

Computation Method for Evaluation of Surface Fine Structure by Highlight Lines

György Gyurecz¹, Dr. Gábor Renner²

¹ Institute of Machine Design and Safety Engineering, Óbuda University

² Computer and Automation Research Institute, Hungarian Academy of Sciences

Abstract: Evaluation of quality is an important issue in the design of surfaces. Highlight lines is a highly sensitive method for quality control of free form surfaces. This paper presents a simple, robust and accurate method for the calculation of highlight lines. The generated highlight lines are suitable for appropriate evaluation of surface fine structure and for disclosure of irregularities of small extent. The method is applicable to any surface representations used in CAD systems.

Keywords: Surface evaluation; highlight lines

1 Introduction

High quality free form surfaces are those external parts of industrial objects which attribute to their aesthetic appeal. They are essential in automotive and ship industry, but numerous application examples can be found in medical or in household devices as well. Aesthetical requirements demand quality features like smoothness and evenness to be met on a high level. Various methods, including analytical and numerical ones have been developed for aesthetical evaluation of surfaces [3, 5, 7, 8, 9].

The highlight lines developed by K.-P. Beier and Y. Chen [1, 2] is a method that calculates and visualizes the reflection status of a surface. It is highly sensitive method, suitable for revealing surface irregularities of small extent, which have no effect on the functional shape and which are manifested in the fine structure of the surface. The sensitivity of the method heavily relies on the accuracy of highlight lines computation, which is a highly complex task. In this paper we present a method that ensures high, user adjustable computation accuracy. The method is robust, and applicable to any surface representation used in CAD applications.

2 Representation of Surfaces

Consequently we use parametric representation of the free form surfaces in Bézier, B-spline or NURBS form [6], as it is widely used in CAD applications:

$$\mathbf{S}(u, v) = \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} \mathbf{P}_{i,j} N_i^r(u) N_j^r(v), \quad (1)$$

with control points $\mathbf{P}_{i,j}$ and Bezier, B-spline or NURBS basis functions N_i^r and N_j^r , of degree r which are fully determined by their degrees knot vectors and weights. For designing the shape control points are primarily used, knots and weights provide additionally degree of freedom in design.

3 Highlight Lines of Surfaces

A highlight-line is created on the surface by the reflection of a linear lightsource of infinite length. The highlight-line is a set of surface points for which the corresponding surface normal and the light source intersect each other, that is the perpendicular distance between them is zero. Let $L(\lambda)$ denote the line of the light source:

$$\mathbf{L}(\lambda) = \mathbf{A} + \mathbf{B}\lambda \quad (2)$$

where \mathbf{A} is a point on $L(\lambda)$, and \mathbf{B} is a vector defining the direction of the line (Figure 1).

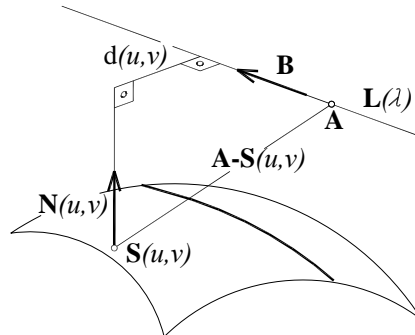


Figure 1
Distance between surface normal $\mathbf{N}(u, v)$ and the lightsource $\mathbf{L}(\lambda)$

The perpendicular signed distance $d(u, v)$ between the normal $\mathbf{N}(u, v)$ of a surface point $\mathbf{S}(u, v)$ and the linear light source is:

$$d(u, v) = \frac{[\mathbf{B} \times \mathbf{N}(u, v)] \cdot [\mathbf{A} - \mathbf{S}(u, v)]}{\|\mathbf{B} \times \mathbf{N}(u, v)\|} \quad (3)$$

If $d(u, v) = 0$ the surface point $\mathbf{S}(u, v)$ is on the highlight line. To obtain a more complete and detailed overview of the surface quality, a series of highlight lines are needed. This is realized by several lightsources, parallel to each other.

Highlight lines are highly sensitive to changes in surface normal directions, which makes them suitable for disclosing surface irregularities of small extent. This is often not possible with wireframe or shaded surface representations as it can be seen in Figure 2 (turbine blade).

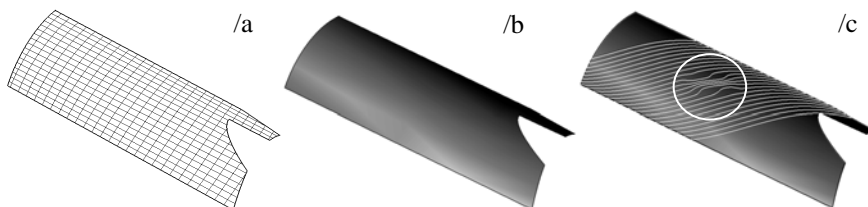


Figure 2

Representation of a turbine blade by wireframe (/a), shaded image (/b) and highlight lines (/c)

While the wireframe and shaded image representation (/a and /b) of the surface seems to be smooth, highlight lines show, it has irregularities around the central region (indicated by a circle in /c). In an interactive graphics environment, the mutual position of the surface and the lightsource series can be easily changed. The surface can be evaluated in detail by the examination of the pattern and shape of the highlight lines in new positions. The shape, smoothness, coherence and distribution of highlight lines are sensitive indicators of the surface quality.

4 Computation of Highlight Lines

Analytical computation of highlight lines requires the solution of the equation $d(u, v) = 0$ for $\mathbf{S}(u, v)$ which is a very complex and time consuming task. Furthermore, a linear lightsource can produce one or more highlight lines. These lines can lie close or far off to each other. They can have complex geometry; closed or open curves (see Figures 5 and 6).

The method we explain here computes and connects discrete points of highlight lines. For determining highlight points, relation (3) is used.

4.1 Computation of Highlight Points

The computation is outlined with the help of tags and notations used in Figure 4 and it is demonstrated on surface shown in Figure 5 (a trunk lid).

First the initial lightsource and vectors \mathbf{A}_0 and \mathbf{B} are determined. The initial lightsource is defined interactively by the user. The further elements of the lightsource series are created by using point \mathbf{A}_0 and vector \mathbf{B} and the parallel distance between the lightsources. This latter is also specified by the user. Total number of elements in the lightsource series is denoted by K .

Next, the surface is evaluated along parameter lines u and v , surface points $\mathbf{S}(u,v)$ and corresponding normals $\mathbf{N}(u,v)$ are calculated. Evaluation is done with a step set by the user, in accordance with the required calculation accuracy and surface complexity. Next, these values are stored into a two dimensional array of row (g) and columns (h) and of size $G \times H$.

Surface points are evaluated using relation (3), that is the distance between the surface normal corresponding to a surface point and the lightsource is determined. The evaluation is performed along parameter lines for every lightsource separately. By assigning the distances to parameter values along a parameter line, a distance function is created. In Figure 3, distance as a function of parameter value v is shown. The distance function belongs to the parameter line $u=0.36$ and to the highlight points of an intermediate lightsource.

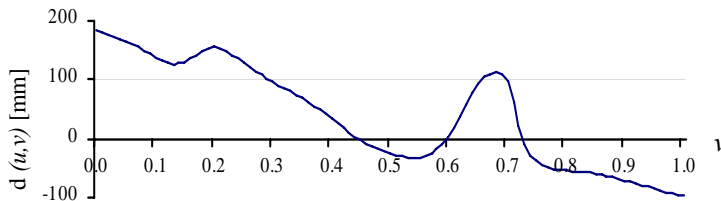


Figure 3
Distance function computed on a parameter line (v)

The zero points of the distance functions are where $d(u,v)=0$ is met, and the corresponding surface point $\mathbf{S}(u,v)$ is on the highlight line. Depending on surface complexity (more precisely variability of the surface normals), distance function can have more zero points. At this stage of calculation, the location of the zero points, (because of finite $G \times H$ number of surface evaluation points) are known only approximately. To determine the exact place of zero point with a desired precision, a search algorithm is applied. The pseudo code of the algorithm is shown in Figure 4/b. In Figure 4/a, the place of the algorithm in the overall process is shown (blocks with highlighted background). The location of the zero point is determined according to a user specified tolerance (defined in millimeters).

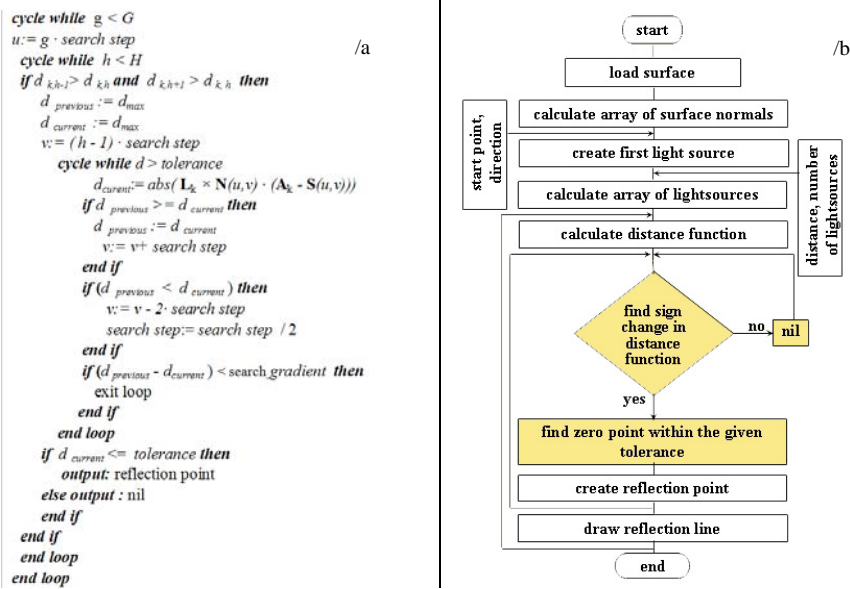


Figure 4

Algorithm to find the location of highlight points (a) and the place of algorithm within the method (b)

After the distance function and their zero points were computed at every parameter line, a set of highlight points is obtained. By connecting these points we obtain the highlight line (one or more) belonging to a single lightsource. Figure 5/a shows surface points used during the search. Dots in white denote highlight points. Red (grey) dots are surface points of the distance function seen in Figure 3. In Figure 5/b the highlight curve fitted on highlight points is shown. The cost of the calculation is proportional to the search gradient and inversely proportional to the tolerance value. Finer tolerance will produce more precise position of the highlight points, and consequently more accurate highlight curves. In the above example, tolerance value

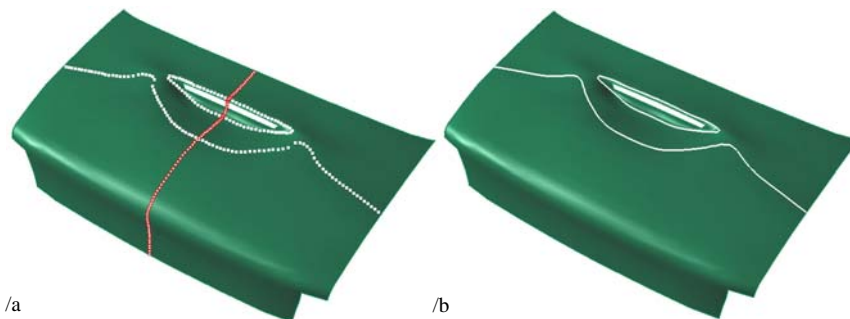


Figure 5

Points emerging at the calculation (5/a) and highlight curve passing through the highlight points (5/b)

was set to 10^{-3} mm which is comparable with the machining precision. In Figures 6, 7 and 8 we give examples of highlight lines calculated by our method. Notice that comparing to rendered images the highlight lines are able to give a more detailed and accurate overview of surface geometry. This is especially advantageous when disclosing errors of the surface fine structure is needed. In Figures 7 and 8 while surfaces seem to be error free by rendered images, highlight lines disclose irregularities (areas marked by circle). For correcting fine structure of surfaces, we developed a method described in detail in [4].

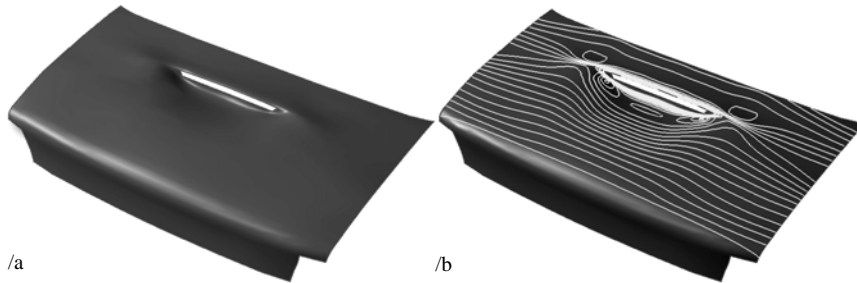


Figure 6
Surface of a trunk lid in rendered (/a) and highlight line representation (/b)

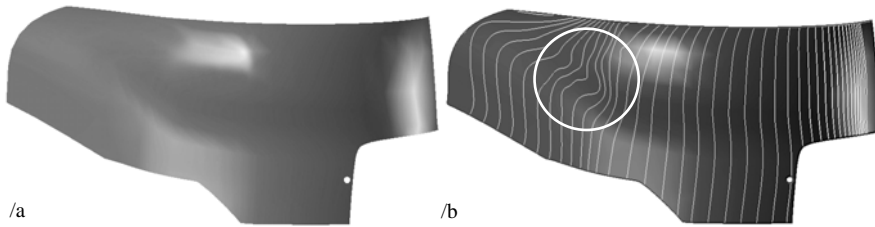


Figure 7
Surface of a car chassis part in rendered (/a) and highlight line representation (/b)

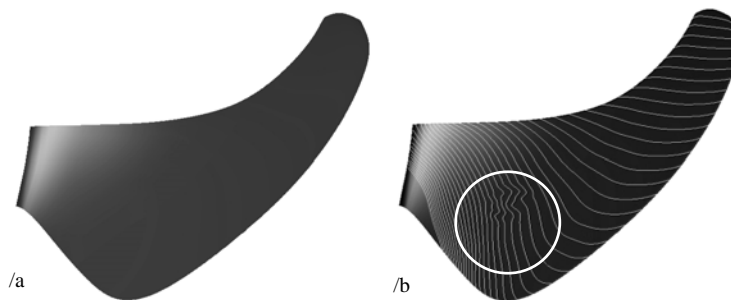


Figure 8
Surface of a propeller wing in rendered (/a) and highlight line representation (/b)

Conclusions

A high-precision method for highlight lines computation is presented. The method generates highlight lines through the computation of local zero points of the distance function interpreted between surface normals and light sources. For the calculations only CAD representation of the surface, spatial position and orientation of light sources are used. The method is robust, fast, and applicable to free form surfaces in any mathematical representations that are conventional in CAD systems. The adjusting of calculation accuracy is simple, measurement units of tolerances are those used in engineering. Its use efficiently helps the design and evaluation of high quality surfaces with complex geometry.

References

- [1] Beier K.-P., Chen Y.: The Highlight-Line Algorithm for Realtime Surface-Quality Assessment. *Computer-aided Design*, 1994, Vol. 26, pp. 268-278
- [2] Beier K.-P., Chen Y.: The Highlight Band, a Simplified Reflection Model for Interactive Smoothness Evaluation in Designing Fair Curves and Surfaces, ed. by N. Spapidis, 1994, SIAM, USA
- [3] Chen Y., Beier K.-P., Papageorgiou D.: Direct Highlight Line Modification on NURBS Surfaces, *Computer Aided Geometric Design*, 1997, Vol. 14, pp. 583-601
- [4] Gyurecz Gy., Renner G.: Surface Shape Optimization With Genetic Algorithm, *Gépészet 2010, 7th International Conference on Mechanical Engineering*, pp. 403-408
- [5] Higashi M., Harada H., Kuroda M.: Generation of Surfaces with Smooth Highlight Lines *Conference on Curves and Surfaces (4th)*, St. Malo, France, 1-7 Jul 1999, Vol. 1, pp. 145-152
- [6] Hoschek J, Lasser D.. *Fundamentals of Computer Aided Geometric Design*, AK Peters, Wellesley, MA, 1993
- [7] Yong J., Cheng F., Chen Y., Stewart P., Miura K. T.: Dynamic highlight line generation for locally deforming NURBS surfaces, *Computer-Aided Design*, 2003, Vol. 35, pp. 881-892
- [8] Yano S., Aoyama H.: Computer Aided Style Design System Based on Highlight Lines, *29th Computers and Information in Engineering Conference, ASME Conference Proceedings*, Vol. 2, pp. 957-965
- [9] Zhang C., Cheng F.: Removing Local Irregularities of NURBS Surfaces by Modifying Highlight Lines. *Computer-Aided Design*, 1998, Vol. 12, pp. 923-930