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NUTRIA – SYSTEM OF MODELLING OF NURBS AND TRIANGULATED SURFACES

Key words

CAD, CAGD, free-form surface, NURBS, subdivision, triangulation, Butterfly.

Summary

The paper presents the idea of a 3D modeller dedicated to bent metal plates modelling, designed as a part of a greater application and destined for small and medium-sized enterprises. The aim of the application is to deliver a simple tool for free form surface modelling in two independent modes: as a rectangular parametric NURBS surface defined by regular net of points or alternatively as a surface smoothly interpolating an irregular set of data points, exposed to the process of triangulation and multiple subdivision of mesh of triangles.

Introduction

NuTria is a modeller we have designed and implemented as a CAD application for free-form 3D modelling, with output allowing subsequent data processing, like finite element analysis or manufacturing. The task has been defined as the necessity to give the user a simple, but comprehensive tool to deliver information about a surface most often defined by points lying on the surface. The necessity of Nurbs representation has been evident, but the second mode of work proved to be indispensable for irregular sets of data points; thus the Triangulation mode (named also the Mesh mode) has been designed. The program can work in one of these modes chosen by the user. The output data of the Nurbs surface can compose the input to the Mesh mode, but not vice versa.

1. Interface – widows configuration and object edition

The interface of the system has been designed as simple and intuitive, similar to those used in commonly known CAD applications and allowing short learning. The user typically works with four windows (Fig. 1), but easily he can switch to one, two or four any type windows. The non-trivial solution is the *uv* window for NURBS mode, presented later in the paper. During designing the common view of the window, we wanted the user to have enough workspace and simultaneously all the buttons visible. Thus the NuTria has two panels for buttons and the additional right panel for input of different data and settings and also for displaying the hierarchy tree of objects which the user can manipulate using this tree (drag between group of surfaces, delete etc.).

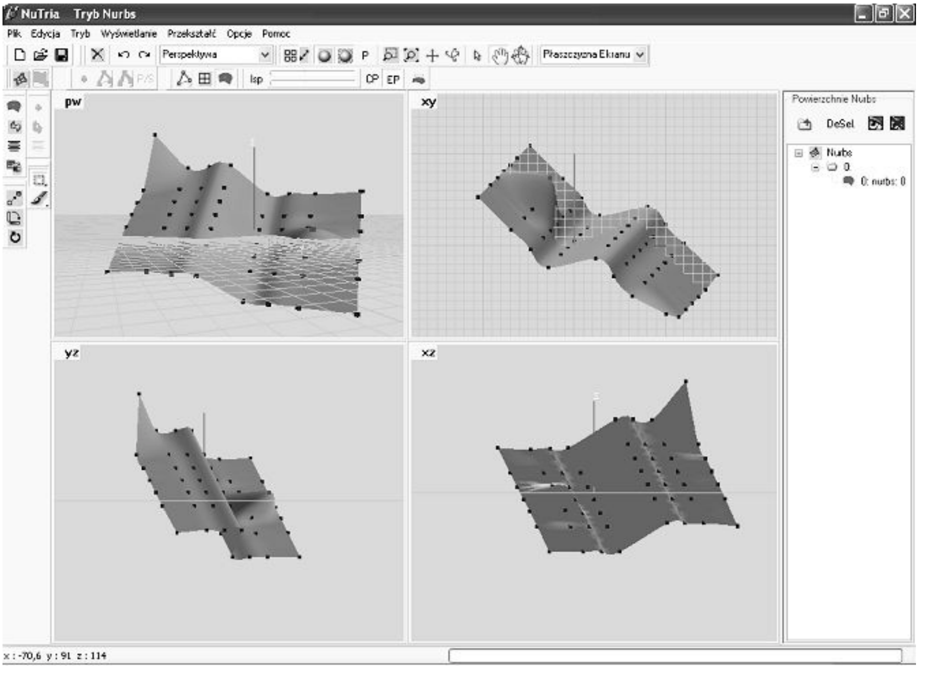

Fig. 1. The interface of NuTria, with active NURBS mode

The user can turn on the history of operations and choose the number of operations back to be saved. Thus the withdrawing of operations is enabled.

2. NURBS modelling mode

We have created a small, but comprehensive tool for defining rectangular patches as parametric surfaces. Their internal representation is the NURBS representation, i.e. Non Uniform Rational B-Splines [2–4]. This form of internal representation a long time ago became a standard in data exchange in CAD applications, but usually, even now, in a high-end modellers not all the parameters of NURBS representation can be accessible and changed by the user, being considered as difficult in usage and less intuitive than other indirect parameters.

The NURBS representation of parametric surface $\mathbf{P}(u, v)$ is composed of

- the rectangular net of control points $\mathbf{D}_{ij}$, $i = 0..m$, $j = 0..n$.
- the degrees (k, r) of surface in both u,v directions
- the weights of control points w_{ij}
- two sequences of knots: $\{u_1, ..., u_{m+k}\}$ and $\{v_1,..., v_{n+r}\}$.

and defined as below:

$$\mathbf{P}(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{ij}\mathbf{D}_{ij}N_i^k(u)N_j^r(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n} w_{ij}N_i^k(u)N_j^r(v)}$$

where $N_i^k(u)$ and $N_j^r(v)$ are B-Spline functions [2–4] defined on adequate sequence of knots.

The user can modify the shape of surface choosing its degrees (if $k = r = 3$, he obtains the most popular bicubic surface), moving the control points, changing the weights of control points and modifying both knot sequences.

We wanted in our modeller the user to become acquainted with the properties and parameters of this form of representation, without the necessity of learning about mathematics and differential geometry. Thus the philosophy approved in the NuTria modeller is to give the user a tool for defining NURBS surfaces in a simple, intuitive manner, simultaneously including the possibility of defining all internal parameters of NURBS representation. With the assumption that the NURBS surface is bicubic, we cannot change its degree, but we can edit the control points (what usually is most popular), and independently edit its weights and change knot vectors.

Defining NURBS surfaces in NuTria always starts from defining a rectangular grid of points, with a selected number of rows and columns, and can be performed in one of two modes:

- interpolation mode, when the points of the grid are the points the user wants to be lying on the defined surface
- control points mode, when the points of the grid are the control points defining bicubic NURBS surface.

The interpolation mode is assumed as the default mode, because it is more intuitive for inexperienced users and more often can occur in practice in the expected usage of the modeller. The switch to the control points mode is available, as in other modellers, and it remains one of the most important functions.

In the control point mode one can observe which part of the surface is changing according to the change of one or more control points moving simultaneously (Fig. 2). This special type of visualisation, not available in other modellers, makes evident for the user that editing of control points has a local influence on the shape of the surface. While dragging the control point, user will see the region of its influence and learn more about the local properties of NURBS representation than from books or manuals. On the contrary, he would know, that dragging grid points in interpolation mode will influence on the shape of all the surface edited. The user can select one or more control points or more rows/columns of control points net and move them simultaneously.

a) b)

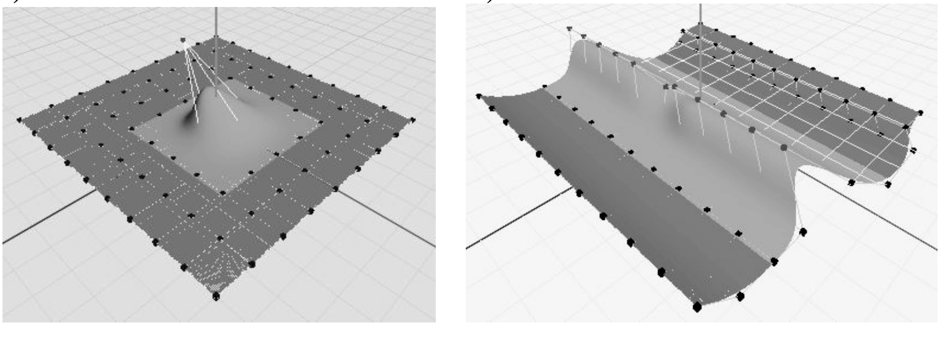

Fig. 2. The effect of modifying a) one control point; b) one row of control points. The region of influence of moving selected control points on the shape of the surface is marked by lighter colour

Changing the weights of control points is also available in NuTria, but this possibility is more typical and can be encountered in other CAD modellers. On the contrary, we also offer a more unique property: the user can change knots in the *uv* plane, dragging the points representing the values of parameters (knots). This way one can obtain multiple knots; using the triple internal knot for bicubic NURBS surface we can easily introduce into the surface the discontinuity of a tangent plane – the sharp internal edge (Fig. 3). The *uv* window opens instead the xz plane in the bottom right window every time we want to edit the knots.

a) b)

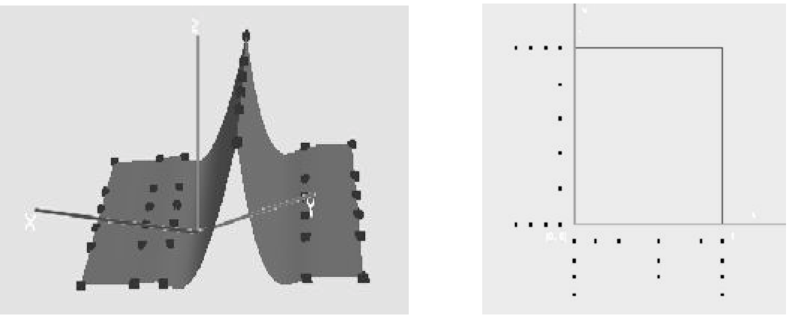

Fig. 3. The multiple knot in the *uv* plane (b) and its influence on the shape of surface (a)

The use of the *uv* plane is also necessary if we want introduce holes into the NURBS surface. The hole in *uv* plane can be circular (or elliptical), rectangular, defined by the closed polygon or by the closed NURBS curve (Fig. 4).

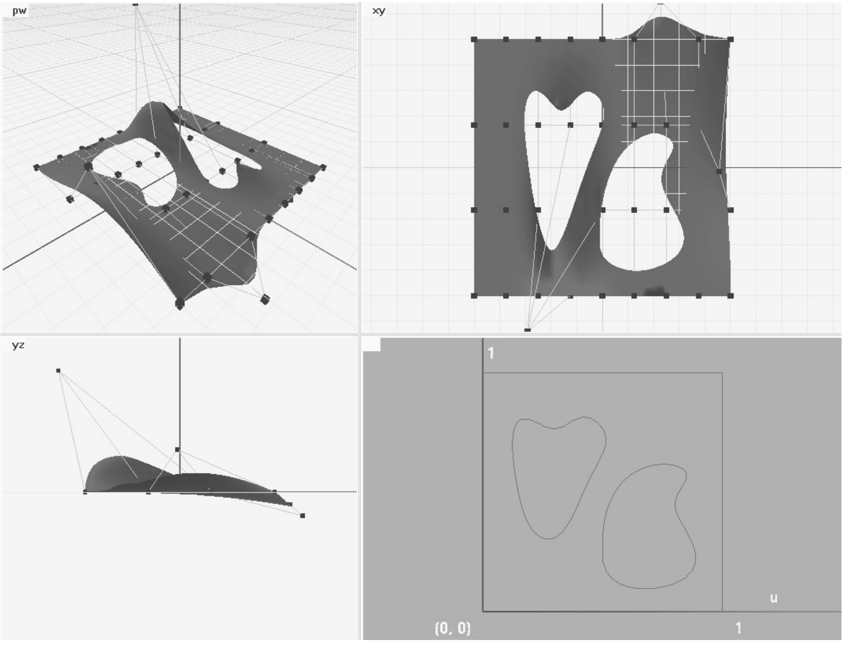

Fig. 4. The holes defined as cubic NURBS curves in the *uv* plane (at bottom right) and their mapping onto the NURBS surface

The linking of NURBS patches is an important functionality of the modeller. The filleting surface, smoothly (with continuity G^1) joining two bicubic NURBS patches along their marked edges, is calculated by the algorithm presented by Kiciak in [4]. The implementation of the algorithm involves knot insertion in the case of different number of control points along the linked edges.

a) b)

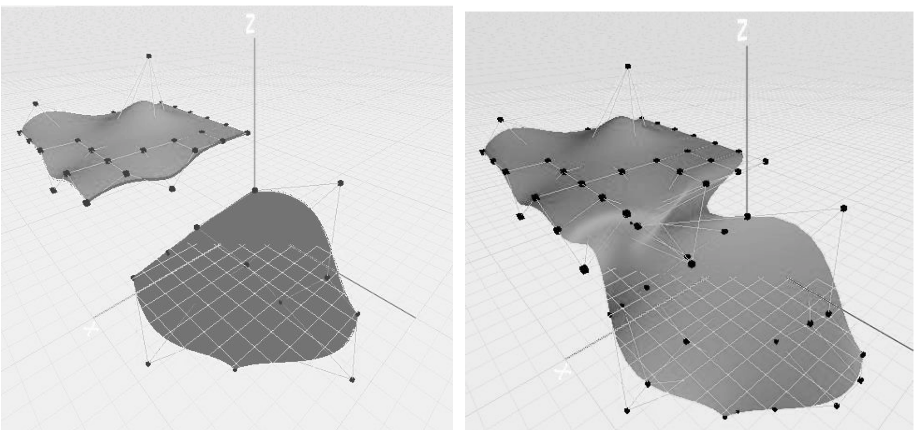

Fig. 5. The linking of NURBS patches: a) two patches before linking; user needs mark edges to be connected; b) the resultant surface is G^1 smooth, but it can be too bent or twisted in the case of unfavourable reciprocal position of linked patches

3. MESH mode

The Mesh mode in NuTria is dedicated to an entirely distinct type of modelling. The user can introduce an irregular set of 3D data points – manually (grid snapping is available) or from the file. The editing of coordinates of points by the mouse or editing values in the edit window (possible with mouse too) is available.

The solution to the problem of triangulation and mesh subdivision in NuTria is presented in detail in [5]. The goal is to get the smooth (in reference to the global shape) surface interpolating data points. The implementation has been done with the base of the Ball Pivoting Algorithm [1] used for triangulation and the modified Butterfly subdivision method [6] as the tool for iterated refinement of the mesh (Fig. 6). After refinement, the user can come back to the original data points, edit them and do the retriangulation with subsequent subdivision.

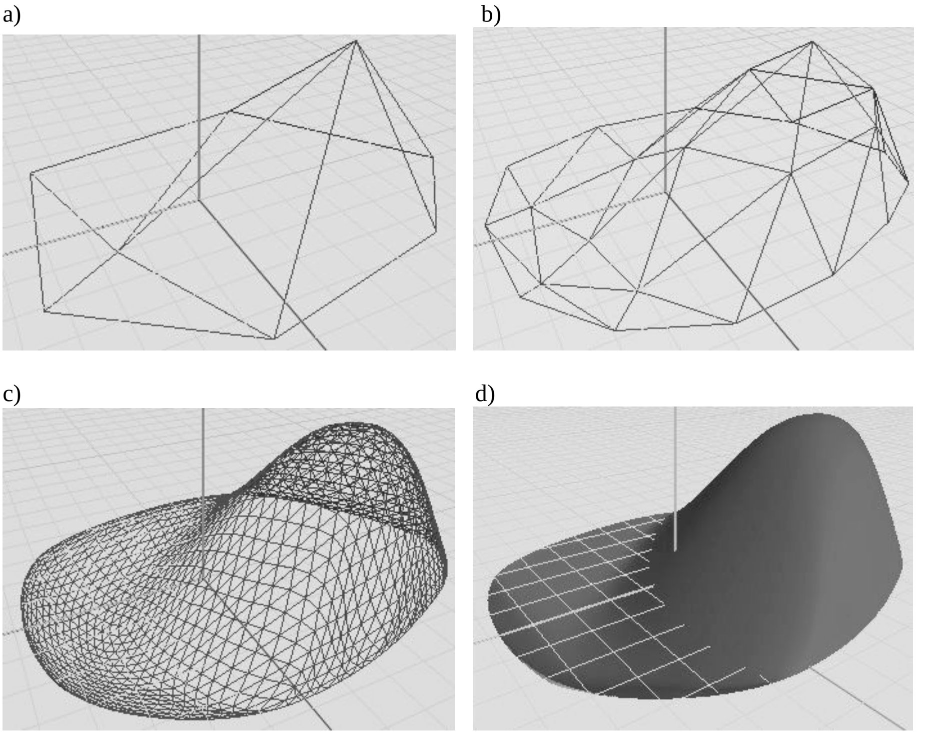

Fig. 6. Modelling in the Mesh mode : a) data points after triangulation; b) the first step of the subdivision; c) the fourth step of the subdivision; d) the shaded image of c) surface

4. Implementation – technical solutions

The implementation of the NuTria has been made with the use of Delphi environment and object programming. As a basis for NuTria GUI, the GLScene was chosen; NURBS and mesh surfaces' definitions and procedures were written without reaching for its utilities, though.

GLScene [7] is an open source graphics library for Delphi/Kylix and Lazarus environments. It utilises OpenGL graphics engine not only making it easy to use, but also significantly expanding its capabilities. Being slightly less efficient than dedicated OpenGL code, GLScene offers time-saving development. Sadly, its documentation is rather poor and lacks a well written help file or object reference. This is the reason why learning its basics can be a struggle with demos and examples. Fortunately, GLScene newsgroup provides strong community support, often being a last resort solving almost every problem.

To design a stage, two components are required to be placed on a form: GLScene, which holds all objects of the scene, and GLSceneViewer, used as a canvas where the scene is rendered. Objects can be added to the scene using the

GLscene editor. The scene has a hierarchical structure – all objects are gathered in a tree-like structure, branching out from a scene root or other objects. This structure is reflected in the rendering process. Thus when the older object is rotated, all its children are rotated respectively. The cameras can be handled very easily, because they are simply just objects of the scene.

The components and procedures of GLScene were used in NuTria for rendering and most of basic editing routines. For handling vertices and edit/control points a class descending from TGLCube (simple cube object) was created. Each movable point had s marker assigned to it. It was used for interacting with the mouse cursor and performing basic operations (vertices displacement and marking). A list of objects found under the cursor can be easily acquired from the GLViewers buffer and then used for marking scene objects (not only markers). Markers, gathered in a list, could be subjected to routines editing the surfaces. These routines (such as rotation or displacement), being of vector nature, took huge advantage of VectorGeometry library, which contains highly optimized routines and type definitions regarding vectors, matrices and quaternions.

Transformation from 2D cursor position to 3D space of scene was solved by the means of ray casting procedures. An intersection point was calculated between a certain plane and a ray projected from a point in the camera's plane corresponding to cursors position. This transformation works for either perspective or orthogonal view.

NuTria program aimed to provide an easy access to advanced editing methods of NURBS surfaces parameters and to provide a variety of surface display methods in both NURBS and MESH mode. To obtain full control over projected objects it was necessary to use pure OpenGL code. Fortunately, GlScene provides a DirectOpenGL object. It behaves the same as other GLScene objects that are placed on the scene. In the rendering procedure of this object the programmer puts a code within which he can use all possibilities included in GL and GLU libraries. In the NuTria program, DirectOpenGL objects were used to display NURBS surfaces and mesh, including display settings and material properties.

Conclusions

NuTria modeller has an open structure. According to requirements it can be improved, modified, expanded and put into practice. The common type of output in both modes is DXF file, thus the data exchange with other applications can be easily realised. The executable file of the modeller is about 1.5 MB.

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Reviewer:
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NuTria – system modelowania powierzchni NURBS i powierzchni triangulowanych

Słowa kluczowe

CAD, CAGD, powierzchnie swobodne, NURBS, subdivision, triangulacja, Butterfly.

Streszczenie

W artykule zaprezentowano modeler powierzchni swobodnych zaprojektowany i zaimplementowany z przeznaczeniem do wdrożenia w małych i średnich przedsiębiorstwach. System pracuje w dwóch niezależnych trybach:

NURBS i Triangulacja. W trybie NURBS służy do modelowania gładkich powierzchni o ciągłej krzywiźnie, zadanych regularnymi siatkami punktów. W trybie Triangulacja (Mesh) służy do wprowadzania nieregularnych zbiorów punktów i generowania na ich podstawie powierzchni interpolujacej. Zadanie to rozwiązano za pomocą triangulacji, a następnie iteracyjnego zagęszczania siatek (tzw. subdivision) z użyciem zmodyfikowanej metody Butterfly. Zapis wyników działania w obu trybach do postaci plików DXF umożliwia przekazywanie danych do innych aplikacji, w celu ich późniejszego wykorzystania do analiz metodą elementu skończonego, w procesie obróbki zaprojektowanej powierzchni itp.