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SEMI-AUTOMATIC METHOD FOR SURFACE SMOOTHING

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ABSTRACT

This paper presents a new method for generating smooth free-form surface by local correction. B-spline surface is used for its convenience of local correction, and the direction of surface correction is fixed to the average-surface-normal direction.

The surface to be corrected is approximated into a uniform cubic B-spline surface. Then, the smoothness (curvature arrows, iso-parametric lines) of the approximated surface is displayed with B-spline control points. When a control point near the region that needs correction is selected, a new point 1 mm higher than the original control point in the direction of the average surface normal is displayed. And the surface is corrected by giving the amount of control point movement interactively.

Since the direction of correction is given by the program and the amount of correction is selected by the user, the method is called semi-automatic. Sufficiently smooth surface can be obtained by this method. Examples are given to illustrate the method.

1. Introduction

Several techniques to smooth a curve have been developed, but there are only a few literatures adressing the problem of surface smoothing. This is mainly due to the fact that one can smooth a surface by fairing the array of curves and generating the surface from them (Curve level smoothing). But this curve level smoothing needs tedious job of refairing the array of curves and regenerating the surface repeatedly. Surface level smoothing can make the problem easier than the curve level one. But, the surface level smoothing has some problems. A parametric surface is 3D object expressed with two independent parametric u,v. The main difficulty in surface smoothing lies in that if smoothing is done in one parameter direction, it usually showes some unfairness in the other direction.

In 1983, Johan A.P. Kjellander(2) presented the automatic smoothing method of bicubic surface by interactively eliminating an external force acting on the mesh point. In 1985, Dong K. Jeong(4) studied the automatic smoothing of cubic B-spline surface by introducing optimization technique. He took a maximum Gaussian curvature on the surface as an objective function, and took an maximum deviation and the smoothing direction calculated from the similar equation as that of kjellandar as the constraints. The main idea of above methods comes from the fact that a surface can be smoothed by being moved in the direction of shear force elimination. But the authors found that those methods can not be applied satisfactorily on the surface such as an automobile body skin which is relatively flat and showes a minute variation of currvature.

In this paper a semi-automatic smoothing technique that can be sucessfully applied to relatively flat surfaces is presented. We adopt a parametric surface as an input for the general use of our program to the surfaces made in other CAD/CAM systems, and use approximated B-Spline surface internally for its convenience of local correction. With much experience we selected an average surface normal as the direction of surface correction. With the smoothness (Curvature Arrow, Isoparametric Line) of the surface displayed, user can correct the surface by selecting control point near the region that needs correction and by giving the amount of control point movement the direction of which is fixed throughout the job. The name 'Semi-Automatic' originates from the automatic direction and user given amount of movement for correction.

2. Semi-Automatic Method

The procedure of correcting a surface is described in detail here. The main steps go as follows ; old surface display, new surface generation, new surface display with B-spline control points, correction, and finally deviation check.

2.1 Old Surface Display(9)

In this step, the smoothness of an input surface (parametric surface) is displayed. If the surface is smooth enough, there is no need to correct a surface and stop the job. But if the surface needs some correction, user should move to the next step. The curvature arrow in the u or v parameter direction, the Gaussian curvature arrow, u or v isometric line scaled to the average surface normal direction are displayed as a measure of smoothness of the surface.

2.2 New Surface Generation(3)

The approximated B-spline surface is generated from the old surface, and this new surface is used throughout the procedure. The certain characteristics of B-spline surface such as the satisfication of curvature continuity between patches and the localness of surface variation about control point movement, make the B-spline surface as the most suitable one for surface correction. We adopted uniform cubic B-spline for easy application. The approximation steps are as follows.

(1) Determination of the number of patches

The default number of patches in each direction and the number of approximation points in a patch are determined by eq.1 and eq.2.

Eq.1 comes from the idea of making the new surface have as much data as that of the old one. these values (NI, NJ, NAPPU, NAPPV) can be changed by the user for more accurate or rough approximation.

$$NI = \sum_{i=1}^{NIO*NJO} NUO/(NU*NJ)$$
$$NJ = \sum_{i=1}^{NIO*NJO} NVO/(NV*NI) \qquad \ldots\ldots\ldots (1)$$

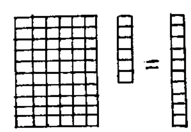
where NI : the number of patches in u direction of new surface
NJ : the number of patches in v direction of new surface
NU(=4): order of patch in u direction of new surface
NV(=4): order of patch in v direction of new surface
NIO : the number of patches in u direction of old surface
NJO : the number of patches in v direction of old surface
NUO : order of patch in u direction of old surface
NVO : order of patch in v direction of old surface

$$NAPPU = NAPPV = 3 \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where NAPPU : The number of approximation points in a patch of new surface in u direction
NAPPV : NAPPU in v direction

(2) v-Approximation

After the number of patches are determined, the surface is approximated in the u direction and the resulting control points are obtained. Eq.3 describes the v approximation of the surface in Fig.1 where each rectangle represents a component of matrix or vector.

$$\underset{(10*6)}{D}\ \underset{(6*1)}{P^{(v)}} = \underset{(10*1)}{S^{(v)}}$$;  ..(3)

where $P^{(v)}$: control points vector to be generated in the u direction
$S^{(v)}$: points vector on the old surface to be approximated
D : system matrix of uniform cubic B-spline approximation

To obtain the approximate solution Least Square Method is applied and eq.4 comes.

$$\underset{(6*6)}{D^TD}\ \underset{(6*1)}{P^{(v)}} = \underset{(6*1)}{D^TS^{(v)}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Applying this equation on the array of $S^{(v)}$ consecutively, each array of $p^{(v)}$ is obtained as in Fig.2.

(3) u - Approximation

The approximation is completed by doing the approximation in the u direction on the array of $P^{(v)}$ $(=S^{(u)})$ obtained above. The procedure is similar to that of v-Approximation.

$$\underset{(13*7)}{D}\ \underset{(7*1)}{P^{(u)}} \doteqdot \underset{(13*1)}{S^{(u)}} \xrightarrow{\text{L.S.M.}} \underset{(7*7)}{D^T D}\ \underset{(7*1)}{P^{(u)}} = \underset{(7*1)}{D^T S^{(u)}} \quad \text{................} \quad (5)$$

where $P^{(u)}$: control point vector to be generated in the u direction

$S^{(u)}$: vector abtained by rearranging $P^{(v)}$ in the u direction

Solution vectors obtained by applying eq.5 to each array of $s^{(u)}$ are B-spline control points (Fig.3).

(4) Deviation Check

The maximum deviation between new and old furface on four boundaries and in domain are needed to accpet the approximated surface as the surface for correction. If deviation is too large, approximation should be done again with much more number of patches and approximation points.

When the input surface is uniform cubic B-spline, there is no need of approximation. In this case interpolation should be done instead of approximation. As a result of interpolation that is the special case of approximation, exactly the same surface is obtained.

2.3 New Surface Display with B-spline Control Points

The smoothness of new surface is displayed with B-spline control points with the same method as that of paragraph 2.1 'Old Surface Display'. The user can find out the region that needs correction and determine the control point to be corrected.

2.4 Correction

The surfaces dealt here, such as an automobile body skin, are generated from the array of curves that is already faired. Thus they show good smoothness in the faired parameter direction(v), but show bad smoothness in the other direction(u). This results from that the users who are interested in the curve fairing can seldom consider the correspondency between the faired curves. During this research, the authors found that when a surface, which is almost flat and showes minute variation of curvature and have been faired in the curve parameter direction, shows bad smoothness, the most appropriate direction for the surface to move is the average surface normal direction. The direction is calculated from eq.6 and this direction of control point movement is fixed during the job (Fig.4)
This idea, the main idea of our research and what seems to be trivial has been successfully applied to the surfaces made in the automobile industry field.

$$U3 = \frac{U1 \times U2}{|U1 \times U2|} \quad \text{.......................} \quad (6)$$

where U3 ; average surface normal

P1 ; origin point of surface

P2 ; end point of u parameter

P3 ; end point of v parameter

$U1 = P2 - P1, \quad U2 = P3 - P1$

The control points can be moved either as a group or one by one; global and local correction.

(1) Global Correction

When a control point is selected, a new point 1 mm higher than the original one in U3 direction is displayed. And the surface is corrected by interactively giving weighting factor about that 1 mm movement. By repeating above job on other points the global correction is completed and the smoothness of the corrected surface is displayed. If the result is not good, one can restore the previous surface or do global correction again or go to local correction. Using global correction one can correct a surface by selecting the control point consecutively with the whole surface displayed. Thus the surface can be corrected in a short time, but it is hard to give the weighting factor without some experience on that surface.

(2) Local Correction

When a control point is selected, u and v isolines corresponding to the point is displayed with their curvature arrow. And also a new point 1mm higher than the original control point is displayed. The surface is corrected by interactively giving weighting factor about that 1mm movement, and the corrected u and v isolines with their curvature is displayed.
If the result is not good, one can restore the previous surface or do local correction again or go to global correction. Using local correction one can given the weighting factor easily

by seeing the corresponding u,v isolines. Thus one can correct the surface without any experience on that surface, but it takes more time to correct the surface.

2.5 Deviation Check

It is very time consuming to check deviation between two surfaces ; initial new surface, corrected new surface. A time saving deviation check scheme has been developed that can be applied to our program only. This method compares the distance between surface points corresponding to the control points of each surface. The maximum distance calculated is approximate maximum deviation, because the control points have moved only to U3 direction during the job.

3. Illustrative Example

The program have been developed in Prime 750 computer using Tektronix 4115B terminal and I.G.L. (plot 10) graphics library.

Fig.5 displayes the uniform cubic B-spline surface which is a portion of automobile bumber and created in our CAD/CAM system. While it showes good smoothness in the v direction, i,e. curve fairing direction, it does not show good smoothness in the u direction.

Fig.6 displayes the interpolated surface which is the same as the original one.

Fig.7 showes the process of global correction with u.v isoline displayed.

Fig.8 showes the result of process in Fig.7. In this figure the region on the left of the corrected region became poor due to the correction.

Fig.9 and Fig.10 show the process of global correction again with u,v isoline and u curvature displayed respectively. The final surface in Fig.11 showes good smoothness.

4. Conclusion

A program which can easily generate smooth surfaces from relatively flat surfaces such as automobile body skin is developed. We adopted parametric surface as an input for the general use of our program to the surfaces made in other CAD/CAM systems, and used approximated uniform cubic B-spline surface internally for its convenience of local correction. The patches of the approximated surface should have nearly same patch size for accurate approximation due to the uniform shape function, therefore the approximated surface needs much more number of patches than original surface. Seeing the surface displayed with isoline or curvature arrow, it is easy to find the control point near the region that needs correction. Since the direction of surface movement being fixed to the average surface normal, the user is only to give the amount of control point movement. For more efficient use of the idea of this paper, it is recommanded to use nonuniform B-spline shape function and develop new approximation skeme that can be applied to it.

5. References

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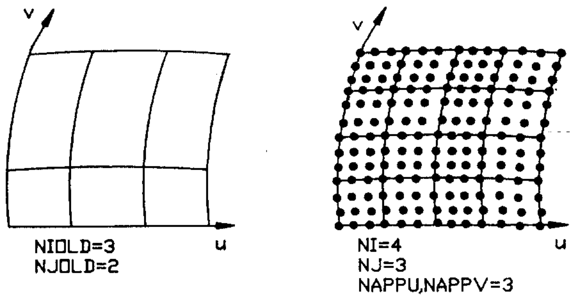

Fig.1 B-Spline Surface Approximation

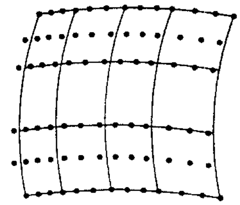

Fig.2 v Approximation

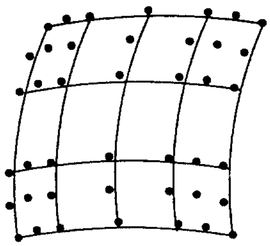

Fig.3 u Approximation

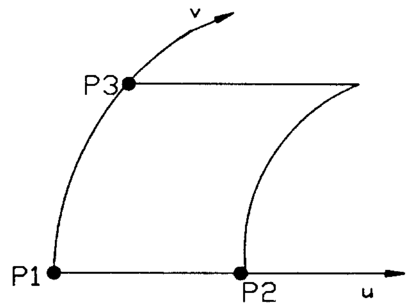

Fig.4 Average Surface Normal

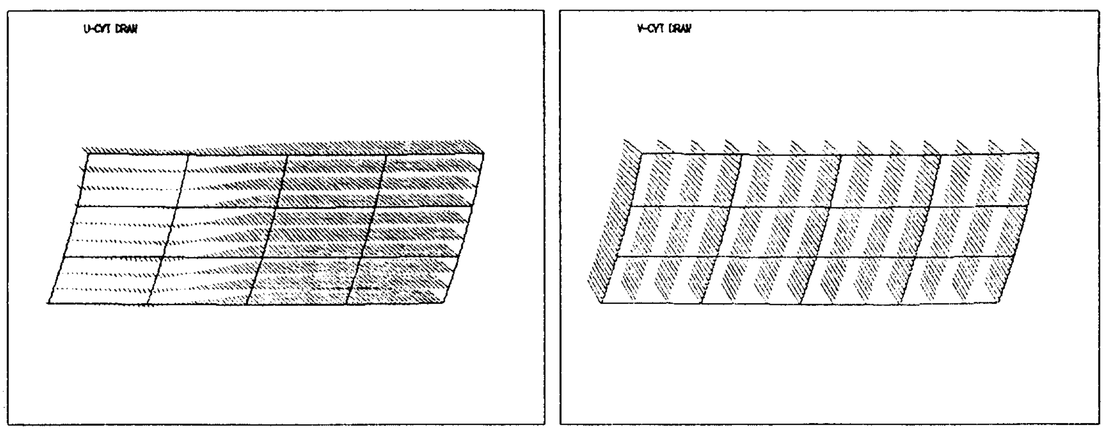

Fig.5 Old Surface

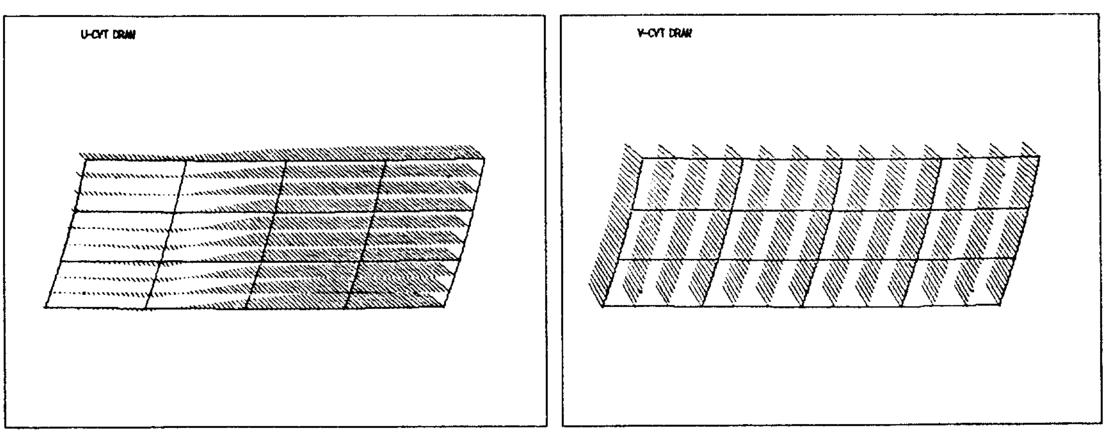

Fig.6 Interpolated New Surface

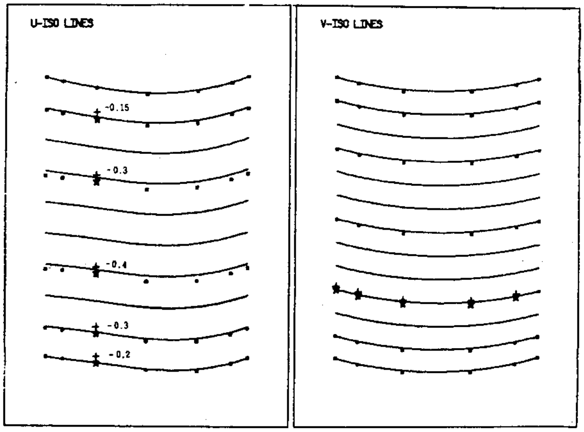

Fig.7 1st Global Correction
(Max. Dev=0.209)

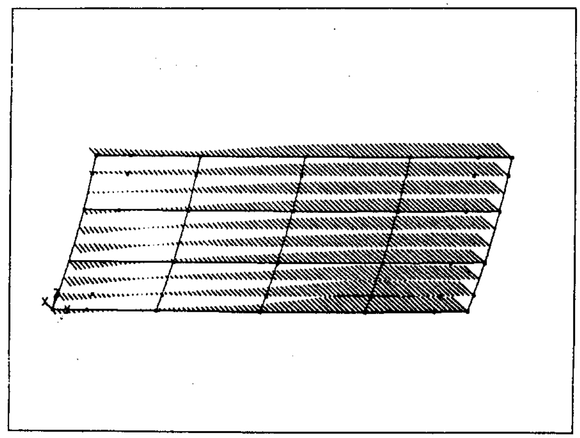

Fig.8 u Curvature as a Result of 1st Correction

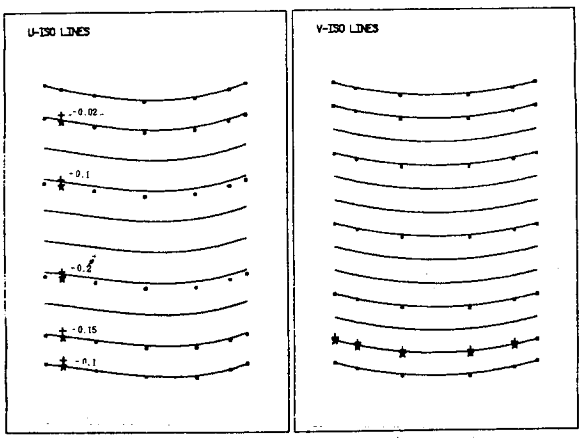

Fig.9 2nd Golbal Correction(Max. Dev=0.252)

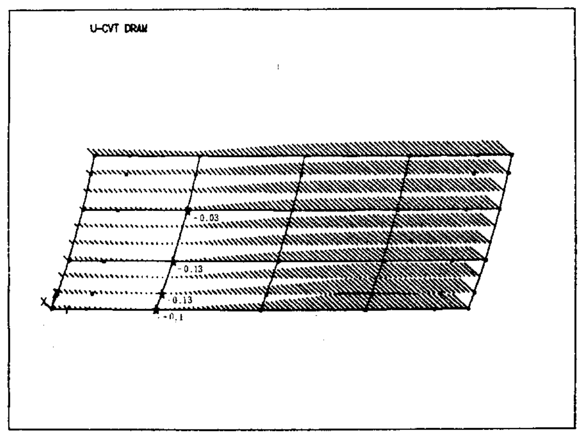

Fig.10 3rd Global Correction(Max. Dev=0.318)

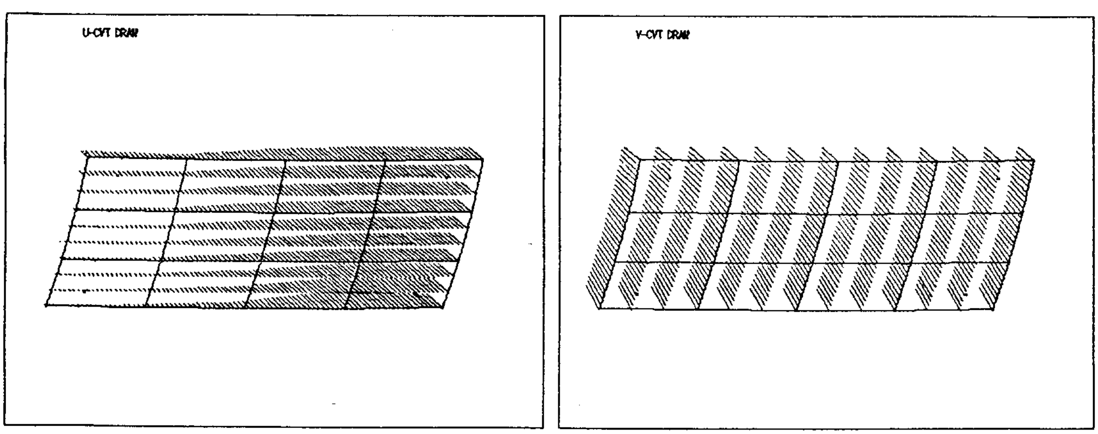

Fig.11 Final Surface