Title:
Reconstruction of Branched Surfaces: Experiments with Disjoint B-spline Surface

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Introduction:

Surface reconstruction is a process where a desired shape is constructed using the scanned data. Some of the applications are modeling of human airway tree, femur, human vasculature, automobile parts (like muffler and tubular frame parts) and terrain reconstruction. This reconstruction, at times, involves branching (furcation) i.e. creation of disjoint surfaces (branch) from one contour to two or more contours in adjacent plane. This branched surface may have various geometrical (like continuity and planarity) and topological (like shape and multi-furcation) complexities.

Accordingly, different techniques in the past have addressed the problem to varying levels of complexities. Amongst them a lot of work [1], [3], [5], [8], [9] has been done towards stepwise surface construction and then gluing them together to get a single surface. Some methods [2], [3], [9] even required an additional hole filling step. These serial processes become complex and involve large computation time especially for applications like modeling of human airway tree [6]. Therefore, in this paper we present a new and simpler method to reduce the steps by adopting a single equation to create disjoint B-spline surface which can have different orders in both parametric directions (u and w). At the same time our method addresses the requirements of continuity, geometric and topological complexities.

Main Idea:

We have considered data points as control points of B-spline surface equation (as described in [7]). In case of fitting requirements the control points can be extracted from data points by method as described in [7]. In this work, surface parameter u is along the closed contours and w is along the length of the branch. First, by experimentation on curves we found a generalized formula to define the range of parameter u to get disjoint B-spline curves (Fig. 1(a)). This algorithm was extended to surfaces to get disjoint surfaces but the result was a open surface (open area circled in black in Fig. 1(b)). Thereafter, we selected a proper arrangement of control points to ensure minimal twisting and most importantly: non-intersection of branched surfaces. After experimentation, a generalized method to manipulate the control polyhedron was adopted (Fig. 1(c)) to construct a disjoint B-spline surface for both cases: periodic (Fig. 1(d)) as well as uniform knot vectors.

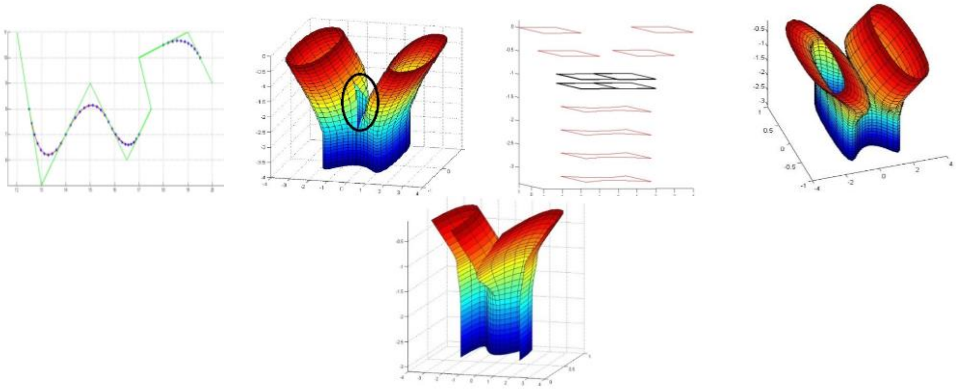

Fig. 1: Steps to generate branch of order 3. (a) Disjoint curve, (b) open 3^{rd} order branched surface (c) Manipulation of control polyhedron: insertion of two adjoining slices. (d) 3^{rd} order branched surface and (e) is its open section.

In this work, the control polyhedron (Fig. 1 (c)) sections are taken as simple polygons for ease of understanding. The control polyhedron is re-defined such that two additional sections (black coloured in Fig. 1(c)) are inserted after the end of single sections and before the beginning of separate sections. It is important here that the inserted sections share one common edge. The control points on these inserted sections are manipulated in a particular fashion to get a closed surface. Their shape, not necessarily be the same as preceding or succeeding section (Fig. 2(a)). In our method the surface is limited to 3^{rd} order along u. The minimum continuity (in parametric space) along u is G^1 (Fig. 1(d)) while along v it is C^1 continuous. But to increase the order of continuity in object space, along w by one unit, the number of sections to be inserted needs to be incremented by 1 unit. Though the position (longitudinal position) of the sections affects the shape, but for all positions a closed branched surface is always obtained.

Amongst earlier efforts using B-splines, [4] encountered open surface similar to Fig.1 (b), for which additional hole filling computations were implemented. While [5] used NURBS to create two surfaces separately and then joined them. These hole-filling and joining steps are not required in our method. Joining of the surfaces together leads to more complexities. For example, amongst the latest efforts [3] glued the furcation with other surfaces to make the complete model using method based on parallel transport frame. They could not fully solve the problem of frame blending required for successful surface integration. Moreover, it was limited to branches with circular profile. Our method can handle complexities of continuity as well as irregular cross-section (Fig. 2(b) and Fig. 2(c)). It can also be extended to multiple furcations unlike method used by [8] which is limited to bifurcations. One of the attempts at constructing G^1 continuous doubly-bifurcated branched model with single equation is shown in Fig. 2(c).

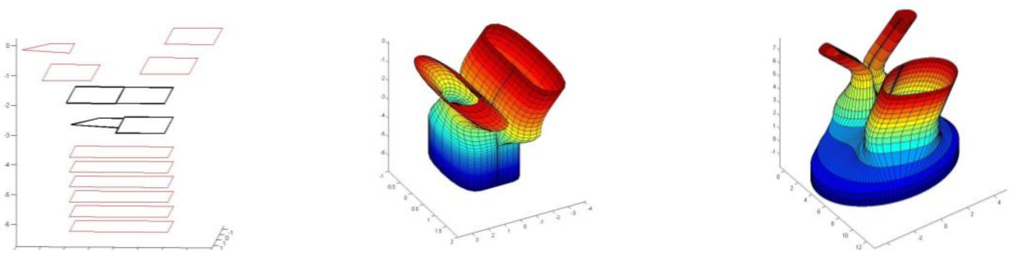

Fig. 2: Some more results. (a) is the control polyhedron for the asymmetric branch (b) with varying cross-section profile. (c) is double bifurcation model.

Conclusion:

The method discussed in this paper has never been used before and opens a new direction for constructing branched surfaces using single equation of B-spline surface. Some of the applications can be design of human airways, automobile manifolds and frame components. Also being a parametric model, meshing is almost automatic and can be used for finite element analysis. This method has given us encouraging results and it can be extended to multi-furcations and other types of branches for which work is going on. Since the method gives a minimum of G^1 continuous (in parametric space) surfaces, it removes additional steps of stitching. Thus, it proves to be easier than other approaches and capable of accommodating design demands of multiple branching, asymmetric branches, continuity and varying cross-sectional profiles.

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