Journal of
Ship&Ocean Technology
©JUNE 2006

SOTECH Vol. 10, No. 2, pp. 24 ~ 36, 2006

Generation of Discrete G^1 Continuous B-spline Ship Hullform Surfaces from Curve Network Using Virtual Iso-parametric Curves

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Abstract

Ship hullform is usually designed with a curve network, and smooth hullform surfaces are supposed to be generated by filling in (or interpolating) the curve network with appropriate surface patches. Tensor-product surfaces such as B-spline and Bézier patches are typical representations to this interpolating problem. However, they have difficulties in representing the surfaces of irregular topological type which are frequently appeared in the fore- and after-body of ship hullform curve network. In this paper, we proposed a method that can automatically generate discrete G^1 continuous B-spline surfaces interpolating given curve network of ship hullform. This method consists of three steps. In the first step, given curve network is reorganized to be of two types: boundary curves and reference curves of surface patches. Especially, the boundary curves are specified for their surface patches to be rectangular or triangular topological type that can be represented with tensor-product (or degenerate) B-spline surface patches. In the second step, surface fitting points and cross boundary derivatives are estimated by constructing virtual iso-parametric curves at discrete parameters. In the last step, discrete G^1 continuous B-spline surfaces are generated by surface fitting algorithm. Finally, several examples of resulting smooth hullform surfaces generated from the curve network data of actual ship hullform are included to demonstrate the quality of the proposed method.

Keywords: Curve network interpolation, Discrete G^1 continuous B-spline surface, Iso-parametric curve, Ship hullform

1 Introduction

Curve network is often used to design complicated free-form surfaces. Using the curve network is easier than directly manipulating control points of surfaces, and it enables more intuitive modelling. In ship design, hullform is usually designed with a curve network. The most important thing in designing ship hullform is to guarantee ship's contract speed by reducing the water resistance. Especially, ship hullform should have special free-form shapes (i.e. bulbous bow) in fore- and after-body for minimizing water resistance and maximizing propulsion efficiency. For this reason, there are several irregular regions in the curve network of fore- and after-body. After modelling ship hullform using curve network, we need to generate a smooth hullform surfaces which interpolate curve network by filling surface patches in the areas surrounded by curve network (see Figure 1).

Unlike mass production in car industry, ship industry need on-demand production which means new ship design for each order. Therefore, it is important to develop an efficient method that can rapidly and automatically generate smooth hullform surfaces from the curve network modelled by hullform designer.

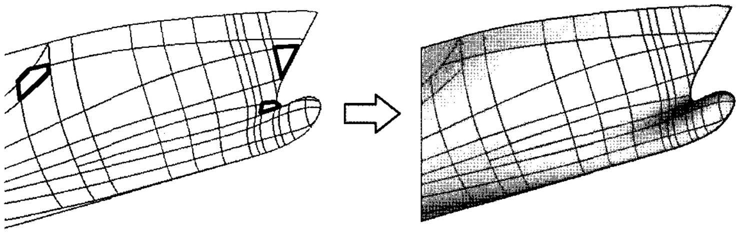

Figure 1: Generation of ship hullform surfaces with from curve network(fore-body)

1.1 Previous Works

Table 1: Comparison of previous works and our study

Author	Surface type	Required Input	Continuity	Remarks
This paper	Cubic B-spline surface	Curve network Reorganizing information	discrete G^1	Irregular curve network is converted to regular curve network
Rhim et al. [1]	Cubic Gregory surface	Curve network Cross-boundary derivatives	discrete G^1	Irregular regions are divided into several rectangular regions Approximation process to B-spline surface is required
Levin [2,3]	Catmull-Clark subdivision surface	Curve network Initial surface meshes	C^2	Approximation process to B-spline surface is required
Nasri [4-8]	Doo-Sabin subdivision surface	Curve network Initial surface meshes	C^1	
Cho et al. [9]	Piecewise Catmull-Clark subdivision surface	Curve network	discrete G^1	

Previous researches on generating surfaces which interpolate curve network can be classified into two categories. First use tensor-product surfaces such as B-spline, Bèzier, Gregory patches. Second are researches on using subdivision surfaces which are the center of attention in the computer graphics.

Tensor product surfaces can only represent the surfaces of irregular topological type by partitioning the region into a collection of individual rectangular patches or using degenerate patches. Then, adjacent patches should be explicitly stitched together and modified to meet complicated geometric continuity constraints such as C^1 or G^1. In general, interpolating such irregular topologies using tensor-product surfaces is not a trivial problem. Rhim [1] generated G^1 ship hullform surfaces using Gregory patches from the given irregular curve network.

Subdivision surface, first introduced by Doo-Sabin and Catmull-Clark, is an alternative to tensor-product surfaces. They can easily generate smooth surfaces of arbitrary topological type by recursively subdividing initial coarse meshes with C^1 or C^2 continuity. However, it is not yet widely used in CAD/CAM field, for there are boundary shrinking problems in the limit surfaces. Levin [2,3], Nasri [4-8] suggested methods that interpolate given curve network using one subdivision surface patch, and Cho [9] proposed the method of generating discrete G^1 ship hull form surfaces using piecewise subdivision surface patches. However, because there are few systems supporting subdivision surfaces, approximation process to industrial standard B-spline surface format is required.

1.2 Outline of proposed hullform surface generation method

We propose a new method which generates smooth ship hullform surfaces from given irregular curve network using B-spline surface patches. Table 1 shows a comparison of previous studies and our study. The main points of proposed surface generation method proposed are as follows;

- We used B-spline surface patches for effective transfer of ship hullform information to following process.
- We converted given irregular curve network to regular one by reorganizing the given curve network into new boundary curves and reference curves of surface patches to be generated. We used the new regular curve network as input information for surface generation process. In this paper, we assumed that appropriate reorganizing information is given by ship hullform designer.
- In each area of regular (i.e., rectangular or triangular) curve network, we generated discrete G^1 continuous B-spline ship hullform surfaces by using virtual iso-parametric curves.

Figure 2 is outline of surface generation process proposed in this paper.

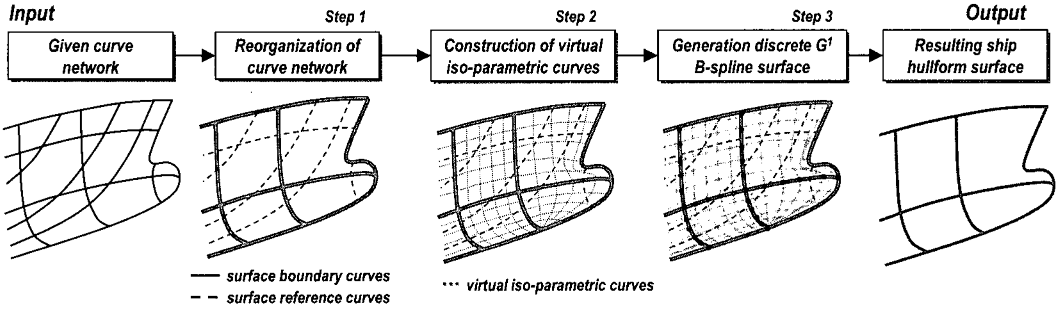

Figure 2: Outline of surface generation process proposed in this paper

This paper is structured as follows. In section 2, we introduced the irregular curve network reorganization method as a pre-process for generating ship hullform surfaces. In section 3, a method for generating virtual iso-parametric curves is proposed. Using this, we generated discrete G^1 continuous B-spline surfaces in section 4. In section 5, we showed the application result of the proposed ship hull form surface generation method to the real ship hullform curve network data. Conclusion and future works are stated in section 6.

2 Reorganization of the curve network

In this section, we explain the method which converts irregular curve network into regular curve network by reorganizing irregular curve network with boundary curves and reference curves.

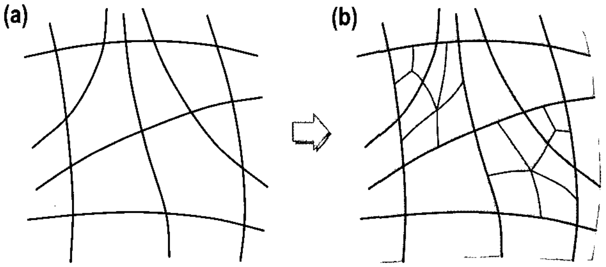

Figure 3: Example of piecewise tensor-product surfaces generation at each subdivided area of irregular curve network

In general, if curve network is given as shown in figure 3, tensor-product surfaces can be generated as follows.

- Subdivide each irregular region to several rectangular regions with appropriate algorithm.
- Generate piecewise tensor-product surface patch in each rectangular area surrounded by subdivided curve network.
- Satisfy continuity condition so that adjacent piecewise surfaces to be smoothly connected.

It is not an easy work to generate surface interpolating the curve network containing irregular topologies. Moreover, in order to generate surface with tensor-product surface patches such as B-spline, irregular topologies should be divided into rectangular topologies However, dividing the area without any information of the inside is not only difficult but also be apt to cause T-Node problem, which makes it difficult to satisfy continuity between surfaces (see Figure3(b)).

In this paper, we avoid irregular topology problem by converting irregular curve network to regular curve network. If we can reorganize given irregular curve network by assuming the solid lines as boundary curves, and dotted lines as reference lines like in Figure 4, curve network consists of newly determined boundary curves only contains regular topological regions. Then, tensor-product surfaces interpolating this regular curve network can be generated in the way below.

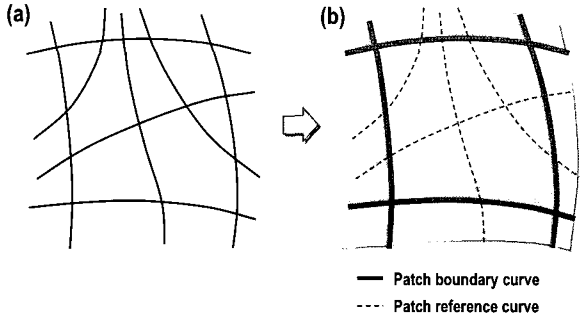

Figure 4: Example of conversion of irregular curve network to regular curve network

- Generate initial piecewise tensor-product surface in each area surrounded by newly determined curve network. Inside shape of the piecewise surface patches should reflect reference curves' shape as much as possible.
- Satisfy continuity condition so that adjacent piecewise tensor-product surfaces to be smoothly connected.

Since there are complicated irregular topologies in the original curve networks of fore- and after-body of ship hullform, it is difficult to reorganize them only with rectangular topologies, even though we can determine a new boundary curve. In these cases we permit triangular topologies (Figure 5). In the triangular regions, we generated degenerate tensor-product surface patches. There are innumerable ways of determining boundary curves, which play an important role in the quality of final ship hullform surfaces. In this paper, we did not consider such influences but supposed that ship hullform designers provide curve network's appropriate reorganization information as well as curve network data.

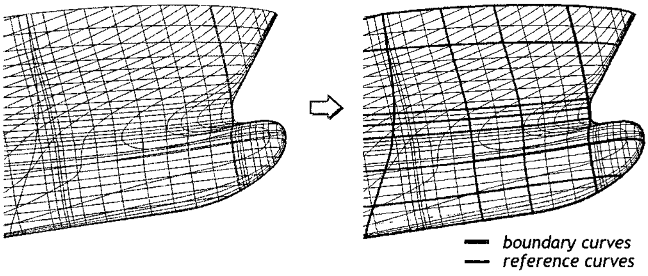

Figure 5: Example of reorganization of ship hullform curve network into triangular and rectangular topologies

3 Generation of virtual iso-parametric curves

In this section, we propose a method to generate virtual iso-parametric curves for piecewise discrete G^1 B-spline surface in the area surrounded by newly determined boundary surface.

3.1 What is iso-parametric curve?

Iso-parametric curve means a curve that consists of points with the same parametric values in u or v direction. With several iso-parametric curves of surface patch, we can easily grasp rough shape of the surface (Figure 6). We utilized these properties reversely. Since there are several reference curves in each region bounded newly determined curve network, first, we construct virtual iso-parametric curves that reflect reference curves' shape as much as possible. Then, using these virtual iso-parametric curves, we generate piecewise surface patch that reflects reference curves' shape.

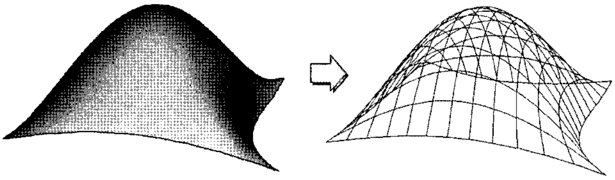

Figure 6: Generation of iso-parametric curves at discrete parameters from a surface

3.2 Method for generating virtual iso-parametric curves

Figure 7 shows a rectangular topological region surrounded by boundary curves and there are two reference curves inside of the region. We are going to piecewise uniform cubic discrete G^1-continuous B-spline surface in this area. If we assume the number of control points of B-spline surface to be generated to be m×m, 2×(m-2) virtual iso-parametric curves are required; m-2 curves for each direction of u, v. The method of generating virtual iso-parametric curve in case of m=6 is described below.

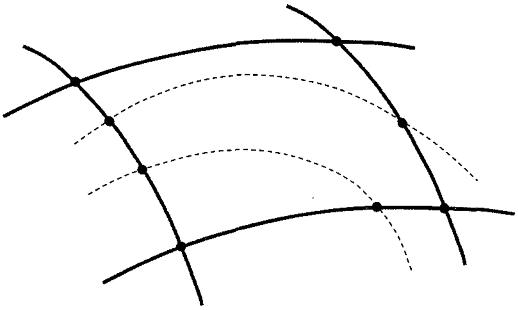

Figure 7: Boundary curves and reference curves of rectangular topology

Step 1: Since, curve network of ship hullform is, in general, designed with non-uniform B-spline curves, we need to approximate each boundary curve into uniform cubic B-spline curve with m control points [10]. These curves are boundaries of piecewise uniform cubic B-spline surface to be generated, and also virtual iso-parametric curves when u=0.0, 1.0, v=0.0, 1.0(Figure 8).

Step 2: We analogy surface normal vectors along the boundary curves as follows. First, the normal vectors at each intersection point between boundary curves and reference curves are calculated. Then, we can generate whole normal vectors along the boundary by linearly interpolating them (Figure 9). In next section, in order to generate discrete G^1 B-spline surface, every tangent vector at both end points of virtual iso-parametric curves must be perpendicular to these normal vectors.

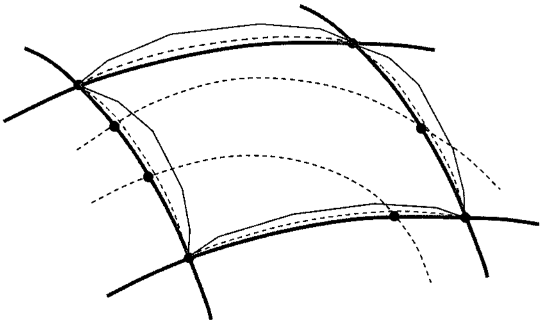

Figure 8: Approximation of given boundary curves to uniform cubic B-spline curves

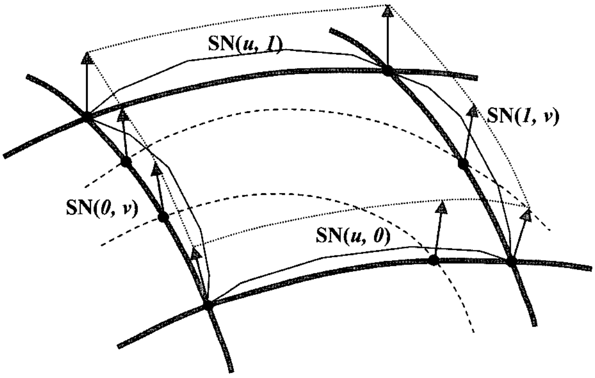

Figure 9: Generation of normal vectors of surface along boundary curves

Step 3: We generate bilinearly blended Coons patch [11] from 4 boundary curves. Then we can easily generate real iso-parametric curves of the Coons patch at u=1/(m-3), 2/(m-3), …, (m-4)/(m-3). In figure 10, iso-parametric curve at u=1/3 is shown.

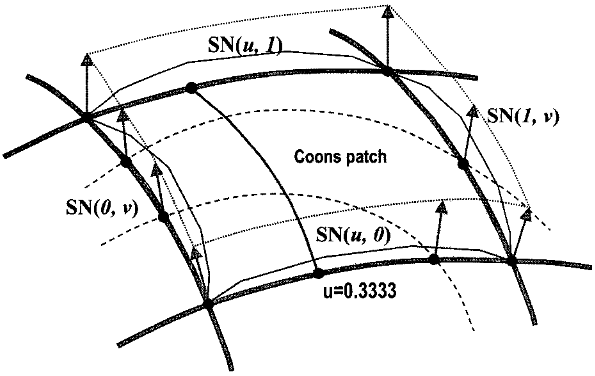

Figure 10: Iso-parametric curve generated from bilinearly Coons patch(In case of m=6)

Step 4: Ruled surface are generated in the average direction of normal vectors at the both ends of the iso-parametric curve generated in Step 3. We calculate the intersection points between this ruled surface and all reference curves (Figure 11).

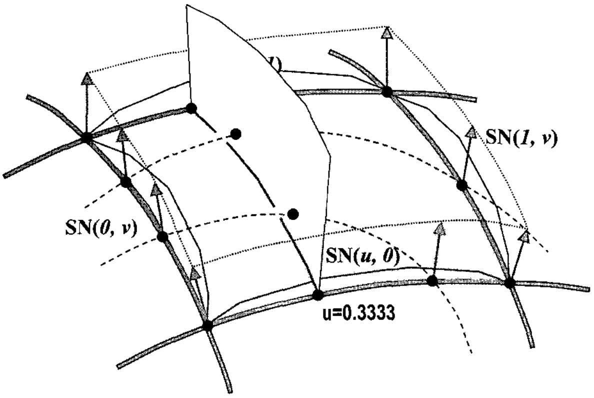

Figure 11: Calculating the intersection points between ruled surface and reference curves

Step 5: We can generate virtual iso-parametric curve of the surface patch that we are going to construct by interpolating intersection points of Step 4 with uniform cubic B-spline curve. As for end tangent vectors of virtual iso-parametric curve, we firstly determine them by Bessel end condition [12]. Then, they are projected on the plane that is perpendicular to surface normal vector at the boundary curve (Figure 12). This projection procedure is necessary for G^1 continuous connection to the adjacent surface patch.

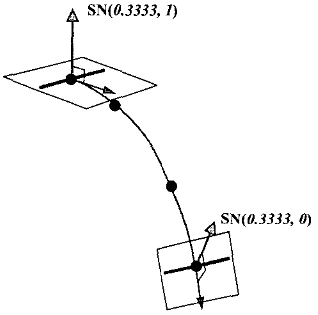

Figure 12: Virtual iso-parametric curve generation by interpolating the intersection points

Step 6: Repeat Step 3 to Step 5 for each virtual iso-parametric curve at u=1/(m-3), 2/(m-3), ..., (m-4)/(m-3) and v=1/(m-3), 2/(m-3), ..., (m-4)/(m-3) (Figure 13).

Step 7: The virtual iso-parametric curves generated from Step 6 do not intersect each other, because they are not real iso-parametric curves of the actually existing surface. To remedy this problem, we repeat virtual iso-parametric curve interpolation process (in Step 5, 6) by assuming the average points between the points (●) on the v=1/(m-3), 2/(m-3), ..., (m-4)/(m-3) of u-directional virtual iso-parametric curves and the points (■) on the u=1/(m-3), 2/(m-3), ..., (m-4)/(m-3) of v-directional virtual iso-parametric curve as new intersection points. When the distance between point (●) and (■) becomes smaller than SPT(same point tolerance, we use 0.0001), we stop this iteration process. Then, we are ready to generate G^1 B-spline surfaces from these virtual iso-parametric curves.

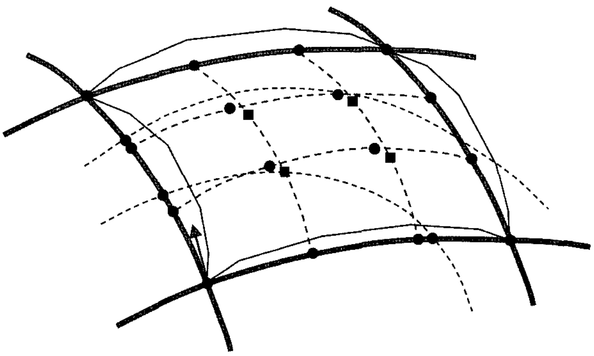

Figure13: Example of virtual iso-parametric curves generated by the proposed method

4 Generation of discrete G^1 B-spline surfaces

In this section, we describe discrete G^1 B-spline surface generation method using virtual iso-parametric curve calculated in the previous section.

Input data

Figure 14 shows boundary curves, virtual iso-parametric curves and tangent vectors of both end points of virtual iso-parametric curves. From intersection points between virtual iso-parametric curves and tangent vectors of each end point, we can generate B-spline surface with well known surface fitting algorithm [12].

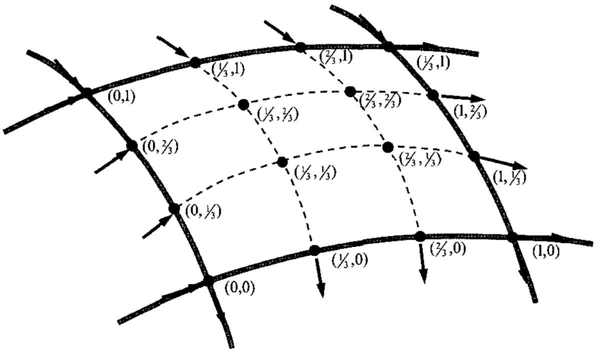

Figure 14: Input data for B-spline surface fitting

4.1 Surface fitting algorithm

First, we interpolate u-directional intersection points (●) and both end tangent vectors with cubic uniform B-spline curve. Then, we can get control points of u-directional B-spline curves; in fact, these curves are the real u-directional iso-parametric curves of the surface to be generated (see Figure 15). By interpolating these control points (O) using v-directional tangent vectors again, we can get control polyhedron (□) of piecewise uniform cubic B-spline surface that interpolate 4 boundary curves. (Figure 16, 17). The surface generated with this method satisfies G^1 continuity condition with adjacent surface patches. The reason is that u- and v-directional tangent vectors used in surface fitting are already corrected so as to be perpendicular to surface normal vectors along the surface boundaries. Using this proposed method, we can generate piecewise B-spline surface patches which satisfy G^1 continuity condition at discrete points of number of m-4 provided that the number of control points of the surface is m.

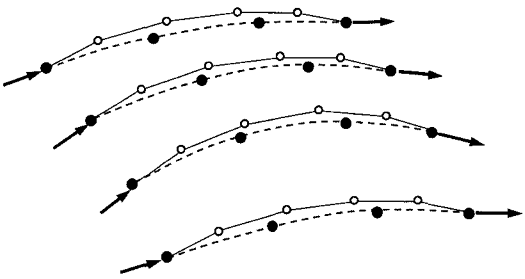

Figure 15: Interpolation of u-directional intersection points(●) using cubic B-spline curve

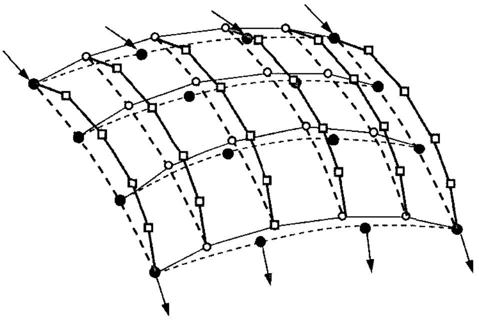

Figure 16: Interpolation of the control points (O) in v- direction using cubic B-spline curve

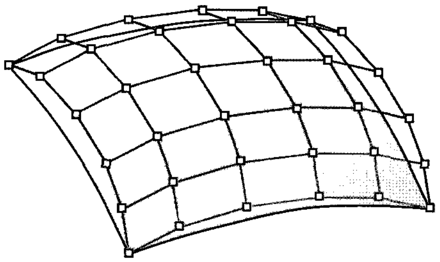

Figure17: Final surface generated using surface fitting algorithm

As for triangular topologies, we can generate degenerate B-spline surface patch using the same method as for rectangular topologies.

5 Result

We implemented the surface generation method proposed in this paper using C++ programming languages and DirectX library for visualization with Visual Studio 6.0 on MS-Windows XP. The implemented program was included as one of the sub modules in EzHull commercial system [13] for initial ship design.

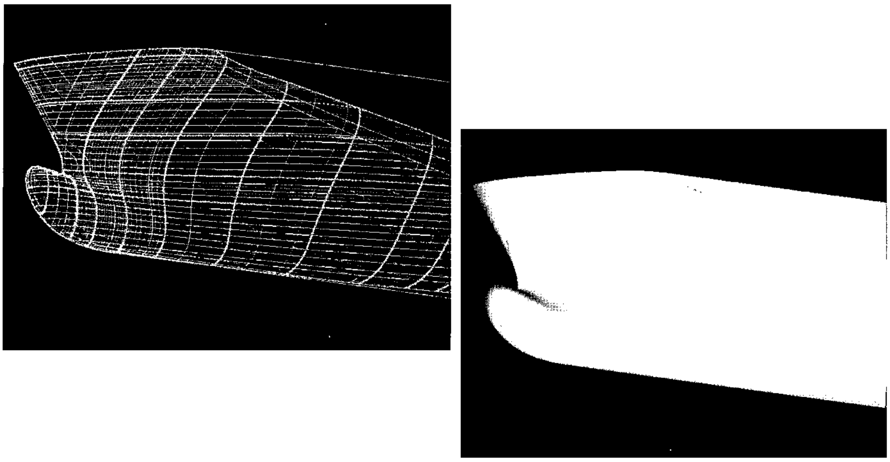

Figure 18: Resulting ship hullform surfaces from curve network of bulk carrier ship

Figure 18 shows resulting ship hullform surfaces generated from the curve network data of about 200m length bulk carrier ship. Left figure shows the reorganized curve network that consists of triangular and rectangular topologies. Right figure shows the final ship hullform surfaces generated using this data.

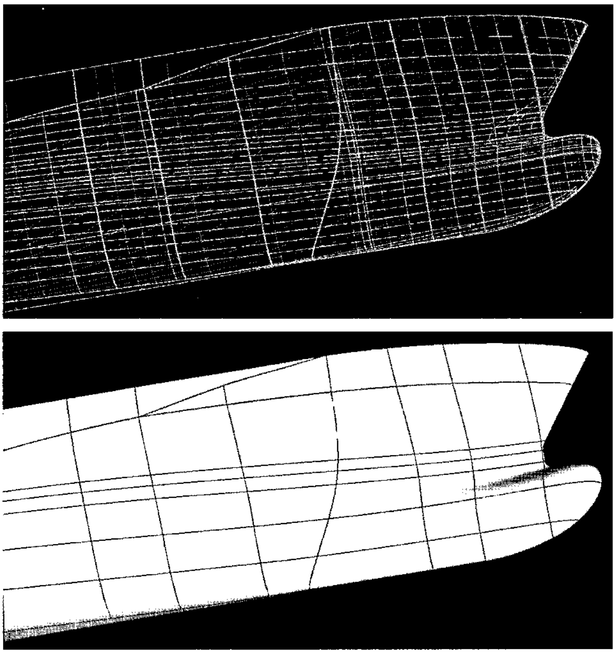

Figure 19: Resulting ship hullform surfaces from curve network of container ship

Figure 19 shows resulting ship hullfrom surfaces from the curve network of about 220m length container ship. Even in the fore-body that is usually designed with complicated free-form curve network, we can get good results. The error between the finally generated ship hullform surface and originally given curve network is approximately 3~5mm, which satisfies the maximum error tolerance approved in industrial field.

6 Conclusions and future works

In this paper, we proposed discrete G^1 B-spline ship hullform surface generation method using virtual iso-parametric curves. We chose B-spline surface form in order to transform the ship hullform surface information to following process without complicated conversion process. Irregularity in the curve network of ship hullform could be overcome by reorganizing given irregular curve network into new boundary curves and reference curves. For B-spline ship hullform surface generation, we generated virtual iso-parametric curves that reflect reference curves.

Applying the proposed method to curve network data of actual ship, we could get satisfactory smooth ship hullform surface which can be transferred to following process efficiently. In this paper, we assumed that ship hullform designers also provide the curve network reorganization information as input data. If automatically generation of such reorganization information is possible, our ship hullform surface generation method will be more effective.

Acknowledgements

This work was supported partially by grant No. R01-2002-000-00061-0 from the Basic Research Program of the Korea Science & Engineering Foundation, and by grant No. 10005460 from the Korea Institute of Industrial Technology Evaluation and Planning. Also this work has been partially supported by the Research Institute of Marine System Engineering of Seoul National University.

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