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Determination of alignments in existing roads by using spline techniques

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Abstract

This paper presents a quick, simple and automatic approximation method that allows the alignments in a road (straights, curves or clothoids) and their respective curvature values to be identified from an approximation point set given by its UTM (Universal Transverse Mercator) coordinates obtained from field data.

The method reconstructs the geometry of the road by a smoothing variational cubic spline, computes the curvature function of this spline and approximates the curvature function using a polygonal function formed by trapezoids on the abscises axis. This method permits to obtain alignments that can be used to study any road system that has certain characteristics.

Keywords: Road; Alignments; Curvature; Approximation; Cubic spline

1. Introduction

The plant layout of a road is defined as a continuous axis formed by a succession of alignments. In the road technique three types of alignments are used: the straights where the azimuth is constant and the curvature is zero (infinite radius), circular curves where the azimuth varies linearly with the path and the curvature is constant, and transition curves, where both the azimuth and curvature vary with the path [10]. Among the existing transition curves that aim to serve as a liaison between straights and curves, the one most frequently used on roads is the clothoid.

The alignment of a road is one of the geometric characteristics that have the greatest impact on the level of service it can give and its safety. Some studies on accident rates indicate that curved road sections cause more accidents and more severe ones than those that occur on straight road sections [5].

For new roads it is easy to obtain the geometry of their alignments and curvatures from the highway design software.

For existing roads, it often happens that this documentation is not available, not properly formatted, not current or inaccurate. It is increasingly common to use of GPS or geographic information systems to obtain data from an existing road. It is necessary to recover the geometry of the road in order to use such data subsequent studies.

The vehicle path can be reconstructed with very easily, but the segmentation of road elements according to their curvature is a complicated task. For instance, García and Camacho [4] have developed a method to restore the geometry

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of the track and profiles of real operating speed, using GPS and developing a computer application. The resulting curvature diagram allows them to distinguish between the sections corresponding to circular curves, transition curves and straights. However, they cannot yet distinguish these elements perfectly because these curvature diagrams show oscillations owing to the fact that drivers tend to smooth the path.

Alignments can be identified manually, which is very tedious and not very accurate, especially when you want to analyze a whole road network, or automatically, as suggested by some authors, in a more complex way than the one proposed in this paper [6,11]. Tong et al. [11] used raw data to determine the geometric parameters of roads and railways by using a least-squares fitting. Imran and Hassan [6] developed an algorithm to be used in ArcView GIS, in which horizontal alignments fit in straights and curves, either with or without clothoids.

In this paper we develop a simple automatic procedure to obtain the status of alignments of a road (curves, straights and clothoids) and their respective curvature values. For this, we have a list of points with UTM coordinates, taken from field data obtained via a positioning system (GPS) or from any other source. The road layout is reconstructed with a cubic spline and the curvature of each item is obtained.

The data obtained using GPS or another source of information (such as maps provided by the authorities) should be pre-processed in order to filter the errors. Ben-Arieh et al. [1] have developed a methodology for preliminary data preprocessing.

The use of a cubic spline to smooth field data has been previous studied [1–3].

Others, like Jiménez et al. [7] have presented an algorithm for determining alignments from experimental points, but they discarded the use of spline functions in their study because they do not afford the possibility to determining the straights, curves and clothoids.

2. Proposed methodology

The main goal of this section is to solve the following problem: given the UTM coordinates of a point data set belonging to an existing road, and uniformly distributed along the road, we wish to determine the sequence of curves, straights and clothoids composing the road geometry.

In order to solve this problem, cubic spline functions will be used for the approximation of the given point data set.

Given a partition of $[a, b]$ in m subintervals,

$$\triangle_m = \{a = x_0 < x_1 < \cdots < x_m = b\},$$

we denote by $S_3(\triangle_m)$ the set of cubic spline functions of degree less than or equal to three and class $\mathcal{C}^2$,

$$S_3(\triangle_m) = \{s \in \mathcal{C}^2([a, b]) \,:\, s|_{[x_i,x_{i+1}]} \in \mathcal{P}_3([x_i, x_{i+1}]),\ i = 0, \ldots, n-1\},$$

where $s|_{[x_i,x_{i+1}]}$ is the restriction of the function s to the interval $[x_i, x_{i+1}]$ and $\mathcal{P}_3([x_i, x_{i+1}])$ is the linear space of the restrictions of the polynomial functions of degree three to the interval $[x_i, x_{i+1}]$. Then $dimS_3(\triangle_m) = m + 3$.

Our method have four main steps:

2.1. Step 1. Approximation by a smoothing variational cubic spline

Let $A^n = \{t_1, \ldots, t_n\} \subset [a, b]$ and $\mathcal{P}^n = \{P_0, \ldots, P_n\} \subset \mathbb{R}^2$ be a points set given by their UTM coordinates.

Let $\triangle_m$ be a partition of $[a, b]$ and let $\{B_i\}_{i=0,\ldots,m+2}$ be a basis functions set of $S_3(\triangle_m)$.

We look for a spline function $s : [a, b] \longrightarrow \mathbb{R}^2$ such that

$$s(t_i) \approx P_i, \quad i = 0, \ldots, n,$$

and $s(t) = (s_1(t), s_2(t))$ with $s_i(t) \in S_3(\triangle_m)$, $i = 1, 2$.

Thus

$$s(t) = \sum_{i=0}^{m+2} \alpha_i B_i(t), \quad t \in [a, b],$$