AN OPTIMIZED SHIP HULL FITTING APPROACH USING NURBS

Ang Swee Wen
Department Of Graphics and Multimedia
Faculty of Computer Science and Information System
Universiti Teknologi Malaysia
angeline_aasw@hotmail.com
019-7004817

Siti Mariyam Hj. Shamsuddin
Department Of Graphics and Multimedia
Faculty of Computer Science and Information System
Universiti Teknologi Malaysia
mariyam@fsksm.utm.my
07-5532321

Yahya Samian
Department Of Marine Technology
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
yahya@fkm.utm.my
07-5535701

Abstract

Ship hull form module is the main module in ship design. The problem of creating fair ship hull surface is of major importance in Computer Aided Ship Design environment. The fitness of these surfaces is generally considered a subjective notion depending on the judgment of the designers (eg. visually pleasing, devoid of unnecessary bumps or wiggles, satisfying certain continuity requirements). One of the restriction in ship hull design is that the existing details of a ship design on paper or a ship that already been constructed physically couldn't be reconstructed accurately and concisely in a ship hull design software. This problem can take on many different characteristics, depending on the goal of the reconstruction, the origin of the offset, and tools or methods available to tackle the job. All of these must be taken into account in developing the best approach to solving the problem in the most efficient manner. In the field of surface modeling of hull form, geometric complexity of hull form gives many difficulties. This leads to the issue of what is the best surface reconstruction method for ship hull? This research strives to solve this problem by creating fair ship hull surface using NURBS. An optimized ship hull fitting approach using NURBS is developed. Evaluation and analysis (percentage of accuracy, fairness and speed of processing) on the proposed approach and also comparison of proposed approach and other systems/softwares will be done.

Key words : NURBS, surface reconstruction, ship hull, fitting, ship design

1. Introduction

This research is to reconstruct a concise and accurate approximated physical surface of the ship hull. The generation of NURBS curves and surfaces are used for the fitting of the ship hull because of its high level of continuity, fairness and flexibility. Besides, the amounts of control points needed are less compared to other available parametric surfaces like parabolic blending, bezier, etc.

1.1 Research Objective

In order to achieve the goal of this research (An Optimized Ship Hull Fitting Approach using NURBS), the following are the objectives :-

i. To develop methodology/approach using NURBS surfaces for Ship Hull
ii. To fully utilized and optimized the capabilities of NURBS in Ship Hull fitting

1.2 Research Scope

In order to achieve the project objective, the following are the research scopes :-

i. Fitting NURBS surface on Ship Hull using proposed methodology/approach
ii. Evaluation and analysis on the proposed methodology/approach (percentage of accuracy, fairness, speed of processing)
iii. Comparison of proposed methodology/approach with other systems/softwares

2 NURBS

2.1 NURBS formulation

A NURBS curve of degree p is a piecewise polynomial curve defined as follows:

$$C^w(u) = \sum_{i=0}^{n} N_{i,p}(u) P_i^w$$

where $P_i^w, i = 0,\ldots,n,$ form the so-called *control polygon* defined by a set of *weighted control points* $P_i^w = (w_i x_i, w_i y_i, w_i z_i, w_i)$, and $N_{i,p}(u), i = 0,\ldots,n$, are the B-spline *basis functions* defined over a *knot vector*

$$U = \{u_0,\ldots,u_m\},\ u_i \le u_{i+1},\ i = 0,\ldots,m-1$$

Throughout this research the knot vector has the following form (open knot vector):

$$U = \{\underbrace{a, a, \ldots, a}_{p+1}, u_{p+1}, \ldots, u_{m-p-1}, \underbrace{b, b, \ldots, b}_{p+1}\}$$

where in most practical applications $a = 0$ and $b = 1$.

A NURBS surface of degree (p, q) is defined similarly as:

$$S^w(u,v) = \sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u) N_{j,q}(v) P_{i,j}^w$$

where $P_{i,j}^w, i = 0,\ldots,n;\ j = 0,\ldots,m$, form the so-called *control net* defined by a set of *weighted control points*

$P_{i,j}^w = (w_{i,j}x_{i,j}, w_{i,j}y_{i,j}, w_{i,j}z_{i,j}, w_{i,j})$, and the basis functions $N_{i,p}(u), i = 0,\ldots,n$, and $N_{j,q}(v), j = 0,\ldots,m$, are defined over the knot vectors

$$U = \{u_0,\ldots,u_r\},\ u_i \le u_{i+1},\ i = 0,\ldots,r-1$$
$$V = \{v_0,\ldots,v_s\},\ v_j \le v_{j+1},\ j = 0,\ldots,s-1$$

For an in depth treatment of NURBS the reader is referred to [Piegl and Tiller 1996].

2.2 Advantages and disadvantages of NURBS

NURBS are very popular both in the academic and commercial geometric modeling world. Indeed, they offer advantages, which make them attractive for design applications [Dimas and Briassoulis 1999]

i. They are more general than Bezier and B-Spline curves and tensor product surfaces.
ii. Evaluation is straightforward, fast and computationally stable.
iii. They offer a common mathematical representation for free-form surfaces and commonly used analytical shapes such as natural quadrics, torii, extruded surfaces and surfaces of revolution.
iv. They are affined (rotation, scaling, translation), parallel and prospectively invariant as well as invariant under shear transformations.
v. It is easy to change their shape through the manipulation of control points, weights and knots.
vi. Degree elevation, splitting, knot insertion and deletion and knot refinement offer a wide range of tools to design and analyze shape information.

Some of the disadvantages of NURBS over traditional representations are [Dimas and Briassoulis 1999]

i. Bad choice of weights can lead to bad curve/surface parameterization.
ii. More storage is needed to define traditional shapes, such as a circle or a sphere.
iii. Some algorithms are numerically unstable (e.g. inverse point mapping).
iv. Some algorithms work better with other forms than with NURBS, e.g. computing the intersection curve of two surfaces.
v. Point member classification is a difficult problem for parametric surfaces. Therefore, it is particularly difficult to include NURBS as nodes in a constructive solid geometry system.

2.3 Used surfaces with NURBS representation

The most common surfaces used in CAGD with NURBS representation are the natural quadrics (plane, sphere, cylinder, cone), torii, ruled surfaces, extruded surfaces and surfaces of revolution (refer to [Dimas and Briassoulis 1999] or [Piegl 1991] for an overview of the common used surfaces). Therefore, it is useful to understand their NURBS representation and characteristics. Other types of surfaces such as cross-sectional design and free-form surface design are covered in the section below which are used in this research.

2.3.1 Cross-sectional design

Cross-sectional design is concerned with surface construction based on curve to generate B-spline surfaces. The most frequently used techniques are skinning, sweeping and swinging.

Briefly, NURBS skinning works as follows: a set of NURBS curves through which a NURBS surface is to pass. In practice these curve are usually planar curves positioned in 3D space with a so-called spine curve. The skinned surface is obtained in three steps (see Figure 1).

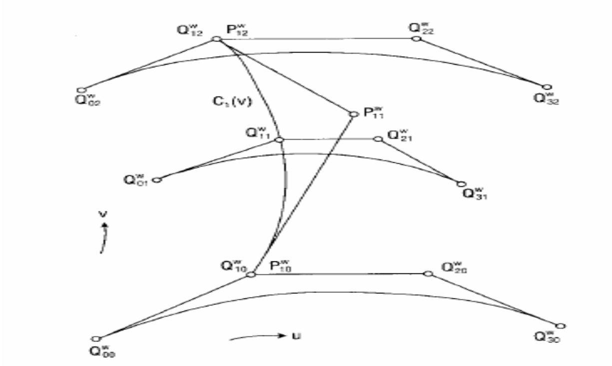

Figure 1. NURBS skinning: surface interpolation through cross-sectional curves.

NURBS sweeping is a special case of skinning that uses a constant section curve. If the curve is a

v curve, then the constant section curve is positioned along the spine at the same u value. Whereas, NURBS swinging is a generalization of rational sweeping (refer to [Piegl 1991]). Skinning is the most suitable method for ship hull fitting because it produces rectangular spline mesh. It will be more difficult to fair non-rectangular meshes. [Hollister 1997]

2.3.2 Free-form surface design

In the previous sections, the most important properties, advantages and disadvantages of the NURBS and the mathematical NURBS representation of commonly used surfaces such as quadrics, ruled surfaces and surfaces of revolution are summurized. However, the real power of NURBS lies with their ability to model complex free-form curves and surfaces.

The available fitting techniques can be categorized in two different groups mainly: *interpolation* and *approximation*. In the following, these fitting methods are discussed in more detail [Sarkar and Menq 1991]. A typical outline of a fitting algorithm would be :

i. Assign initial parameter values to the data points (parameterization of the data points).
ii. Assume an initial knots distribution (uniform knots is the most common case).
iii. Go through an interpolation or approximation procedure to obtain the weights and control points of the NURBS curve or surface, i.e. obtain the fitting curve or surface.
iv. Optimize the parameter distribution if necessary to obtain a better fit.

The common steps are to be followed for assignment of initial parameter and knot values. There are different techniques available in order to parameterize the given data such as the centripetal method, the cumulative chord length and the base curve or surface method. See also [Jung HB. and Kim 2000] for an overview of existing parameterization methods.

Interpolating a set of points with a NURBS surface can be formulated as follows: Given a set of points $Q_i, i = 0,...,l$ and an initial parameterization and knot distribution, find an interpolating surface to fit the data. More precisely, find control points $P_{i,j}$ and weights $w_{i,j}$ of a NURBS surface $R(u,v)$ such that

$$Q_r = R(u_r, v_r) = \sum_{i=0}^{k} \sum_{j=0}^{n} P_{i,j} R_{i,j}^{p,q} (w_{i,j}; u_r, v_r),$$

$$0 \le r \le l = (k+1)(n+1).$$

Solving equation above requires the solution of a non-linear system of equations because of the presence of the unknown weights.

There are several ways of approximating the surface with the NURBS definition:

i. Reposition control points.
ii. Change the weights.
iii. Modify the knot vector.
iv. Move data points and re-interpolate.

2.4 Optimization using Simulated Annealing

There are many ship design softwares available in market. For example, AutoShip, MaxSurf, Tribon, Catia, Defcar, Foran, Intergraph, Napa, Nupas-Cadmatic, PCG-Goddess, Pro/Engineer, FastShip dan ShipConstructor. A survey in boatdesign.net referring to software packages that naval architects prefer to use. The result shows that Maxsurf has the highest percentage of usage. For the time being, only Maxsurf has been using genetic algorithm (GA) optimization method for fitting. Other global optimization methods used are Simulated Annealing (SA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Genetic Programming (GP), Cultural Algorithms, Evolutionary Strategies and etc. The proposed method is SA on the weights of the NURBS surface.

The following pseudo-code implements the simulated annealing heuristic, as described above, starting from state w_0 and continuing to a maximum of $k_{\max}$ steps or until a state with energy $e_{\max}$ or less is found. The call neighbour(*w*) should generate a randomly chosen neighbour of a given state *w*; the call random() should return a random value in the range [0, 1). The annealing schedule is defined by the call temp(r), which should yield the temperature to use, given the fraction *r* of the time budget that has been expended so far.

$w = w_0$
$e = E(w)$
$k = 0$
while $k < k_{\max}$ **and** $e < e_{\max}$
w_n = neighbour(*w*)

$e_n = E(w_n)$

if $e_n < e$ **or** random() < $P(e_n - e$, temp$(k / k_{max}))$ **then**

$w = w_n$; $e = e_n$

$k = k + 1$

return w

where w is weight of n number of control points and e is error of the surface define by root mean square (RMS) formula $E(w)$.

3. Methodology

The methodology of the research is consists of six major steps: (1) extract ship definition/data offsets from ship hull drawings, (2) control points generation using NURBS curve, (3) data offsets generation using NURBS surface, (4) preliminary surface fitting (cross-sectional design concept), and (5) approximated surface fitting by increasing control points weight using simulated annealing optimization. The methodology of this research was graphically summarized in Figure 2.

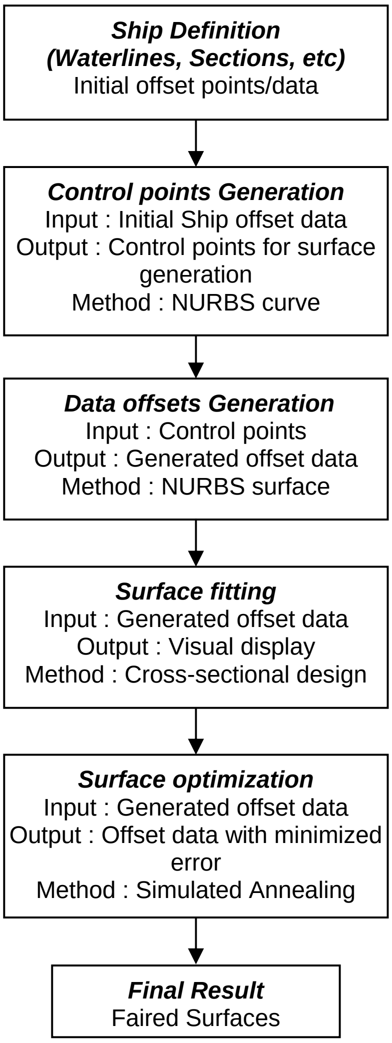

Figure 2. Process in order to produce expected results.

4. Result and Discussion

The data offsets used in this research are existing ship that already been build physically. For the time being, only manage to get 4 types of ship data offsets because many other ships are confidential (reserve rights of companies that own the ship drawings). Analysis of the effectiveness of the NURBS surface for fitting the ship hull surface is done by calculating Root Mean (RMS) Square error.

At this moment, prototype of each module/process has been developed (control points generation, data offset generation, surface fitting, surface optimization). However the surface optimization module is not fully completed. Testing of SA optimization is only done on NURBS curve. The results have been obtained shown in Table 1.

Table 1. Results of generated NURBS curves.

Ship name	Percentage of Accuracy (RMS)				
	without SA	w = 0.1	w = 0.5	w = 1	w = 5
40m btv	98.485 %	98.733 %	98.742 %	98.739 %	98.636 %
Fire fighting	98.565 %	98.919 %	98.928 %	98.93 %	98.932 %
Fishing vessel	98.412 %	98.672 %	98.661 %	98.679 %	98.636 %
Yacht	97.796 %	98.357 %	98.365 %	98.366 %	98.34%

The table shows that surface fitting by increasing control points weight either by 0.1, 0.5, 1 or 5 using simulated annealing optimization improves the percentage of accuracy. There is always improvement compare to generated NURBS curve without optimization. The highlighted ones are the highest percentage of accuracy of each ship.

5. Conclusion

There are some constraints in this research. One of them is that there is no researches that really evaluate on parameterize curves and surfaces method on ship hull thoroughly. So it is hard to compare the usage of NURBS on ship hull with other parameterize method like parabolic blending, Bezier, B-spline, etc. What is known is that NURBS is the best available method as it is state in [Hollister 1997] that it is the dominant mathematical technique available and [Alexanov 2003] standard of computer modeling for many industries. Other constraints are unable to obtained journals or papers from conferences or symposiums that might be useful for this research.

The main objective of this research is to reconstruct the ship definition surfaces accurately using NURBS. Both visual and numerical results are produced to demonstrate the effectiveness of NURBS for fitting the surfaces of the ship hull. This development of this software may also be a contribution to the local naval architecture field. This may also encourage other local software developers to produce local software which are more economical and also meet the local needs.

Reference

Alexanov A. 2003. Generalize Some Practical Principles of Ship Modeling. *Steelcad Consultantas AS Norway.*

Ang SW. 2002. Rekabentuk Rangka Kapal Menggunakan Parabolic Blending. *Thesis, Department Of Graphics and Multimedia, Faculty of Computer Science and Information System, Universiti Teknologi Malaysia, Johor, Malaysia.*

Dimas E. and Briassoulis D. 1999. 3D geometric modelling based on NURBS: a review. *Advances in Engineering Software.* 30: 741-751.

Fisher J., Lowther J. and Shene CK. 2004. If You Know B-Spline Well, You Also Know NURBS! *SIGCSE 2004.* 343-347.

Hollister SM. 1996. Automatic Hull Variation and Optimization. *New England Section, The Society of Naval Architects and Marine Engineers.*

Hollister SM. 1997. The Dirty Little Secrets of Hull Design by Computer. *New Wave Systems Inc.*

Jung HB. And Kim K. 2000. A New Parameterisation Method for NURBS Surface Interpolation. *Advanced Manufacturing Technology*. 16: 784-790.

Peters J. 1990. Local smooth surface interpolation: a classification. *Computer Aided Geometric Design*. 7: 191–195.

Piegl L. 1991. On NURBS, a survey. *IEEE Computer Graphics and Applications*. 11(1): 55–71.

Piegl. L. and Tiller. W. 1995. The NURBS Book. *Springer-Verlag, New York.*

Piegl. L. and Tiller. W. 1996. Algorithm for approximating NURBS skinning. *Computer Aided Design*. 28(9): 699–706.

Piegl. L. and Tiller. W. 2000. Reducing Control Points in Surface Interpolation. *IEEE Computer Graphics and Applications*. 70–74.

Sarkar B. and Menq CH. 1991. Parameter optimisation in approximating curves and surfaces to measurement data. *Computer Aided Geometric Design.* 8: 267–290.

Woodward CD. 1987. Cross-sectional design of B-Spline surfaces. *Computers and Graphics.* 11(2): 193–201.

Woodward CD. 1988. Skinning techniques for interactive B-Spline surface interpolation. *Computer Aided Design.* 20(8): 441–451.