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Project-Team Tsinghua-CAD

Computer Aided Design

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Theme : Computational models and simulation

Activity Report

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Tsinghua-CAD is a research project shared by INRIA and Tsinghua University. It is a research group of the Institute of Computer Aided Design at Tsinghua University.

1. Team

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2. Overall Objectives

2.1. Overall Objectives

Our overall objectives are to increase precision of shape modeling and processing, and more fundamentally to study mathematical and computational aspects of curves and surfaces. We thus propose to construct a new system of continuity theories, called floating-point continuities, to bridge the gap between the traditional mathematics and modern computer science. Based on the floating-point continuities and epsilon-geometry continuities approaches introduced in our recent publications, we reconsider several key geometric modeling operators.

Note that we also proposed some contributions in Computer Graphics with some Master students and with two young Tsinghua researchers, who prepared a Ph D (Weiming Dong) or a Post Doc (Bin Wang) at INRIA with us.

2.2. ε-geometry continuities

Continuities are the basic and important properties of shapes. Continuities of a surface can be addressed by the continuities of curves on the surface in arbitrary directions. Our prior works have found that epsilon-geometric continuities have some advantages over traditional parametric continuities and geometric continuities. Thus, we focus on designing curves with epsilon-geometric continuities and completely lying on a free form surface. This work will play an important role in surface blending, surface-surface intersection, surface trimming, numerical control (NC) tool path generation for machining surfaces, and so on as well.

To ensure positional continuity between the blending and base surfaces for example, linkage curves are usually first computed in the parametric domain, and then represented as the mapping of the domain curves on the base surfaces. To compute the exact curve on a free form surface in control point representation, many algorithms have been presented. However, the degrees of exact curves are considerably high, which results in computationally demanding evaluations and introduces numerical instability.

To overcome the problems of the exact, explicit representation, many approximation algorithms have been presented. To our knowledge, all presented approximation algorithms generate curves not lying completely on the surface.

If such a curve is used as a boundary curve of another surface, gaps may occur between the two surfaces, which are not acceptable in many CAD applications. In surface blending for example, if the linkage curves are not completely on the base surfaces, the blending surface and the base surfaces are not even G^0 continuous.

Novelty and originality:

We plan to study approximation algorithms that generate low degree curves lying completely on the free form surfaces. Until now, we know how to generate the initial approximate polyline, how to control the Hausdorff distance between the approximate curve and the user-specific tolerance and, finally, how to generate an $\varepsilon - G^1$ continuous curve. Our goal is to climb-up a new step in the continuity problem. We plan to study approximation algorithms that generate low degree curves lying completely on the free-form surfaces and satisfying the epsilon-continuity condition.

2.3. Floating points continuities

Up to now, almost all geometric modeling tool kits are based on traditional mathematics. They ignore the fact that computers can only represent a finite set of real numbers and simply use the formula $(a - \varepsilon < b)$ and $(b < a + \varepsilon)$ to compare whether two real numbers a and b are equal to each other or not. In the way, it becomes a very hard problem how to choose the proper value ε, i.e., the precision is often out of control in geometric modeling tool kits although few documents report such the fact. Our previous researches showed that it would require much more data for representing bodies as well. We need to build new theories from traditional mathematics such that they can well fit in with the modern computer science.

Let's consider, for example, the problem of whether two line segments intersect in the plane in Euclidean geometry. A lot of researches on this problem focus on the accuracy of the testing results by computers. Some authors find that the errors in floating-point arithmetic may make two lines intersect more than once. Exact arithmetic methods are able to make each step of computations exact and always produce correct results. However, they require much more execution time than the inaccuracy floating-point arithmetic methods, which are frequently used. Thus, one of the research directions on this problem is to improve the efficiency of the exact arithmetic. Some authors propose a technique, named double precision geometry, which could replace exact arithmetic with rounded arithmetic in computing intersections of a set of lines or line segments. Some authors give a method to reduce the cost of exact integer arithmetic with a floating-point filter and interval analysis or provide another method, named static-analysis techniques, to reduce the cost of exact integer arithmetic.

Another research direction is to investigate how to reduce the error when using fixed length floating-point arithmetic. Following this way, we have achieved a lot of important results, such as our efficient exact floating-point summation method.

Originality and novelty:

We will propose a new approach to construct a new system of continuity theories, called floating-point continuities. Based on this theory, we propose to construct NURBS surfaces satisfying the floating-point continuity condition. With this contribution, we hope to bridge the gap between the traditional mathematics used in Shape Modeling and modern computer science and act as a pioneer in this new research avenue.

3. Scientific Foundations

3.1. Scientific Foundations

In Geometry Modeling, shapes are described in term of Parametric Surfaces. The pioneering work in this domain was the theory of Bézier curves and surfaces (theory of polynomial curves and surfaces in Bernstein form), later combined with B-spline methods. Today, Non-Uniform Rational B-Spline (NURBS) have become the standard curves and surfaces description in the field of CAD. Differential Geometry is also an important scientific foundation for Geometry Modeling. Differential geometry is based largely of the pioneering work of L. Euler (1707-1783), C. Monge (1746-1818) and C.F. Gauss (1777-1855). One of their concerns was the description of local curves and surface properties such as curvature. These concepts are also of interest in modern computer-aided geometry design. The main tool for the development of general results is the use of local coordinate systems, in term of which geometric properties are easily described and studied.

3.2. Previous Works

Our Project was created in 2005. Since 2005, we published more than 15 articles in the most prestigious journals related to CAD, i.e. Computer Aided Design (Elsevier) and Computer Aided Geometry Design (Elsevier) and about 40 articles in other International Journals and Conferences (References in website).

4. Application Domains

4.1. Application Domains

Geometry Modeling and Computing has a dramatic impact on the way. Design and Engineering's work: Sketch design, Aerodynamics simulations, Mechanical Engineering, Manufacturing, Crash test, Pilot training, Marketing, Maintenance operation, etc. Today, all these operations are based on a mathematical ad computational representation of surfaces and volumes and require a high level of precision.

5. Software

5.1. Software

TiGems: TiGems is a Geometry Modeling Library.

6. New Results

6.1. Geometry Modeling and Computing

6.1.1. Computing the minimum distance between two Bézier curves

Keywords: *Bézier curve*, *Minimum distance*, *Sweeping sphere clipping method*.

Participants: Xiao-Diao Chen, Linqiang Chen, Yigang Wang, Gang Xu, Jun-Hai Yong, Jean-Claude Paul.

A sweeping sphere clipping method is presented for computing the minimum distance between two Bézier curves. The sweeping sphere is constructed by rolling a sphere with its center point along a curve. The initial radius of the sweeping sphere can be set as the minimum distance between an end point and the other curve. The nearest point on a curve must be contained in the sweeping sphere along the other curve, and all of the parts outside the sweeping sphere can be eliminated. A simple sufficient condition when the nearest point is one of the two end points of a curve is provided, which turns the curve/curve case into a point/curve case and leads to higher efficiency. Examples are shown to illustrate efficiency and robustness of the new method [12].

6.1.2. A torus patch approximation approach for point projection on surfaces

Keywords: *Point projection; Torus patch approximation; Parametric surface*.

Participants: Xiao-Ming Liu, Lei Yang, Jun-Hai Yong, He-Jin Gu, Jia-Guang Sun.

This paper proposes a second order geometric iteration algorithm for point projection and inversion on parametric surfaces. The iteration starts from an initial projection estimation. In each iteration, we construct a second order osculating torus patch to the parametric surface at the previous projection. Then we project the test point onto the torus patch to compute the next projection and its parameter. This iterative process is terminated when the parameter satisfies the required precision. Experiments demonstrate the convergence speed of our algorithm [18].

6.1.3. Computing the minimum distance between a point and a clamped B-spline surface

Keywords: *B-spline surface*, *Exclusion criterion*, *Minimum distance*, *Newton' s method*.

Participants: Xiao-Diao Chen, Gang Xu, Jun-Hai Yong, Guozhao Wang, Jean-Claude Paul.

The computation of the minimum distance between a point and a surface is important for the applications such as CAD/CAM, NC verification, robotics and computer graphics. This paper presents a spherical clipping method to compute the minimum distance between a point and a clamped B-spline surface. The surface patches outside the clipping sphere which do not contain the nearest point are eliminated. Another exclusion criterion whether the nearest point is on the boundary curves of the surface is employed, which is proved to be superior to previous comparable criteria. Examples are also shown to illustrate efficiency and correctness of the new method [14].

6.1.4. Computing lines of curvature for implicit surfaces

Keywords: *Implicit surface*, *line of curvature*, *principal configuration*, *principal foliation*, *umbilical point*, *visualization*.

Participants: Xiaopeng Zhang, Wujun Che, Jean-Claude Paul.

Lines of curvature are important intrinsic characteristics of a curved surface used in a wide variety of geometric analysis and processing. Although their differential attributes have been examined in detail, their global geometric distribution and topological pattern are very difficult to compute over the whole surface because of umbilical points and unstable numerical computation. No studies have yet been carried out on this problem, especially for an implicit surface. In this paper, we present a scheme for computing and visualizing the lines of curvature defined on an implicit surface. A key structure is introduced, conveying significant structure information about lines of curvature to facilitate their investigation, rather than computing their whole net. Our current framework is confined to a collection of manageable structures, consisting of algorithms to locate some seed umbilical points, to compute the lines of curvature through them, and finally to assemble this structure. The numerical implementations are provided in detail and a novel evaluation function measuring the violation of umbilical points in an implicit surface, i.e. indicating how much a point is to be umbilical, is also presented. This paper is the continuation of [Che, W.J., Paul, J.-C., Zhang, X.P., 2007. Lines of curvature and umbilical points for implicit surfaces. Computer Aided Geometric Design 24 (7), 395-409] [22].

6.1.5. Constructing G^1 quadratic Bézier curves with arbitrary endpoint tangent vectors

Keywords: *Quadratic Bézier curve*, *endpoint condition*, *geometric continuity*, *smoothness*.

Participants: He-Jin Gu, Jun-Hai Yong, Jean-Claude Paul, Fuhua Cheng [Frank].

Quadratic Bézier curves are important geometric entities in many applications. However, it was often ignored by the literature the fact that a single segment of a quadratic Bézier curve may fail to fit arbitrary endpoint unit tangent vectors. The purpose of this paper is to provide a solution to this problem, i.e., constructing G^1 quadratic Bézier curves satisfying given endpoint (positions and arbitrary unit tangent vectors) conditions. Examples are given to illustrate the new solution and to perform comparison between the G^1 quadratic Bézier cures and other curve schemes such as the composite geometric Hermite curves and the biarcs [24].

6.1.6. Approximate computation of curves on B-spline surfaces using quadratic reparameterization

Keywords: *Approximation*, *B-spline*, *Curve approximations*, *Curves on surfaces*.

Participants: Yi-Jun Yang, Jun-Hai Yong, Jean-Claude Paul.

Curves on surfaces play an important role in computer-aided geometric design. Because of the considerably high degree of exact curves on surfaces, approximation algorithms are preferred in CAD systems. To approximate the exact curve with a reasonably low degree curve which also lies completely on the B-spline surface, an algorithm is presented in this paper. The Hausdorff distance between the approximate curve and the exact curve is controlled under the user-specified distance tolerance. The approximate curve is $\epsilon_T G^1$ continuous, where ϵ_T is the user-specified angle tolerance. Examples are given to show the performance of our algorithm [21].

6.1.7. $\overrightarrow{\epsilon} - G^2$ B-spline Coons surface construction

Keywords: *B-spline surface*, *Coons surface*, *G 2 continuity*, *geometric tolerance*.

Participants: Kan-Le Shi, Jun-Hai Yong, Jia-Guang Sun, Jean-Claude Paul.

Coons surface is one of the most significant and widely used representations of shapes in computers. Its construction method is a recurring and essential operation in computer aided geometric design. This paper proposes an approach to construct a biquintic Coons surface having $\overrightarrow{\epsilon} - G^2$ continuity with the specified boundary derivatives in the B-spline form, for arbitrary geometric tolerance vector $\overrightarrow{\epsilon}$. It presents the definition of this geometric invariant measure of angular and curvature tolerances. The methods of handling six types of the compatibility problems in constructing biquintic B-spline Coons surfaces are also proposed. Several examples are provided as well in this paper [19].

6.1.8. G^n blending multiple surfaces in polar coordinates

Keywords: *Multiple surface blending*, *Polar coordinate; NURBS surface; G n continuity; N-sided hole filling*.

Participants: Kan-Le Shi, Jun-Hai Yong, Jia-Guang Sun, Jean-Claude Paul.

This paper proposes a method of G^n blending multiple parametric surfaces in polar coordinates. It models the geometric continuity conditions of parametric surfaces in polar coordinates and presents a mechanism of converting a Cartesian parametric surface into its polar coordinate form. The basic idea is first to reparameterize the parametric blendees into the form of polar coordinates. Then they are blended simultaneously by a basis function in the complex domain. To extend its compatibility, we also propose a method of converting polar coordinate blending surface into N NURBS patches. One application of this technique is to fill N-sided holes. Examples are presented to show its feasibility and practicability [20].

6.2. Others

6.2.1. Optimized image resizing using seam carving and scaling

Keywords: *DCD*, *IMED*, *Image distance function*, *Image resizing*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul, Xiaopeng Zhang.

We present a novel method for content-aware image resizing based on optimization of a well-defined image distance function, which preserves both the important regions and the global visual effect (the background or other decorative objects) of an image. The method operates by joint use of seam carving and image scaling. The principle behind our method is the use of a bidirectional similarity function of image Euclidean distance (IMED), while cooperating with a dominant color descriptor (DCD) similarity and seam energy variation. The function is suitable for the quantitative evaluation of the resizing result and the determination of the best seam carving number. Different from the previous simplex-mode approaches, our method takes the advantages of both discrete and continuous methods. The technique is useful in image resizing for both reduction/retargeting and enlarging. We also show that this approach can be extended to indirect image resizing [17].

6.2.2. Robust tile-based texture synthesis using artificial immune system

Keywords: *Artificial immune system*, *Clonal selection*, *Sample patches selection*, *Texture synthesis*, *ω-tile*.

Participants: Weiming Dong, Ning Zhou, Jean-Claude Paul.

One significant problem in tile-based texture synthesis is the presence of conspicuous seams in the tiles. The reason is that sample patches employed as primary patterns of the tile set may not be well stitched if carelessly picked. In this paper, we introduce a robust approach that can stably generate an ω-tile set of high quality and pattern diversity. First, an extendable rule is introduced to increase the number of sample patches to vary the patterns in an ω-tile set. Second, in contrast to other concurrent techniques that randomly choose sample patches for tile construction, ours uses artificial immune system (AIS) to select the feasible patches from the input example. This operation ensures the quality of the whole tile set. Experimental results verify the high quality and efficiency of the proposed algorithm [16].

6.2.3. Review on recent patents in texture synthesis

Keywords: *Texture synthesis*, *anisometric synthesis*, *block sampling*, *image repairing*, *neighborhood matching*, *texture magnification*.

Participants: Weiming Dong, Jean-Claude Paul.

Computer graphics applications often use textures to render synthetic images. These textures can be obtained from a variety of sources such as hand-drawn pictures or scanned photographs. Texture synthesis is an alternative way to create textures. Because synthetic textures can be made any size, visual repetition is avoided. The goal of texture synthesis can be stated as follows: given a texture example, synthesize a new texture that, when perceived by a human observer, appears to be generated by the same underlying process. This paper reviews the recent patents on texture synthesis schemes. The key components in a texture synthesis algorithm, such as neighborhood matching, block sampling, anisometric synthesis, etc., are discussed. Then we discuss the applications of texture synthesis in texture magnification and image repairing. This paper also points out future works on this issue [15].

6.2.4. Geometry Textures and Applications

Keywords: *Geometry texture*, *Mesostructure*.

Participants: Rodrigo de Toledo, Bin Wang, Bruno Lévy.

Geometry textures are a novel geometric representation for surfaces based on height maps. The visualization is done through a GPU ray casting algorithm applied to the whole object. At rendering time, the fine-scale details (mesostructures) are reconstructed preserving original quality. Visualizing surfaces with geometry textures allows a natural LOD behavior. There are numerous applications that can benefit from the use of geometry textures. In this paper, besides a mesostructure visualization survey, we present geometry textures with three possible applications: rendering of solid models, geological surfaces visualization and surface smoothing [23].

6.2.5. High quality solid texture synthesis using position and index histogram

Keywords: *Index histogram matching*, *Position histogram matching*, *Solid texture*, *Texture synthesis*.

Participants: Jiating Chen, Bin Wang.

The synthesis quality is one of the most important aspects in solid texture synthesis algorithms. In recent years several methods are proposed to generate high quality solid textures. However, these existing methods often suffer from the synthesis artifacts such as blurring, missing texture structures, introducing aberrant voxel colors, and so on. In this paper, we introduce a novel algorithm for synthesizing high quality solid textures from 2D exemplars. We first analyze the relevant factors for further improvements of the synthesis quality, and then adopt an optimization framework with the k-coherence search and the discrete solver for solid texture synthesis. The texture optimization approach is integrated with two new kinds of histogram matching methods, position and index histogram matching, which effectively cause the global statistics of the synthesized solid textures to match those of the exemplars. Experimental results show that our algorithm outperforms or at least is comparable to the previous solid texture synthesis algorithms in terms of the synthesis quality [13].

7. Contracts and Grants with Industry

7.1. Mesh-NURBS (with CHIDI China)

Participants: Jean-Claude Paul, Jun-Hai Yong, Nabil Anwer.

The goal of this project was to design dams and to simulate their impact in the geological structures. In civil engineering, numerical geometric models are based on B-spline representations. Geological structures are based on mesh representation. As a first step, we have proposed an algorithm for mesh-mesh Boolean operations.

7.2. Modeling of Winglets (with AIRBUS)

Participants: Wenke Wang, Jean-Claude Paul, Hui Zhang.

The goal of this project is to generate and control the Mesh representation of Flight Physics simulation for "Winglet" design. The challenge is to increase the geometry precision and the need of the design process by using untrimmed B-Spline representations.

7.3. Geometry Modeling from NC Simulation (with Spring Technologies, France)

Participants: Yijun Yang, Jean-Claude Paul, Hui Zhang.

The goal of this Project is to construct a NURBS Model from triangle sets and complex machining operations. The reconstruction process needs to create vertices, edges, wires, faces, shell and then the solid. The output solid must be topologically closed and must suit current CAM software requirements.

8. Other Grants and Activities

8.1. International Initiatives

The *IEEE International Conference of Shape Modeling* in 2009 has been co-chaired at Beijing by Pr. Jia-Guang Sun (Tsinghua University) and Pr. Jean-Claude Paul (INRIA). Prof. Jun-Hai Yong co-chaired the committee papers.

9. Dissemination

9.1. Teaching

- Pr. Jun-Hai Yong (128 hours), Pr. Jean-Claude Paul (64 hours) and Dr. Hui Zhang (96 hours) gave courses in the School of Software and in the Department of Computer Science at Tsinghua University.

9.2. Invited Talks

Pr. Jean-Claude Paul and Pr. Jun-Hai YOng gave lectures at Wuhan University, Hunan University, Guangxi University, Xiamen University and Zhejiang University.

9.3. Visiting Scientists

Pr. Jean-Claude Paul obtained in 2009 a grant for the Tsinghua Chair Professor Group for three Years (Computer Science).The grant supports the invitation of world-wide renowned professors at Tsinghua University. The participants of this year were: Francois Sillion (INRIA), Fredo Durand (MIT), Jean Daniel Boissonnat (INRIA), Pierre-Louis Curien (CNRS), Jean-Pierre Jouannaud (INRIA), Joseph Sifakis (INRIA-VERIMAG).

In 2009, Mathieu Desbrun (CalTech), Mark Pauly (ETH Zurich), Takeo Igarashi (Tokyo University) and Georges-Pierre Bonneau (University of Grenoble) as Lecturers at Tsinghua University. Bonneaud (UJF) visited our team and gave Lectures at Tsinghua University.

9.4. Program Committees

Pr. Jun-Hai Yong and Pr. Jean-Claude Paul are Programm Committee Members and Reviewers in several International Journals and Conferences.

10. Bibliography

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Articles in International Peer-Reviewed Journal

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