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A sketch-based system for highway design with user-specified regions of influence

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ABSTRACT

To create traffic simulations of high visual-fidelity, each component part needs to be designed and modelled in great detail. Roads can be created manually, but this can become a time-consuming and laborious process when modelling large-scale networks. Therefore, automated techniques for generating road networks efficiently and effectively, is highly desirable in both urban-planning and entertainment industries. In this paper we present a novel sketch-based tool to semi-automate the design, creation, and visualisation of road networks across both flat and undulating terrains. Our tool is guided by input sketches and a combination of prioritised constraints, including the curvature of roads, their inclination, and the volume of ground that would be displaced during construction. We introduce 'Influence Regions' which are user-specified areas of the terrain that influence the path of the roads generated, and are used to attract or repel roads to/from certain obstacles or designated areas, such as forestation, listed buildings, marshland, etc. A user study is conducted to evaluate the usability of the system and the quality of roads generated in a diverse range of scenarios. The results indicate that our system is both user-friendly and able to produce roads that are true to the user's intention.

1. Introduction

To design and create road networks for virtual environments, each component part needs to be designed and modelled in great detail. In addition, a combination of artistic and modelling skills is often necessary to complete this time-demanding and costly process. Roads can be created manually, but this can become a time-consuming and laborious process when modelling large-scale networks. Therefore, automated techniques for generating road networks efficiently and effectively, is highly desirable in both urban-planning and entertainment industries. There are a multitude of commercial products available to aid the development process, including CryENGINE 3, Quadstone Paramics, and Trafficware. However, these packages typically use unintuitive and repetitive 'point-and-click' input methodologies to generate roads.

In recent years there has been an abundance of research on sketch-based modelling techniques with applications in a diverse range of disciplines. Systems that are able to utilise the intuitive feel of conventional drawing methodologies are becoming a popular alternative to those that use more traditional input techniques, primarily due to their increased usability and resulting productivity. Recent advances in this field have provided the motivation and need to develop techniques that allow novice users to create road networks in both urban and rural virtual environments with relative ease through assisted sketch-based tools.

In this paper we present a novel sketch-based tool to semi-automate the design, creation, and visualisation of road networks for virtual environments that is guided by input sketches and a combination of prioritised constraints, such as the curvature of roads, their inclination, and the volume of ground that would be displaced during construction. Our technique extends previous work in the field by developing an algorithm that constrains the geometric properties of roads in three-dimensions to generate road networks across both flat and undulating terrain. We demonstrate how constraints can be tailored to generate roads that exhibit particular characteristics, such as roads with little inclination that cut-through the environment and roads with high curvature that meander across the terrain. Furthermore, we extend previous work on sketch-based systems for road design [1], presenting a significant and novel contribution that both complements and advances previous work. We introduce the concept of 'Influence Regions' which are user-specified areas of the environment that influence the path of generated roads. These regions provide guidance throughout the road design process and can be tailored to either attract or repel roads to/from certain obstacles or designated areas, such as forestation, listed buildings, marshland,

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etc. A user study is conducted to evaluate the usability of the system and to evaluate the quality of roads generated in a diverse range of scenarios. The results indicate that our system is both user-friendly and able to produce roads that are true to the user's intention.

Our algorithm for generating a road in our system is summarised in the steps below:

1. Sample the user's sketch.
2. Identify connection constraints.
3. Generate a clothoid curve.
4. Constrain curve in the *xz*-plane.
5. Project curve onto the terrain.
6. Constrain curve in the *y*-dimension.
7. Construct the road geometry.

1.1. Contributions

In this paper we present two significant contributions that both complement and extends existing work on sketch-based systems for road design [1]:

- A novel sketch-based system that allows novice users to design, create, and visualise roads on both flat and undulating terrain. Parameters in the algorithm can be tailored to exhibit particular road characteristics (Fig. 7).
- Influence regions: These are user-specified areas of the environment that influence the path of generated roads by attracting or repelling roads to/from certain obstacles or designated areas (Fig. 8).

2. Related work

A variety of techniques to automatically generate roads have been studied in the literature. Chen et al. [2] propose a method to interactively and intuitively generate large-scale road networks based on tensor fields that guide the structural layout of roads. In their work, the authors present a variety of techniques to manipulate these tensor fields to obtain typical urban street networks. The technique presented focuses on the layout of roads rather than geometric detail and is limited to environments with relatively flat terrain, as the algorithm is unable to displace the height of the landscape to smooth road inclination. Galin et al. [3] proposed an automated technique for generating roads in complex environments that contain rivers, lakes, mountains, and forests. A weighted shortest-path algorithm is performed between an initial and final location on the landscape which is discretised into a regular grid. Weightings can be adjusted interactively to create roads which exhibit certain characteristics. However, there is no facility to explicitly describe the desired path of the road and may require significant editing to meet user expectations. More recently, Talton et al. [4] have proposed an algorithm to generate grammar-based procedural models, given a high-level specification of the desired output and an associated grammar. The input specification can be image-based, volume-based, or as an analytical objective. The algorithm has been demonstrated on trees, cities, buildings, and Mondrian paintings, with the resulting models having high similarity to the input specifications.

There has been an abundance of research on sketch-based modelling techniques that allow novice users to intuitively design and develop geometric structures. Jeon et al. [5] presents a sketch-based interface to create three-dimensional animations using a multiple-pass system that allows users to draw the trajectory of motion in different planes. The authors approximate the input sketch using a uniform cubic B-spline due to their affine invariance and local control. To provide increased functionality, additional parameters can be specified using gestures. Sketch-based systems for road design have been explored by Blessing et al. [6], who generate the shape of a road by segmenting the user sketch into a series of straight lines and Bézier curves. Consecutive tangent lines are then connected using cubic curves to construct a continuous centre-line for the road. The resulting roads are generated in real-time, but the system is restricted to the generation of roads in two-dimensions only.

Our work is most similar to McCrae and Singh's research on piecewise clothoid curves for sketch-based path design [7,8]. Clothoid curves (also known as Euler Spirals or Cornu Spirals) are used in road design as their curvature varies linearly along the length of their arc (Fig. 1). This property allows resulting roads 'to be navigated at constant speed by linear steering and at a constant rate of angular acceleration' [7]. In their work, the authors present a technique for creating roads from sketches by transforming input strokes into a discrete curvature-space representation. In this space the sketch is simplified using a dynamic programming algorithm to reduce its complexity and the resulting linear pieces can be mapped to clothoid segments in Euclidean-space using Fresnel integrals:

$$v = \pi B \begin{pmatrix} C(t) \\ S(t) \end{pmatrix}$$

$$C(t) = \int_0^t \cos \frac{\pi}{2} u^2 \, du$$

$$S(t) = \int_0^t \sin \frac{\pi}{2} u^2 \, du$$

where v is the two−dimensional Euclidean−space vertex at length t along the arc and πB is a scaling parameter. Evaluating Fresnel integrals can be computationally expensive, therefore rational approximations are used to obtain similar results when performance of the algorithm is more important than accuracy [9]:

$$C(t) \approx 0.5 - R(t)\sin(0.5\pi(A(t) - t^2)) \quad (1)$$

$$S(t) \approx 0.5 - R(t)\cos(0.5\pi(A(t) - t^2)) \quad (2)$$

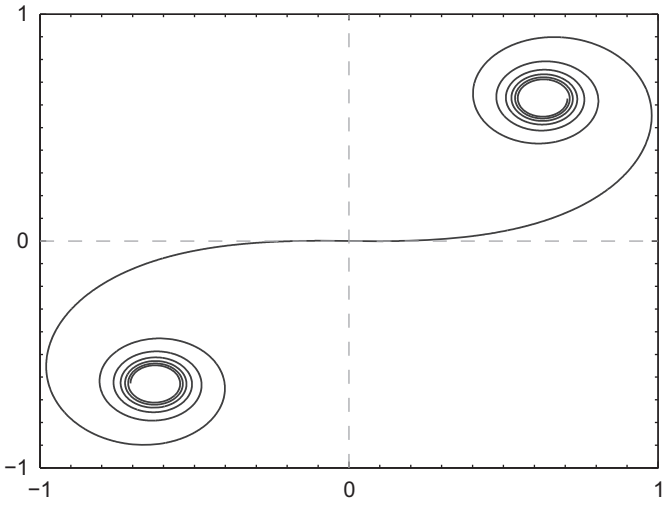

Fig. 1. Clothoid: A curve whose curvature varies linearly along the length of its arc.