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ISOSURFACE VERTEX NORMAL COMPUTATION

Summary. This paper discusses the use of scalar field's gradients for computing normal vectors in the vertices of such field's isosurfaces. Three schemes for the gradient vector estimation are compared with respect to their accuracy and thus their influence on the Gouraud shaded isosurface appearance.

OBLICZANIE WIERZCHOŁKÓW NORMALNYCH IZOPOWIERZCHNI

Streszczenie. W artykule omówiono użycie gradientu pola skalarnego do obliczania wektora normalnego w wierzchołkach pól izopowierzchni. Schematyczne drzewo dla gradientu wektora oszacowane jest z uwzględnieniem jego dokładności i tym samym wpływu na cieniowania na typy Gourauda izopowierzchni.

1. Introduction

Isosurface extraction and visualization snatd for a powerful tool to explore the information contained in scalar volumetric data defined over regular as well as irregular grids. Moreover, along with dimension contraction, isosurfaces can also depict quantities derived from vector fields and other multidimensional data. The advantage of employing isosurfaces as a visualization tool consists in their ability to describe the character of the rriginal data in an inuitive and easy to understand way. On the other hand, a single isosurface does not show how the investigated quantity evolves within the dataset. To compensate this flaw, a set of surfaces corresponding to different isovalues can be incorporated. Being visualized swquentially one after another or simultaneously, such a set of isosurfaces gives a good notion of the quan-

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tity dustribution in the input volumetric data. To fully exploit the benefits of this approach, two requirements should be met. First, the extraction algorithm needs to respond quickly to changes of the isovalue so that it provides as interactive rates as possible. Second, the isosurfaces (usually represented by a triangle mesh) should be rendered smoothly, thus suppressing the disturbing effect of seeing edges between individual polygons.

2. Computing Vertex Normal from Triangle Normals

Many techniques dealing with the former of the two above described issues have appeared. Most of them focus on minimizing the number of investigated cells in the input volumetric mesh. To meet the later requirement, Gouraud shading technique is applied, which, however, requires the normal vectors to be known in all the vertices of the isosurface being displayed. For triangle meshes representing general surfaces, the normal vector in each vertex is usually computed as an average of the normals af the adjacent polygons ($N = \sum_{i=1}^{n} N_i / \left| \sum_{i=1}^{n} N_i \right|$, where N is the vetex normal and N_i are the adjacent triangles' normals)[1]. To improve accuracy, weighting each polygon's normal by its angle at the processed wertex has been suggested ($N = \sum_{i=1}^{n} \alpha_i N_i / \left| \sum_{i=1}^{n} \alpha_i N_i \right|$, where α_i are the angles enclosed by the adjacent trian les [6]. We denote it later as *TW*.

3. Computing Vertex Normal from Scalar Field's Gradients

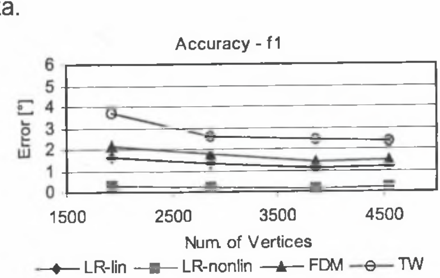
When working with meshes, which represent isosurfaces, however, one may utilize the fact that the gradient vector $\nabla \varphi = \frac{\partial \varphi}{\partial x}\vec{i} + \frac{\partial \varphi}{\partial y}\vec{j} + \frac{\partial \varphi}{\partial z}\vec{k}$ in location **Q**[x_0, y_0, z_0] of the function ϕ(**P**), which defines the values of a scalar field, is perpendicular to the field's isosurface passing throught **Q**{x_0, y_0, z_0] [5]. Thus, it has the same direction as the normal of the surface in location **Q**. Unfortunately, the function ϕ(**P**) is unknown and the only information availble consists of the function values in the grid vertices of the scalar field. Therefore, the gradient vector can not be determined exactly but must be estimated. We have studied two estimation algorithms (the first from [4] will be denoted here as *LR-lin*, the other from [3] *FDM*) and improved the first in [2] (*LR-nonlin*).

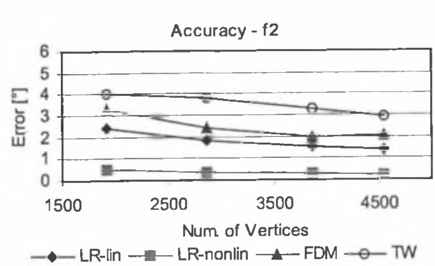
4. Tests and Results

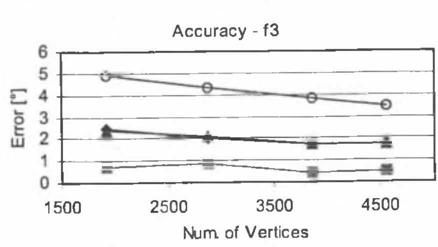
In the tree graphs bellow, the accuracy of the *TW* method and the gradient utilizing methods *LR-lin, FDM* and *LR-nonlin* is compared. For the tests, four volumetric datasets of $0{,}5 \cdot 10^4$, 10^4, $1{,}5 \cdot 10^4$ and $2 \cdot 10^4$ vertices have been used. These vertices were randomly distributed in a unit cube and the volume was decomposed into Delaunay tetrahedra. As well as in [2], the following functions were used to generate values in the vertices:

1. $f_1(x,y,z) = x^2 + y^2 + z^2$,
2. $f_1(x,y,z) = x^3 + y^3 + z^3$,
3. $f_1(x,y,z) = 3 \cdot x^4 \cdot y^2 \cdot e^z + 8 \cdot y + 5 \cdot x \cdot e^y + 16 \cdot z^5$.

From these data, isosurfaces have been extracted mand their normals estimated by individual methods and compared to analytically obtained normals. The number of verices in the graphs bellow relates to the isosurfaces, not the volumetric data.







Althought the maximum average error of all the methods does not exceed 5 degrees, the accuracy influences the final image significantly as shown in Fig 1. This difference faded with the increasing density of verticed. However, it did not disappear entirely even for the largest dataset.

Fig. 1. 50% isosurface through the data set of 5000 vertices with values defined by *f3*. Normals were estimated by *WT, FDM, LR-lin, LR-nonlin* (from upper left to bottom right)

Rys. 1. 50% izopowierzchnia przechodząca przez 5000 danych wierzchołków, których wartości określono za pomocą *f3*. Normalne są przybliżone w oparciu *Wt, FDM, Rl-lin, Rl-nonlin* (w kolejności od górnego lewego do dolnego prawego rogu)

5. Conclusion

Besides that the gradient based methods are more accurate and give smoother images, another advantage arises from the fact that the scalar field's gradients may be computed in advance. The same interpolation as that used for generating the isosurface vertices then yields normals in these verices as well, making it possible to use the Gouraud shading technique while reducing the delay caused by vertex normals computation. These two advantages, however, come at a proce of longer preprocessing as described in [2].

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Abstract

In this paper, the possibility to compute isosurface vertex normals from gradient vectors of the scalar field is discussed and compared to the generally used approach of computing vertex normals as an (possibly weighted) average of the

normal vectors of the adjacent triangles. The importance of the gradients' accuracy for the isosurface appearance is shown and three methods for estimating these gradients are evaluated.