parallel) curves using offsets and intersections between these. The hybrid curve can be more similar to one of the two initial curves depending on a weight attributed to its vertices, in order to increase likelihood of the curve to the curve references located in steeper regions. Recursively hybridizing the curves, a final seed curve is obtained which has to be remodeled to achieve a degree of smoothness to avoid parallel tracks to narrow into non-steerable turns. The method was successfully implemented in two stages: for hybridization and steerability; obtaining optimized references for machine traffic.

Keywords: path-planning, slope, steerability, robotics, controlled traffic farming.

1. INTRODUCTION

One issue that affects the driving pattern of machinery is the slope of fields. It is well known that working fields (like countour tillage) perpendicular to the direction of the slope on the surface reduces soil loss by erosion (FAO Soils, 1996). Tilling and planting perpendicular to a natural slope creates a series of dams which redirect and slow down runoff (Agriculture and Agri-Food Canada, 2010).

Carvalho et al. (2008) found that soil loss for corn rows sown perpendicular to a 9% slope amounted to 3.877 kg ha^{-1} compared to 12.399 kg ha^{-1} for corn lines sown in downhill direction. The impact of direction was found to be larger than that of crop choice and coverage crops. Sparovek and Schnug (2001) suggested practices such as contouring, terracing and waterways to drain excessive runoff to be combined with tillage and other management practices. The authors also suggested that in smoother parts of the field, contouring and terracing could be combined in a way to avoid or reduce their impact on efficiency of mechanical operations by avoiding dead rows near terraces, but making terraces more parallel to them.

The advance in geo-positioning systems, applied in guidance and self-steering of farm machinery, creates a demand for coverage path-planning, where eventually machinery

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can operate free of human intervention (robots) in pre-planned paths. The establishment of machine paths got importance with the increasing adoption of the controlled traffic farming concept, in which these are permanently defined in the fields. A number of computer algorithms were developed in order to create optimized machine paths on fields for flat terrains (Jin and Tang, 2010a; Hameed et al., 2010; Hofstee et al, 2009). A reduced number of works focused in path planning in steeper fields.

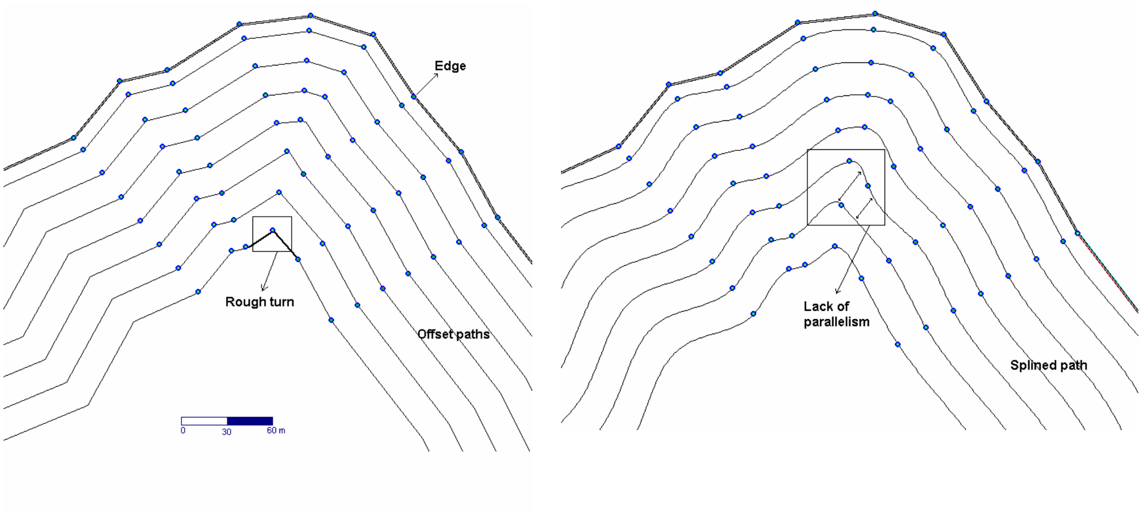
1.1. Problem Definition

In practice, level lines across slope are seldom straight and hardly (if ever) parallel to each other.

Jin and Tang (2010b) proposed a path-planning algorithm for working in rolling terrains. The authors selected reference curves (level lines across slope) to cover the terrain with tracks parallel to it until the path reach a critical point, where machine tracks loss significant perpendicularity to slope, requiring a change in the reference curve.

Such changes of direction are undesired for machine efficiency; the option of selecting one optimal reference curve for the whole terrain would be strongly appreciated by farmers and operators.

Moreover, machine tracks on concave faces of curves tend to converge towards each other in parallel passes, leading to rough turns. Algorithms where proposed (Spekken and Bruin, 2010) to reduce such roughness by the use of splines, but these can only manage such situations with the loss of parallelism in favor of steerability. Figure 1 shows an example of such phenomenon.



a B

Figure 1. Example of problems in path generated by sequential offsets (a) and spline interpolation between the offset edges (b). Extracted from Spekken and Bruin (2010).

In this work two methods are proposed: to obtain an optimal reference curve against slope and to remodel a curve in order to reduce the convergence of its parallel tracks.

2. METHODOLOGY

In here, a field and its features are polygons (field boundary and obstacles) and polylines (like level curves, terraces and roads) composed by a sequence of vertices defined by X and Y coordinates.

The level lines are extracted in adjacent pairs and its vertices are submitted to a simplification process (Douglas and Peucker, 1973) to remove excessive points that delay significantly the smoothing and offsetting processes furthermore.

2.1. Hybridizing polylines

The curves are than sequentially offset towards each other in increasing distances. The offsetting process herein used is adapted after Wein (2007) in order to keep round and equidistant edges from the original curve.

At certain offsetting distance the two curves start to intersect, and the intersections are stored as the exact mid-vertices between the two original lines. This process is illustrated in Figure 2a.

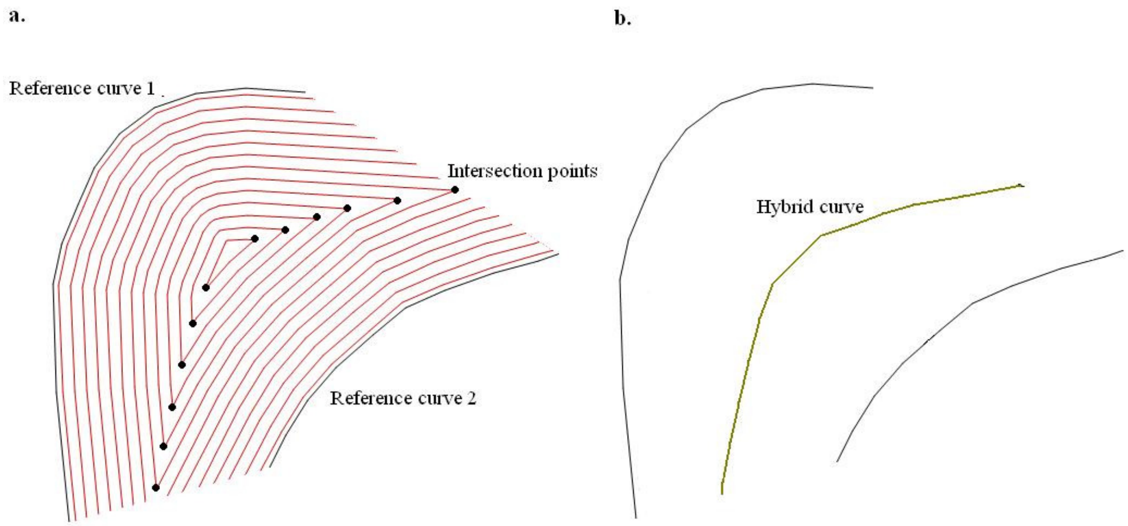


Figure 2. Offset-intersection method used to obtain a hybrid line between two reference curves.

The intersected points must be, afterwards, re-ordered in a sequence of closer neighbors to define the final hybrid curve (Figure 2b).

When curves are offset in distinct distances, the shape of the new intersection vertices will be in close likeness to the curve with the shortest offset distance (Figure 3). This

allows controlling the offset distances in order to achieve hybrid curves in closer shape to the curves located in steeper regions.
The offsetting method was implemented allowing the vertices of the original curves to receive weights that control the offset distance between the reference curves and along also in the same curve.

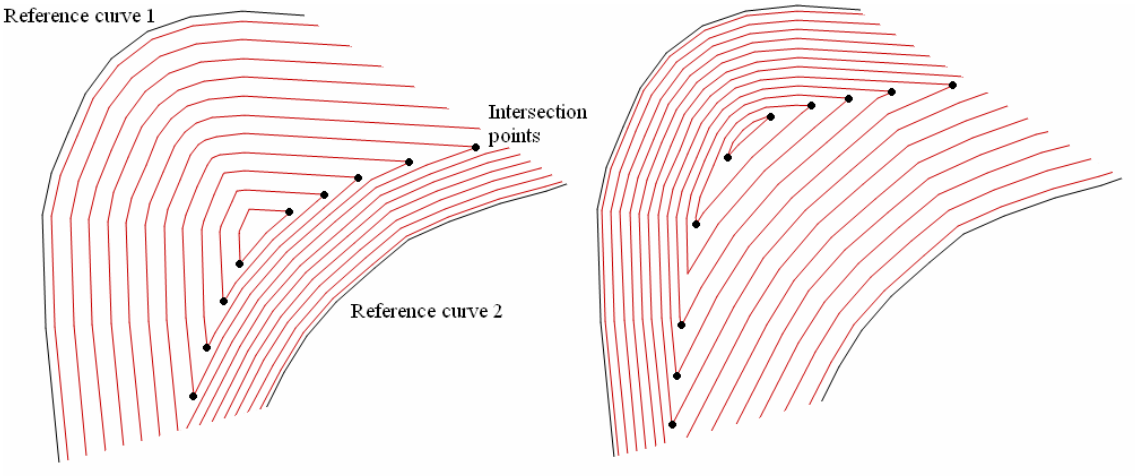


Figure 3. Distinct offsetting distances leading to a resulting curve in higher likeness to one of the references.

By recursively hybridizing the reference curves and, sequentially, the resulting hybrid curves, a final curve is obtained that had embedded in it the influence of all level references on a field. This resulting curve is the suggested seed curve for covering the field in parallel passes.

2.2. Modeling a steerable path-reference

To reduce the problem of rapid convergence of curves in concaves corners, the curve is remodeled.
Given a sequence of vertices the method here proposes to link the mid-distance between a pair of vertices to the next mid-distance pair, staying always in the middle of the points. Doing it recursively, a continuously smother path is found. This can be seen in Figure 4 for three consecutive iterations of the process.

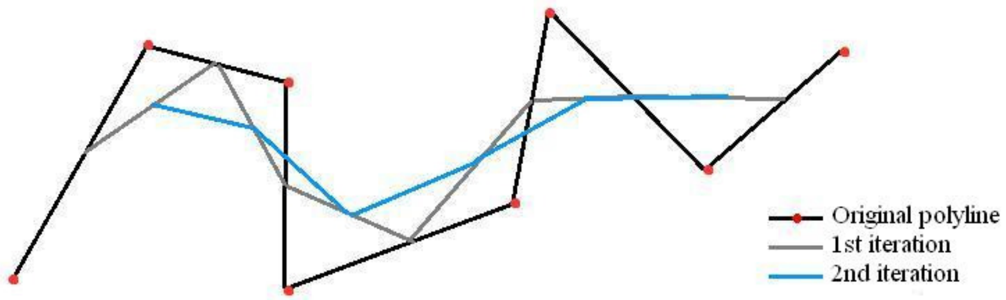


Figure 4. Continuous smoothing iterations between vertices of a polyline.

Bezier-splines are created in a similar process, but to determine how far a sequence of points must be smoothed, the bisectors of two edges of a line are retrieved and the distance of this line to the bisector intersection is retrieved. This process is illustrated in Figure 5, which shows that the further iterations of the program tend to increase the line to intersection distance (LID). The iterations stop when a certain minimum LID is found for all the line-segments.

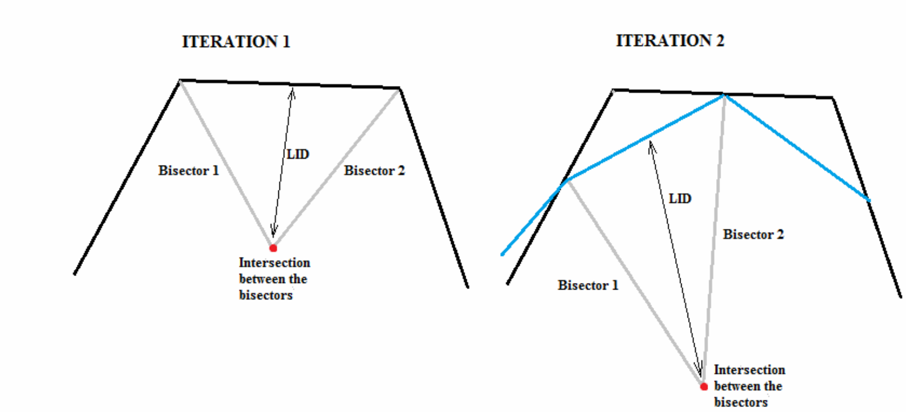


Figure 5. Bisectors intersection between two points and the LID retrieved. The iterations show the increase in the LID which defines a numeric output for smoothness.

3. RESULTS AND DISCUSSION

Three case studies were distinctively applied to the proposed methods.
A case study in Figure 6 shows the results for two reference level lines (in green) hybridized in a seed line (in red). In “a” the weights attributed to the reference lines were the same, while in “b” the weight attributed to the inferior level line was higher assuming this one is located in a steeper region.

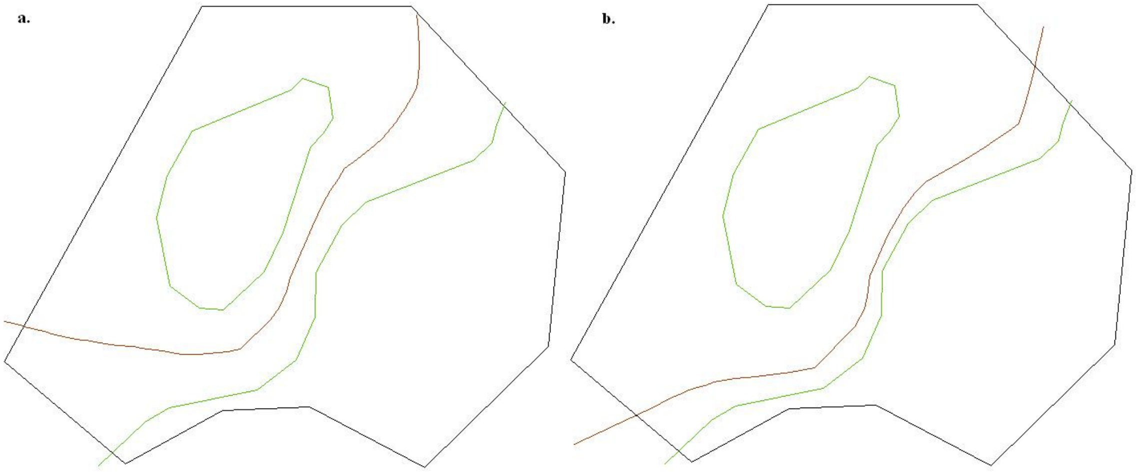


Figure 6. Case study with resulting hybrid lines (in red) with different weight attributed to the reference level lines (in green).

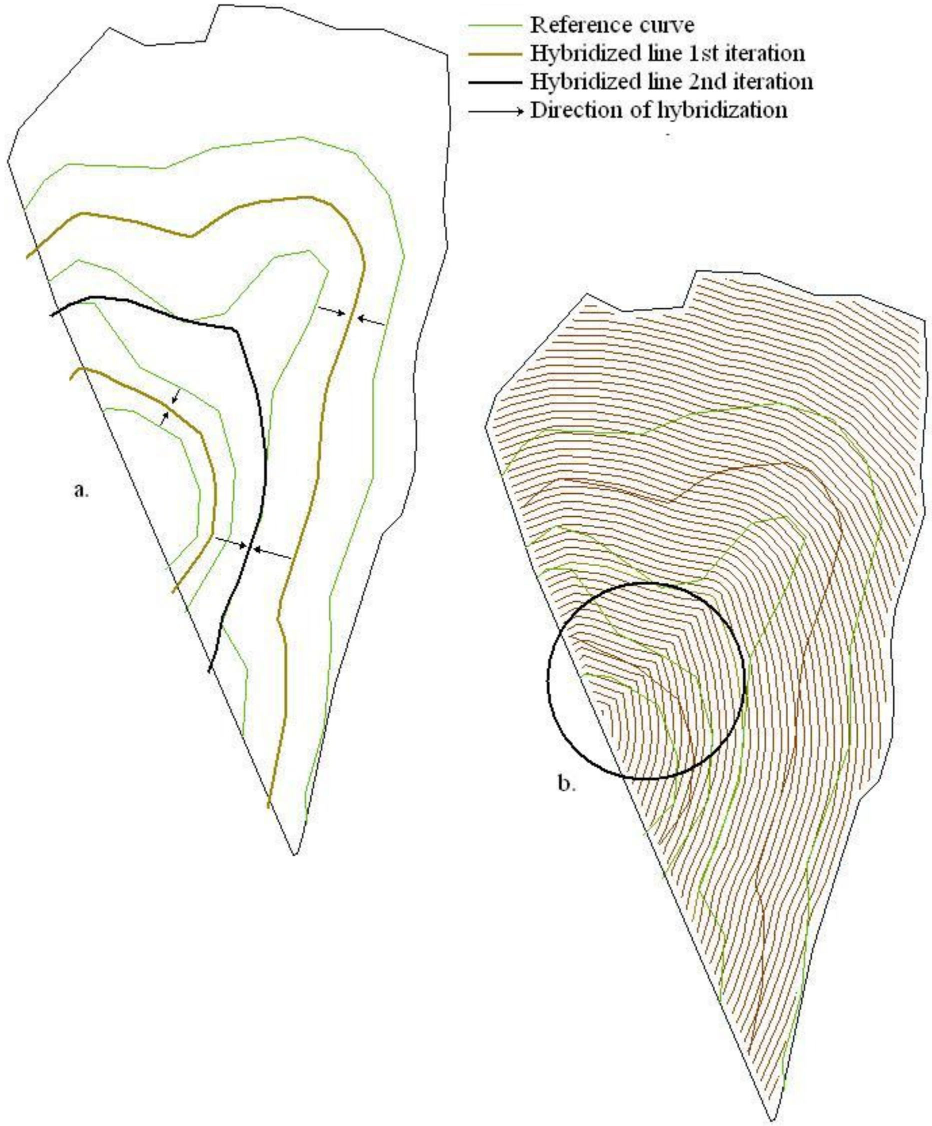


Figure 7. Sequence of two recursive hybridizations into a seed curve in “a”, and the respective coverage of the field tracks parallel to it in “b”.

In Figure 7 “a” shows a field containing four reference curves, representing the level lines, that were subjected to a sequence of two hybridizations: between the reference curves and between the resulting hybrid curves. The tracks generated parallel to the final seed curve obtained (the 2nd iteration curve) can be seen in “b”.

In general, the process of hybrizing curves reduces the roughness of edgy vertices, but in Figure 7b (enhanced by the circumference) parts of the generated tracks still lead to rough changes of direction, unsuitable for machine traffic.

Methods still have to be applied to evaluate the resulting seed curves obtained towards potential erosion process, and comparing it to other patterns of machine track coverage.

The method of remodeling a curve using the two different LID (Line to Intersection Distance) of neighbor bisectors was applied in a case study shown in Figure 8. The LID values used in “a” and “b” were of 20 and 50m respectively.

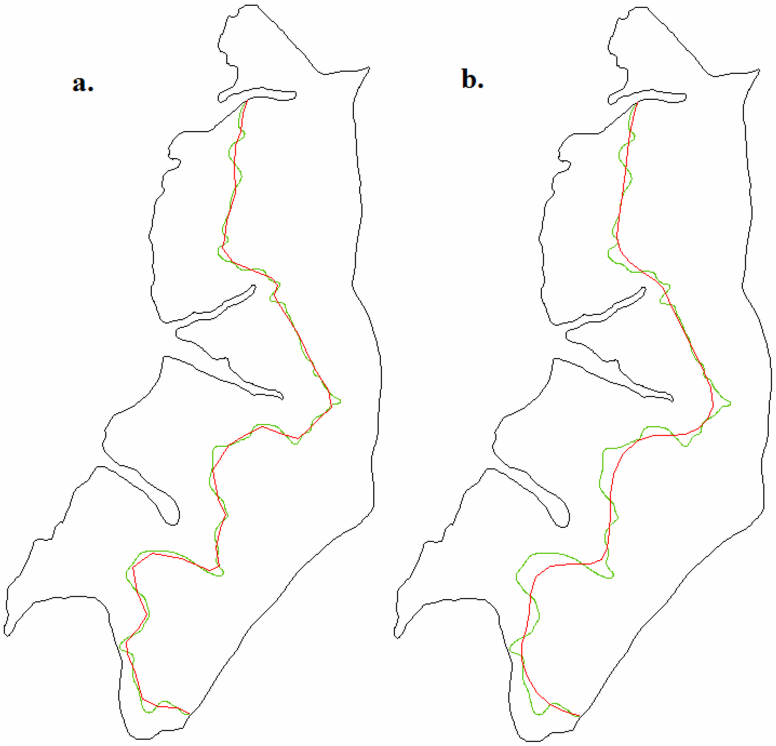


Figure 8. Curves obtained from two distinct LID parameters.

In Figure 8, the green lines represent a true level reference of the field, while the red lines are the result of the smoothing method applied. In “b” a path was obtained aiming a full field coverage without rough changes of direction in the path itself, as well as in its parallel passes.

The proposed algorithms are part of a wider project still being carried. Methods herein created still required comparisons and validations besides in-field applications, but the results obtained so far seem to achieve the desired output.

4. CONCLUSIONS

Two methods are here proposed for defining a suitable seed curve to cover a rolling field towards its slope. These were implemented in algorithms and applied into case studies achieving comprehensible steerable paths.

Methods still have to be developed in order to evaluate the outputs, which is a further step of the actual project.

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