Systematic Modification of Ship Hull Forms Using B-Splines

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B- スプラインを用いた船型の系統的変形

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ABSTRACT

縦横のメッシュ状のスプラインネットで定義された、例えば船体のような滑らかな物体形状は、メッシュの交点を移動させることによって高い自由度で変形させることができる。しかし、この高い自由度は却って実施作業を困難にする。先ず、設計者である人間がこの変形作業を実施する場合、変形によって元の曲面の滑らかさが損なわれないためには、各交点の移動量が全体として滑らかに分布していなければならないが、設計者がそのような移動量を直接各交点で与えることは殆ど不可能である。メッシュを粗くすると、滑らかな分布を与えることは容易になるが、形状表現の自由度が低下する。次に、最適化アルゴリズムによって計算機が物体形状を自動的に変形させる場合には、メッシュの各交点での移動量を形状表現パラメータとすることが適当であるが、メッシュを細かくするとパラメータ数が飛躍的に大きくなり、計算量とパラメータ間の独立性の点で問題になる。また、メッシュを粗くすると、やはり表現力の点で問題が生じる。

本報告は、粗いメッシュの問題点の例として、Bスプラインの基底関数の山の位置を連続的に変化させたとき、山の形状を保てないことを示す。次に、この問題点の解決法として、細かいメッシュを用いながら、少ないパラメータ数で変形を表現するグループ化を提案する。そしてその実現例として、船体形状をスプラインネットで表し、その一部に変形量をオーバラップさせて船尾形状を変形させた場合を示す。

1. Introduction

The progress of CFD has reached a stage in which inverse problems are feasible, i.e., a body shape having specified fluid dynamic performances is obtained after iterative modification of the shape through a huge amount of computation. In many cases, the process of obtaining a body geometry having a desired fluid dynamic performance takes the form of optimization with constraints. For example, a ship hull form is optimized to get minimum drag under the constraint of constant volume.

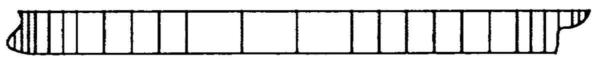
In optimization, a body shape must be given a high degree of freedom, in order that the search for optimization covers a wide area. This accompanies a large number of shape parameters. But, at the same time, the number of shape parameters should be as small as possible, because, otherwise, the CPU time would be too much and the independece among the parameters would be degraded.

Perhaps the most flexible way of representing a body shape is to fit its surface with a mesh, and give coordinates to points of intersection of the mesh. By refinement, one can fit the mesh to almost all body shapes. A natural chocie of parameters in such a mesh system is to use coordinates of intersection points. But, by refining the mesh, the number of parameters increases rapidly, and the process of optimization using the system would be impractical.

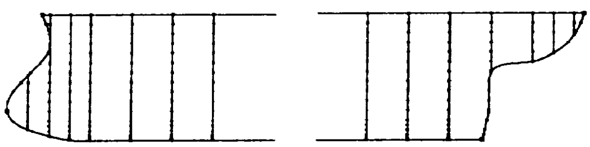
In order to solve the problem, Hamazaki et al[1]. used a fine mesh for representing a ship hull, and overlapping coarse mesh for changing the body shape, thus retaining the flexibility of body geometry and reducing the number of parameters for optimization at the same time. But, as will be shown in §3, the use of a coarse mesh has its own problem, and in §4, another method for solving the problem will be proposed.

2. Representation of a Ship Hull Form

A ship's hull form is defined by a set of discrete points called offsets. Fig. 1 shows its example of a tanker model. The hull form has a bulb at the bow (front) for reducing wavemaking resistance. Fig.1(d) shows interpolated x=constant sections at 1/100 length pitch.



(a) Total side view



(b) Magnified side view

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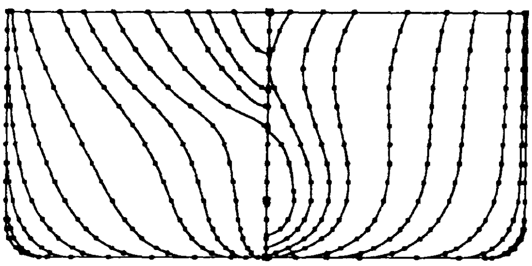
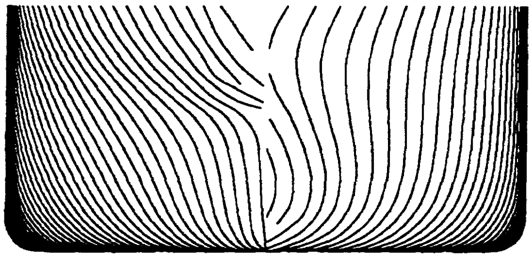


Aft Fore

(c) Body plan



Aft Fore

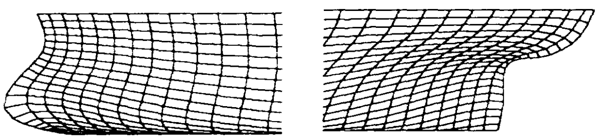
(d) Interpolated x=constant sections

Fig.1 Offset data of a ship hull form

Based on the offset data, splines passing through the spline curves at each offset sections are generated lenghtwise and crosswise using the Implicit Geometrical Method[2],[3],[4]. They are called a spline net as shown in Fig. 2, and by interpolating those splines in a tensor product manner, a spline surface that covers continuously the entire hull surface is defined.

Bow Stern

(a) Total side view



Bow Stern

(b) Maginfied side view

Fig. 2 A spline net for a tanker model.

3. B-splines on a coarse net

B-spline can be conveniently used for representing a body geometry. It defines a curve by interpolating a set of control points $\mathbf{Q}_i$ using basis functions $N_i^4(s)$ as shown in Fig.3.

$$\mathbf{P}_i(s) = N_{i-3}^4(s)\mathbf{Q}_{i-3}+N_{i-2}^4(s)\mathbf{Q}_{i-2}+N_{i-1}^4(s)\mathbf{Q}_{i-1}+N_i^4(s)\mathbf{Q}_i$$

$$(s_i \leqq s \leqq s_{i+1}) \qquad (3.1)$$

$$\mathbf{P}_i(s_i) = \mathbf{P}_i$$

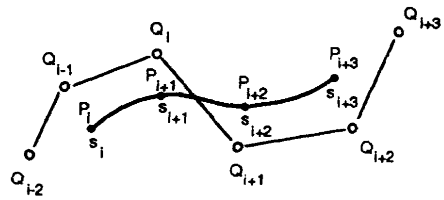
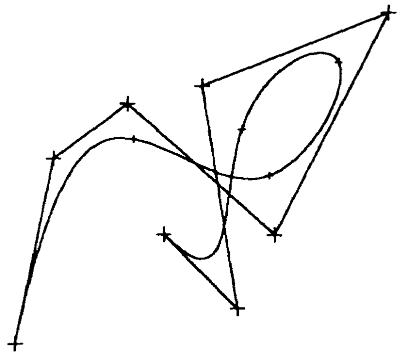


Fig. 3 A B-spline curve and control points.

An example of a generated B-spline is shown in Fig. 4(a). It is also possible to compute a B-spline that passes through given points, as shown in Fig. 4(b), where 2nd derivatives at boundary points are set zero.



(a) Control points are given.
+ : control points

(b) Passing points are given.
+ : control points
+ : passing points

Fig.4 1-D non-uniform B-spline

For the ease of extension to 2D, knot vectors s_i are equally spaced with a spacing of unity, i.e., uniform B-splines are used. Then the basis functions take the following forms.

$$\begin{cases} N_{i-3}^4(\xi) &= \frac{1}{6}(1-\xi)^3 \\ N_{i-2}^4(\xi) &= \frac{1}{6}(3\xi^3 - 6\xi^2 + 4) \\ N_{i-1}^4(\xi) &= \frac{1}{6}(-3\xi^3 + 3\xi^2 + 3\xi + 1) \\ N_i^4(\xi) &= \frac{1}{6}\xi^3 \\ & \qquad (0 \leq \xi \leq 1) \end{cases} \qquad (3.2)$$

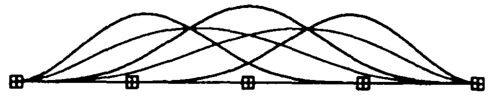


Fig. 5 A hump moving on a coarse 1-D B-spline.

In 1-D, if the value of a function at a certain control point is unity and the values at all the other control points are zero, a B-spline gives a hump which extends in four consecutive intervals. It is shown as a thick curve in the center of Fig. 5. It is called a basis function of B-spline. The two neighboring humps shown by thick curves have a function value of unity at adjacent control points. Their asymmetry is caused by the influence of boundary conditions. If one wants to place the peak of the hump at somwhere between the control points, one would give the values of function which sum up to unity to the two control points while changing their ratio depending on the location of the peak. In case the peak is at the middle of the two control points, the function values should be 0.5 each. The case is shown by thin curves in Fig. 5. Clearly, the hump is shorter and wider, and does not preserve its shape.

The extension of uniform B-splines to 2-D curved surfaces is straightforward. It is carried out by the tensor product of B-splines in two direction, as shown below.

$$\mathbf{P}_{i,j}(\xi,\eta) = [N^4_{j-3}(\eta), N^4_{j-2}(\eta), N^4_{j-1}(\eta), N^4_{j}(\eta)]$$
$$\times \begin{bmatrix} \mathbf{Q}_{i-3,j-3}, & \mathbf{Q}_{i-2,j-3}, & \mathbf{Q}_{i-1,j-3}, & \mathbf{Q}_{i,j-3} \\ \mathbf{Q}_{i-3,j-2}, & \mathbf{Q}_{i-2,j-2}, & \mathbf{Q}_{i-1,j-2}, & \mathbf{Q}_{i,j-2} \\ \mathbf{Q}_{i-3,j-1}, & \mathbf{Q}_{i-2,j-1}, & \mathbf{Q}_{i-1,j-1}, & \mathbf{Q}_{i,j-1} \\ \mathbf{Q}_{i-3,j}, & \mathbf{Q}_{i-2,j}, & \mathbf{Q}_{i-1,j}, & \mathbf{Q}_{i,j} \end{bmatrix} \begin{bmatrix} N^4_{i-3}(\xi) \\ N^4_{i-2}(\xi) \\ N^4_{i-1}(\xi) \\ N^4_{i}(\xi) \end{bmatrix}$$
$$(\xi_i \leqq \xi \leqq \xi_{i+1}\ ,\ \eta_j \leqq \eta \leqq \eta_{j+1}) \tag{3.3}$$

where the control points $\mathbf{Q}_{i,j}$ are distributed meshwise as shown in Fig. 6.

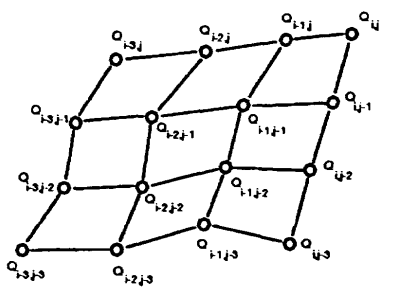


Fig. 6 Control points $\mathbf{Q}_{i,j}$ for B-spline surface.

If all those humps in Fig.5, drawn in thick or thin lines, are distributed at consecutive sections in 2-D, the contour plot of the height distribution would be like that in Fig. 7. The figure shows clearly the poor quality of a coarse mesh in preserving the hump shape when its location changes continuously.

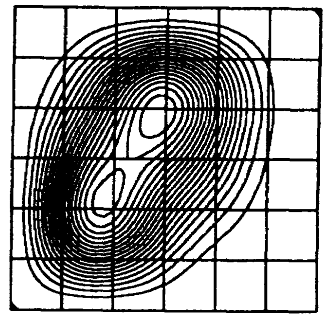


Fig. 7 Humps changing location at a half mesh pitch on a B-spline net.

Fig. 7 shows the severest test case for the moving hump problem, while Fig. 8 shows the easiest, where the location of the hump agrees with that of the control point at each section. But one can observe slight wiggles in the contours even in this easiest case.

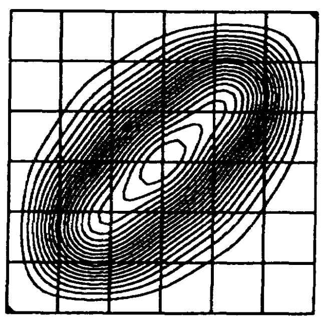


Fig. 8 Humps changing location at a mesh pitch on a B-spline net.

4. B-splines on a fine net with grouping

In order to get better quality in preserving the shape of the hump, the number of control points are doubled as shown in Fig. 9.

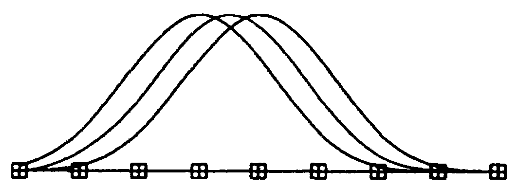
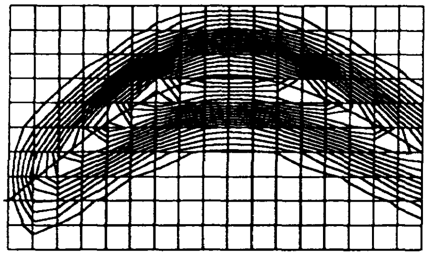


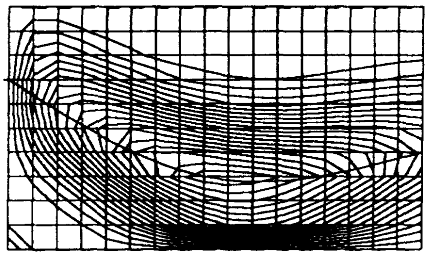
Fig. 9 A hump with least square fitting on a fine 1-D B-spline.

The location of the hump in the center is at the mid point of the two control points, and the locations of the other two are at control points. The values of the function at control points for the middle hump are obtained by least square fitting. As shown in the figure, the shape of the middle hump is indistinguishable from the other two. Thus the problem related with a coarse mesh has been solved. Note that the basis function of a coarse mesh is only one example of target functions for least square fitting. A function of arbitrary shape can be used.

The problem with refining a mesh is the rapid increase of control points. Therefore, instead of using directly the values of the functions at control points as body geometry parameters, a new set of parameters, much smaller in number, which group control points, should be defined. An example of the grouping is shown in Fig. 10, in which the location and height of the hump is given at three horizontal locations (i.e., the left end, the middle, and the right end), and the values in between are interpolate using B-splines. Thus the number of parameters representing a series of humps in this case is only six. These parameters can be easily controlled by a designer. If more complexity in geometry is needed, more groups should be add.



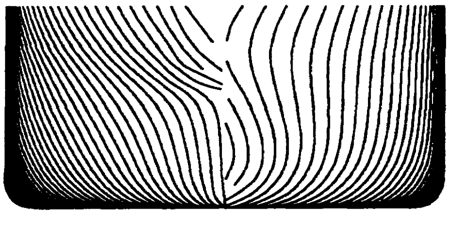
(a) Case 1



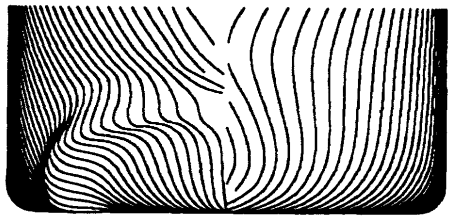
(b) Case 2

Fig. 10 Grouping of control points on a fine 2-D mesh.

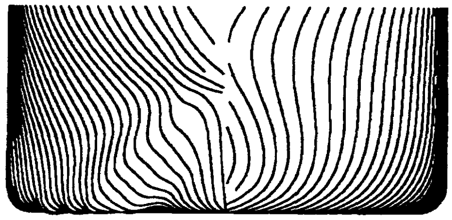
Figs. 11(b),(c) show the modified hull forms, where the height distributions shown in Fig. 10 are added in normal direction to the original shape shown in Fig. 11(a).



(a) Original shape



(b) Case 1



(c) Case 2

Fig. 11 Hull forms with modification

5. Conclusions

A new method for grouping control points on a spline mesh for representing and modifying body geometry has been proposed. The method reduces the number of body geometry parameters significantly, so that a designer can easily control. In order to use this method in practical applications, further study is needed to select suitable form of target functions, and to avoid unnecessary wiggles in the functions obtained using least square fitting.

References

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