

GAP AND FLUSH VISUALIZATION OF VIRTUAL NONIDEAL PROTOTYPES

T. Stoll and K. Paetzold

Keywords: tolerances, visualization, virtual reality

1. Introduction

When a product is manufactured, it always has deviations from the ideal CAD-geometry. Therefore tolerances are assigned by the product developer, so that everybody who is involved in the product development process knows how much the parts are allowed to deviate from the ideal shape. Problematic is, that for the allocation of the tolerances different persons with opposed goals are involved. The product developer wants to assure that tolerances are rather tight, so that all functions are met, and the parts can be assembled properly. Otherwise, to reduce production costs, it is necessary that the parts have wide tolerances, so that low priced manufacturing methods can be used. In the case of automotive design this process is even more difficult, because additionally the designer wants that the aesthetic quality of the product is high, since otherwise the product sells badly. The problem is, that the output of commonly used tolerance analysis and synthesis tools are only distribution curves of previously defined points. While this curves can be interpreted by the tolerance specialists, it is hard for designers to imagine the impact of the tolerances on the aesthetic quality.

In this paper a method is presented where the designer can generate different nonideal prototypes independently from the proposed tolerances. This is done by defining gap and flush measurements at selected points. The designer can then evaluate whether or not the product meets the desired aesthetic quality. This information is later on given to the product developer or tolerance specialist, who then assures that the requirements of the designer are met. Other tools, e.g. 3DCS Advanced Analyzer Optimizer which were developed from SOVA methodology [Ceglarek 2004], can be used to set the tolerances accordingly to the designers specification. All visualizations that are generated can be viewed in virtual reality, so that the scenes are more realistic, and the interpretations made by the designer are even more reliable.

By using the proposed methods, tolerances can be set involving the designers and the product developers need at the same time. This will decrease the number of iterations in the tolerance allocation process, and thus leads to a shorter development process. Time consuming adjustments in the later design phases, because aesthetic quality targets are not met by the tolerance definition the product developer created, will occur less likely.

2. Related Work

In this chapter two other methods about tolerance visualization are explained. Afterwards different papers about deformation methods are presented.

2.1 Tolerance Visualisation

One method to generate nonideal visualizations is proposed by the VITAL project [Maxfield 2002]. The method consists of two steps. At first the user selects some points where the gap and flush

measurements are of interest. He then can view some ideal parts, which he can manipulate by using translations and rotations. The resulting gap and flush values at the defined points will be displayed. By this he will find out the rough boundaries of acceptable gap and flush measurements. In the next step he can set specific gap and flush targets at any of the defined points. A new position is then calculated which satisfies the different gap and flush measurements as good as possible. The designer can then judge whether or not the resulting assembly is acceptable or not.

The perception of gap and flush in virtual environments is analysed in [Wickman 2007]. Different nonideal views were generated and presented to different participants, which all were professionals. The impact of different factors (e.g. gap, flush, number of parts, colour, perspective, viewing mode) in perceiving gap and flush measurements were then calculated by averaging the guessed values of each participant. The experiments showed that the perception of gap and flush is different and depending heavily on the used visualization. Gaps should be evaluated with a stereoscopic view combined with texture, while flush should be evaluated with a small distance to the gap.

2.2 Deformation methods

Deformation methods were used relatively early in computer graphics, to generate complex object out of simpler ones easily [Barr 1984]. Barr proposes different transformations, like bending, twisting, and stretching for the deformation of solid objects. The methods are rather efficient, but the problem is that arbitrary deformations are not possible. Another commonly used method is the free-form deformation. A control lattice is put around the object which shall be deformed. By moving the points of the lattice all points of the geometry are moved in the direction of the point. The nearer a point is to the point of the lattice, the more the point is moved (see [Sederberg 1986] for details).

Coquillart extended the method, so that an arbitrary control lattice could be used [Coquillart 1990]. Prismatic lattices with rational splines are used to deform the geometry in an intuitive manner. To enable customized deformations, a library of different lattices, which could also be enhanced by the user, was proposed. Another way for deforming object is proposed by [Guillet 1998]. He uses Free-form deformation combined with a rigid bar network. The method can change the measurements of free-form surfaces by extending or shrinking the geometry in a certain direction. It can also be used to perform local deformations. Both methods are an approximation of other commonly used deformation methods in CAD, e.g. FEM, which generates realistic objects. While FEM needs very much computing time, the proposed methods can be used at interactive rates.

3. Gap and flush visualization

The new method is a further development of the method proposed by [Koch 2005]. In this method a triangular mesh is generated from CAD-geometry. After points are moved inside the tolerance boundaries a visualization of the mesh can be presented (see figure 1). As the differences are usually very small, various visualization techniques can be used to visualize the deviations, e.g. color coding, glyphs or transparent overlapping with the ideal geometry.

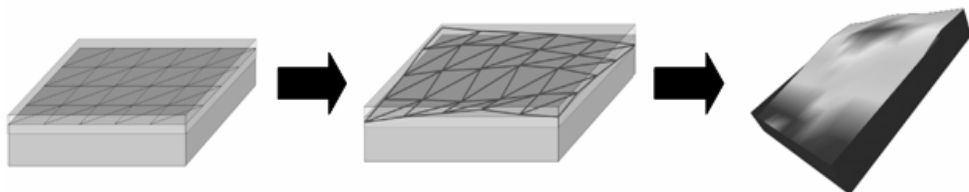


Figure 1. Method to generate visualizations of nonideal geometry

The developed method is divided in the steps mesh generation, deformation of the geometry and visualization. The method can be applied before tolerance analysis took place, after the CAD-geometry is available (see figure 2).

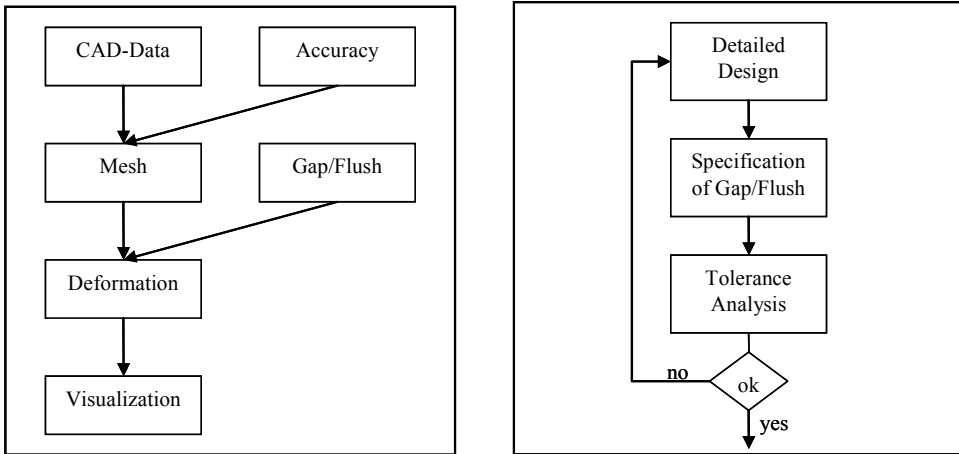


Figure 2. Process for generating visualizations of deformed geometry (left) and incorporation of the specification in the product development process (right)

As input the method needs geometry from an arbitrary CAD-system. In the developed prototype CATIA and Pro Engineer files can be read. At first the user can specify the needed accuracy of the mesh which is generated. The mesher used in this project (provided by the project partner Bytes + Lights) can be customized with many parameters. The important ones are: maximum edge length, maximum error in normal direction and maximum error in tangent direction. Since the generation of a triangular mesh is necessary for visualization but always is an approximation (see figure 3), this parameters are of great importance. If the maximum edge length is too big, the mesh consists of very large triangles. In our method only vertices of the mesh are manipulated, therefore we need many of them to apply the changes to the geometry evenly. The other parameters involved is the accuracy of the mesh in normal and tangent direction of the mesh. To make the generated visualization realistic, the error has to be set to a value which has no impact on the designer's decision. As the coarse values for the tolerances are known before, this error should be made smaller than at least 1% of the smallest tolerance value. In the examples in chapter 4 we used 0,1% of the expected range of the tolerances as maximum error in normal and tangent direction. By using this value, the influence of the discretization error can be ignored.

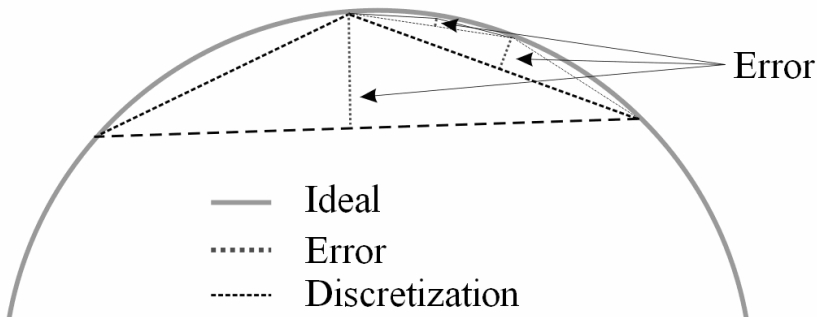


Figure 3. Triangulation error when generating a mesh for a circle

If large scenarios with many spherical or free-form surfaces have to be visualized the maximum error has to be made bigger, because the number of triangles increases if the value is small.

After the mesh generation the user of the method has to specify different gap and flush values at defined measurement points. Figure 4 shows a possible selection of points for the front auto body example. The points are marked with small grey dots.

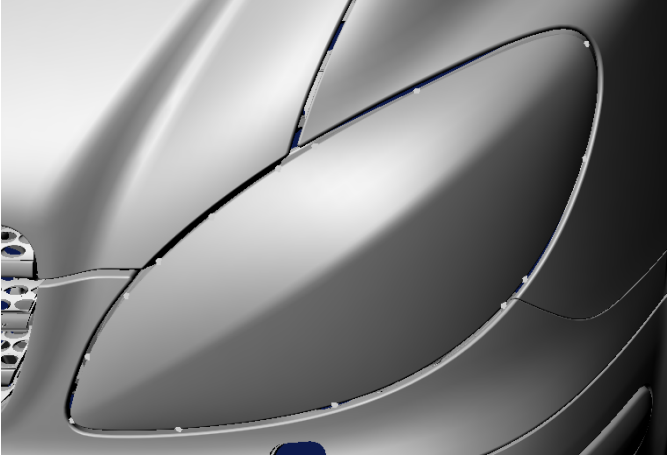


Figure 4. Defined points for gap and flush evaluation for the lamp of the front auto body

The next step is the definition of the gap and flush directions for each of the points. In the implemented prototype the values for both are entered manually in a file which is read when the application starts. If the method is used in a commercial system, there must be different ways to specify both values interactively. The gap direction can be computed by searching the closest point on the nearest part, or by using the normal direction of the point. The flush direction must be orthogonal to the gap direction. As there are infinitely many directions, the user has to fully constrain the direction, by specifying a plane in which the gap and flush vectors lie. To do this, there are different ways, depending on the topology of the geometry near the gap. In the example in figure 4 a normal of a point on the surface near the gap could be used, but this procedure cannot be applied with any example. When this is done, the user can finally define the gap and flush values at each of the points, by using the dialog shown in figure 5.

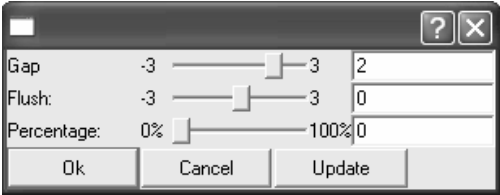


Figure 5. Dialog for gap and flush specification

The first to edit boxes are for the amount of the change in gap or flush direction. The units are in millimeters in this example. The percentage value in the last box defines how much the lamp or the surrounding parts are changed. If the value is zero, only the lamp is changed to achieve the new gap and flush values, if the value is one, only the geometry surrounding the lamp (bumper, engine hood and fender) is changed.

If all points are specified (not all values have to be changed) the geometry is deformed. This is done by manipulating all points of the mesh of the parts located near the gap. For a better differentiation between points of the triangular mesh which are deformed, and the points where gap and flush measurements are defined the former are called vertices and the later are called points. For the

deformation method, different rules have to be fulfilled, so that it can be used in the context of gap and flush visualization:

- The specified gap and flush values at the defined points have to be fulfilled exactly. Otherwise the designer will make a wrong specification of the tolerable gap and/or flush.
- One vertex is influenced either by two points, if it lies between them, or by only one point, if all other points lie in the same direction. This rule is needed in the case that a vertex with two points lying close in one direction and one point lying far away in the other direction exists. E.g. the second point right to the vertex in figure 6 should not influence the vertex.
- The nearer a vertex is to a point the greater is the influence of the point. As the gap and flush values are only specified at a small number of the vertices lying at the gap, the other vertices have to be interpolated.
- If a vertex is a certain amount (first border) away from the nearest point, the amount of the deformation is decreased, after another amount (second border) it is reduced to zero. As the designer only wants to see visualizations of the gap, geometry lying far away from it should not be deformed.

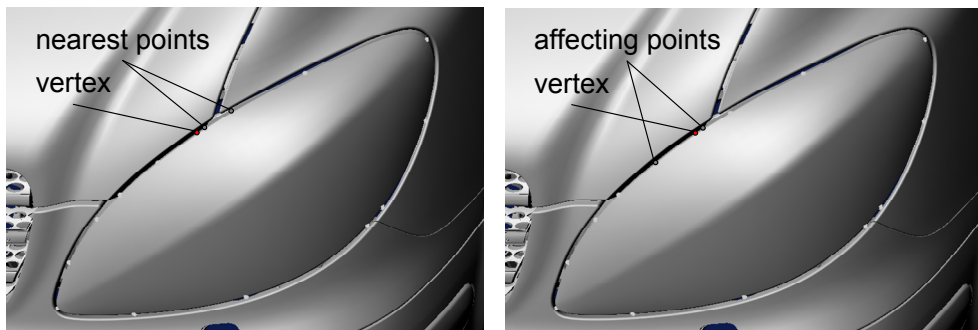


Figure 6. Vertex lying close to two points right to it (left image) but influenced by a point farther away to the left (right image)

The interpolation can be done with many different functions, and the border where the influence should be decreased can vary. Therefore many possible deformation functions fulfilling the above defined rules exist. Since these parameters depend on the desired visualization scenario, they can be configured by the user of the application. Therefore three different interpolation functions can be chosen, and the two distances where the influence of points to vertices decreases or is set to zero can be specified. As interpolation functions a linear, a quadratic and a cubic function were used. The quadratic and cubic ones make the deformation more local but also smoother than the linear function (see chapter 4 for details). The overall deformation function works as follows (see the flow chart in figure 7): At first it is checked whether one or two points affect the deformation of the vertex. If one, the deformation is decreased appropriately if distance lies beyond the first or second border, then the deformation value is added to the coordinate value of the vertex. If the vertex lies between two points, the distance to both points is calculated. Depending on the selected interpolation method, the influence of the deformation of each point is calculated. The resulting values are then multiplied by the specified deformation of each point. Both deformation values are then added to the resulting deformation at the vertex. In the last step the resulting value is decreased depending on the distance of the points and the selected first and second border. Different deformed gaps using the proposed method are presented in the next chapter.

Vertex between two points?	
Yes	No
<pre> distance1=calculateDist(vertex, point1) distance2=calculateDist(vertex, point2) inter1 = interpolate(distance1, distance2) inter2 = interpolate(distance2, distance1) decr = decrease(border1, border2, distance1, distance2) deformation = (inter1 * deformation1 + inter2 * deformation2) * decr </pre>	<pre> distance1=calculateDist(vertex, point1) decr = decrease(border1, border2, distance1) deformation = decr * deformation1 </pre>
new_vector = vertex + deformation	

Figure 7. Flow chart for the deformation of a vertex

4. Results

The method has been tested with data from a front auto body from Daimler. In the first example shown in figure 8 the gap has been narrowed at two of the specified points near the gap between engine hood and fender.

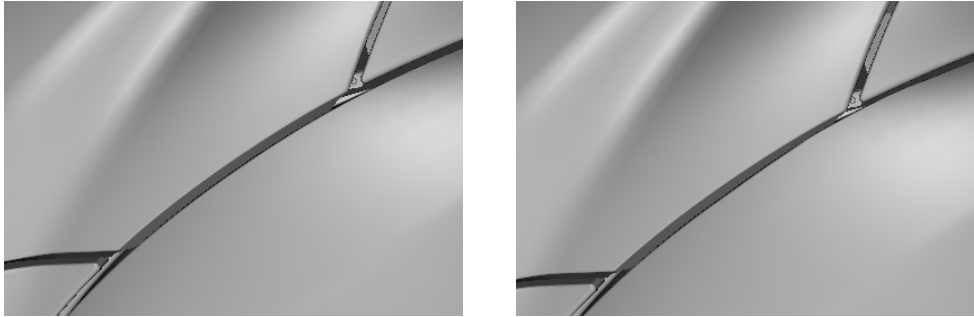


Figure 8. Original gap of the front auto body (left) and deformed gap (right)

The linear function has been used for interpolation in this example. The difference between the interpolating functions can be seen in figure 9. The deformations are set to high values, so that the effect of the different functions becomes clear. While the linear interpolation produces acuted-angled deformations, the quadratic one is smoothly. The cubic interpolation function did not provide a smoother deformation, but resulted in a more locally deformation.

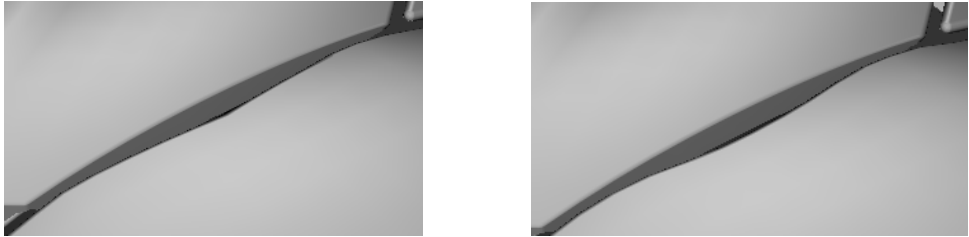


Figure 9. Deformed gap of the front auto body with linear interpolation function (left) and quadratic interpolation function (right)

The next examples (figure 10) show a scenario where the gap has been expanded and narrowed respectively as a whole by applying the same gap value at each of the points. These visualizations can be used to specify the tolerable gap and flush values for all points simultaneously. Different points can be changed locally afterwards (see example in figure 8 at the right), if more precise values are needed at one or more of the points.

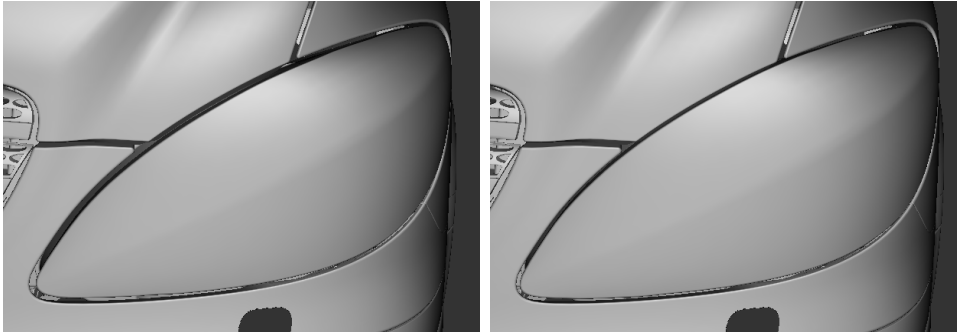


Figure 10. Different visualization of gap sizes generated by the prototype

The effect of different flush sizes can be visualized, too. From the perspective used for the other examples, the difference can hardly be recognized (see figure 11 at the left). To analyse the flush, a different view point has to be taken, like shown in figure 11 at the right. If a system which allows stereoscopic visualization is available, also the left perspective can be used to interpret the impact of the flush on the aesthetic quality. This is no contradiction to the work presented in [Wickmann 2007] (see chapter 2 for an overview), who suggests that only gap should be visualized with stereoscopic view. While the aesthetic quality can be judged with a stereoscopic visualization, the actual value of the flush cannot be guessed by the designer. For all visualizations the use of a stereoscopic display will allow the designer to make a more meaningful decision.

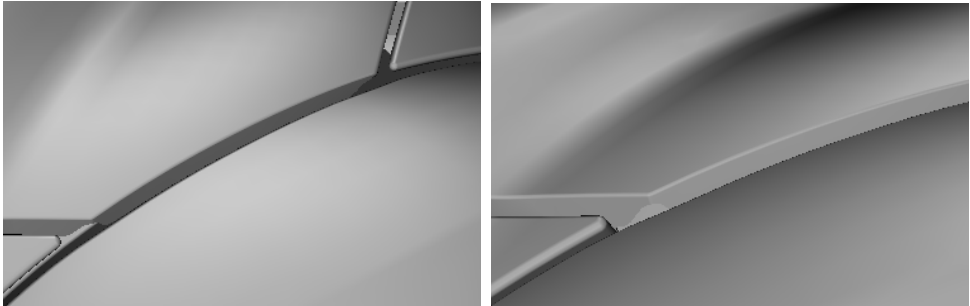


Figure 11. Different perspectives of an example where flush has been changed

5. Conclusion and future work

A method to generate nonideal geometry has been presented. As input it takes geometry from a CAD system. A triangular mesh is generated, with accuracy depending on the input of the user. Then points where gap and flush measurements can be specified are selected, and the mesh is deformed according to the input of the user. The used deformation method has been described in detail. Different generated visualizations with the implemented prototype were shown. Since the method only takes a few seconds, the designer can view different nonideal scenarios. The application allows the designer to

make meaningful predictions about acceptable gap and flush measurements. In contrast to [Maxfield 2002] all parts surrounding the gap can be deformed with the suggested method.

The results of this analysis are forwarded to the product developer and the tolerance specialists. By the specification of tolerable measurements, the aesthetic quality of a product can be taken into account very early in the product development process, and therefore leads to a shorter process, since time consuming iterations in the tolerance analysis will become less likely.

Future work would be to enhance the method, so that it is possible to generate geometry not only for thin gaps, but gaps which are composed of two large surfaces, e.g. a cylinder which is put into a bored hole. To evaluate the methods with industrial partners the manual input of the gap and flush directions should be replaced by a graphical user interface where the directions can be chosen. To allow the visualization of measured geometry it is planned to enable the positioning of parts measured with laser scanners directly in the prototype.

Acknowledgement

This research project has been funded by the German Research Foundation (DFG). It's a project of the Collaborative Research Centre 396. Three industrial partners, namely Daimler, Bytes + Lights and IC:IDO provided essential input to the project. Many thanks to Stefan Wittmann and Andreas Stockinger from the institute of engineering design of the University Erlangen-Nuremberg for the lively discussions.

References

- Barr, A.H., "Global and local deformation of solid primitives", *Computer Graphics*, Vol. 18, No. 3, 1984, pp. 21-30
- Ceglarek, D., Huang, W., Zhou, S., Ding, Y., Kumar R., Zhou Y., "Time-based competition in manufacturing stream-of-variation analysis(SOVA) methodology-review", *International Journal for Flexible Manufacturing Systems*, Vol. 16, No.1, 2004, pp. 11-44
- Coquillart, S., "Extended Free-Form Deformation: A Sculpturing Tool for 3D Geometric Modelling", *Computer Graphics*, Vol.24, No. 4, 1990, pp. 187-196
- Guillet, S., Leon, J.C., "Parametrically deformed free-form surfaces as part of a variational model", *Computer Aided Design*, Vol. 30, No. 8, 1998, pp. 621-630
- Koch, A., Meerkamm, H., "TolVis – visualization of possible shape variations resulting from shape and position tolerances", *Proceedings of 15th International Conference on Engineering Design (ICED 05)*, Melbourne, 2005, pp. 311-312 (full paper on CD)
- Maxfield, J., Dew, P., Zhao, J., Juster, N., Fitchie, M., "A Virtual Environment for Aesthetic Quality Assessment of Flexible Assemblies in the Automotive Design Process", *SAE 2002 World Congress, Detroit*, 2002, pp 209-217
- Sederberg, T.W., Parry, S.R., "Free-Form Deformation of Solid Geometric Models", *SIGGRAPH*, Vol. 20, 1986, pp.151-160
- Wickman, C., Söderberg, R., "Perception of gap and flush in virtual environments", *Journal of Engineering Design*, Vol. 18, No. 2, 2007, pp. 175-193

Dipl.-Inf. Tobias Stoll
Scientific employee
University of Erlangen-Nuremberg, Institute for Engineering Design
Martensstr. 9, Erlangen, Germany
Tel.: 049 9131/85-23218
Fax.: 049 9131/85-23223
Email: stoll@mfk.uni-erlangen.de
URL: <http://www.mfk.uni-erlangen.de>