Available online at www.sciencedirect.com

ScienceDirect

Journal of Computational Design and Engineering 2 (2015) 67–72

www.elsevier.com/locate/jcde

An algorithm for estimating surface normal from its boundary curves

Jisoon Park[a,*], Taewon Kim[b], Seung-Yeob Baek[c], Kunwoo Lee[b]

[a] *3D Systems Korea, Inc. Innovation Center, 525, Seolleung-ro, Gangnam-gu, Seoul, Republic of Korea*
[b] *School of Mechanical and Aerospace Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul, Republic of Korea*
[c] *Institute of Advanced Machinery and Design, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul, Republic of Korea*

Received 11 August 2014; received in revised form 13 November 2014; accepted 27 November 2014
Available online 6 December 2014

Abstract

Recently, along with the improvements of geometry modeling methods using sketch-based interface, there have been a lot of developments in research about generating surface model from 3D curves. However, surfacing a 3D curve network remains an ambiguous problem due to the lack of geometric information. In this paper, we propose a new algorithm for estimating the normal vectors of the 3D curves which accord closely with user intent. Bending energy is defined by utilizing RMF(Rotation-Minimizing Frame) of 3D curve, and we estimated this minimal energy frame as the one that accords design intent. The proposed algorithm is demonstrated with surface model creation of various curve networks. The algorithm of estimating geometric information in 3D curves which is proposed in this paper can be utilized to extract new information in the sketch-based modeling process. Also, a new framework of 3D modeling can be expected through the fusion between curve network and surface creating algorithm.

Keywords: Computer-aided design; Curve network; Surface modeling; Surface normal estimation

1. Introduction

Despite decades of research and development, three-dimensional (3D) modeling remains a significant challenge. Computer-aided design (CAD), notwithstanding its enormous progress from the initial-phase Boolean operations on basic diagrams to a variety of geometric operations, still requires a lengthy training period and a high degree of technical expertise. Recent years have seen the emergence of novel modeling technologies for building 3D curve networks from designers' two-dimensional (2D) sketches in an effort to lower the hurdle for using professional 3D modeling tools [1–3]. Such modeling methods are widely used for concept design in the initial phases of design because they facilitate the intuitive expression of the designer's ideas and allow room for additional creative elements.

Despite the advantages of sketch-based modeling tools, 3D curve networks alone cannot provide sufficient visual feedbacks. 3D curve networks give us only the feature lines, which are drawn by designer, not the complete rendered model. In the strict sense, they are not the models, just set of lines. They do not have any surface information so that it is hard to imagine detailed shape of the model. Therefore, constructing the surface model from its drawn curve networks is essential. Besides providing more precise visual feedback, the constructed surface model can be used in a wide variety of application fields, such as analysis, simulation, and 3D printing.

However, constructing a model with only position information and topological relationships on the curve has an inherent problem of uncertainty that provides room for numerous analytical approaches rather than an optimal solution.

This fundamental problem has long been treated in the field of CAD, and is referred to as lofting or skinning. This is a problem arising from the lack of geometric information on the generated model. In order to address this problem, an optimization model that can precisely reflect additional constraint conditions or design intentions needs to be defined.

*Corresponding author. Tel.: +82 2 3218 0596; fax: +82 2 6262 9999.
E-mail address: Jisoon.Park@3DSystems.com (J. Park).
Peer review under responsibility of Society of CAD/CAM Engineers.

http://dx.doi.org/10.1016/j.jcde.2014.11.007

The difficulties related to solving these problems are as follows: (i) whether additional geometric information can be obtained from the position information and the topological relationships of curves (possibility issue), and (ii) whether the geometric information obtained in one manner or another reflects the design intention correctly (validation issue).

Against this background, this study aims to achieve an automatic implementation of curved surface modeling by determining the geometric features of 3D curve networks. For the determination of such geometric features, a new frame for points on the target curve was determined using a rotation-minimizing frame (RMF).

RMF is one kind of moving orthogonal frame defined on curves that has no rotation about the instantaneous tangent of the curve. Due to its minimal twist, RMF is widely used in computer graphics, motion design and sweep surface modeling in CAD. Though it is harder to compute than Frenet frame, it does not have discontinuity that is unacceptable in surface modeling. With these features, RMF is suitable for estimating geometric information of curves.

Using this newly defined frame, we determined the normal vector to the curve that matches the design intention on the basis of sketch tutorials and previous cognition-related studies.

The method proposed in this paper is different from the methods presented in existing papers in that the proposed method allows curve modeling under the condition of a lack of geometric information by establishing an optimization equation reflecting the design intention and determining the normal vector. The methods to create surface model in most previous studies are based on patch generation algorithm with known geometric information. In this paper, we proposed new method that estimating surface normal vector from its boundary curve. It has significance for not only constructing 3D model from curve network with better result but also estimating unknown geometric information.

The remainder of this paper is organized as follows: Section 2 presents the problem-solving approaches adopted by existing papers in relevant fields. Section 3 describes the entire procedure for the proposed curved surface modeling. Section 4 contains an elaborated description of the algorithm used for the determination of geometric features and the modeling process based on these features. Section 5 provides an overview of the modeling results for various curve networks. Finally, Section 6 contains conclusions, limitations, and the future research direction.

2. Literature review

Since the introduction of the modeling method using a sketch-based interface over a decade ago, it has been the object of intense research. Teddy, a system developed by Igarashi et al. [4] converts a 2D silhouette into a 3D surface by adding an inflated appearance to the surface surrounded by the silhouette, thus enabling intuitive modeling from a simple sketch. Fibermesh developed by Nealen et al. [5] added functional features allowing free transformations and corrections of Teddy-based surfaces. Rivers et al. [6] presented a new algorithm for 3D modeling by integrating multifactorial 2D silhouette data.

In parallel to this stream of research, there has been considerable research focused on the methodologies for the construction of 3D curve networks. ILoveSketch presented by Bae et al. [1] is a system for constructing 3D curve networks allowing direct sketching on gesture-based interfaces. With JustDrawIt!, Grimm and Joshi [2] presented a 2D-to-3D conversion method by analyzing a newly drawn 2D sketch and defining its relationships to an existing sketch. Schmidt et al. [3] implemented a mathematical model by analyzing the sketching process and reconstructing a 2D sketch as a 3D sketch.

The paper by Schaefer et al. [7] is representative of the studies presenting surface modeling based on the 3D curve networks thus constructed. This paper presented a method of improving a model towards satisfying C1 continuity after generating rectangular patches from the adjacent curves within the constructed curve networks and segmenting them using the Catmull–Clark subdivision method. Although this method shows satisfactory results provided that curve networks describe the model exactly, it has the limitation of model entanglement when dealing with complicated curve sketches.

Abbasinejad et al. [8] defined problems through linearization by using a Laplacian method instead of an optimization approach. In this method, any given circle is rendered in triangular meshes, followed by model construction by joining meshes on the silhouette of each curve patch and generating a model similar to a soap film by using linear interpolation. Although it has the advantage of rapid linear algebraic computation, it is limited by the inferior quality of a thus-yielded model because of the insufficient exploitation of geometric data.

Bessmeltsev et al. [9] conducted a study on a design-based modeling method, wherein a model is generated from rectangular meshes constructed with the curve pairs that best reflect the design after iteratively extracting them from the curves on a surface. This method has the advantage of the superior quality of the resulting model because it uses an optimization method considering the design, but has the drawback of requiring an enormous amount of time for extracting all curve pairs from the targeted curves.

The latest method known thus far is the patch decomposition method proposed by Abbasinejad et al. [10]. In this method, the problem of patch generation on a complicated curve is addressed by decomposing patches into quasi-planar ones. The main limitation of this new approach is the unsmooth continuity because patches are generated through decomposition.

Although these studies also convert curve network to 3D surface model, the results are different with our aim which is providing visual feedback to designer. It should compute quickly enough to show the result model in response to designer's sketch and also provide precise visual feedback. Schaefer et al. [7] does not get the consistent results when used in complex curve network. Bessmeltsev et al. [9] takes too much time so it cannot show its result in real-time. Abbasinejad et al. [8,10] possibly generate the surface model in real-