Special Topics in Visualization

Final Project Report

Dual contouring of Hermite Data

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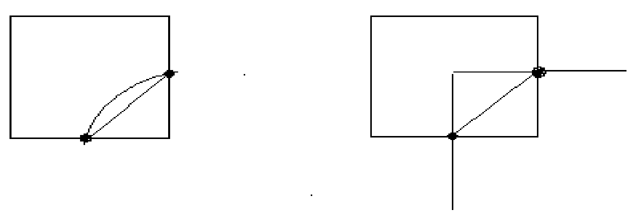
Introduction

Iso-surface extraction from 3D volumetric data is an interesting and important problem in computer visualization which has many application different fields ranging from medical image analysis to game programming. Over the years, many algorithms have been proposed for iso-surface extraction. Marching Cube is one of the well known contouring methods.

In contouring method, a uniform 2D or 3D grid with scalar values is given and the task is to find an iso-contour or iso-surface with certain iso-value. Contouring methods scan the entire grid and construct the surface. Surface is generally a represented as a triangular mesh or quad mesh.

In general, there are two different types of contouring algorithms. One type is known as direct contouring methods (Example, Marching Cube) and the other category is dual methods. Direct contouring methods places the vertices of the surface mesh on the edge of grids and hence they can not render any sharp feature which falls inside the grid cell. But, dual methods places the mesh vertices inside the grid cell, which allow them to handle to problem of rendering sharp corner which falls inside the grid cell (Fig 1)



A: good approximation B: Bad Approximation

Fig1. Bad approximation of sharp feature

In this project I have studied and implemented a dual contouring method for iso-surface extraction and contouring. Rendered examples demonstrate that dual methods can approximate the sharp corners of the surface quite well than direct contouring methods.

Dual Contouring algorithm

In dual contouring, input is a sign valued grid. Also edges of the grid with opposite signs must have exact intersection point and associated normal of the iso-surface. This type of data is known as Hermite data. In some cases if the sign values grid does not contain this intersection points and normals, one can determine the intersection point using linear interpolation along the edge and finite differencing method can be used to determine the associated normal. Fig 2. Shows a grid tagged with hermite data.

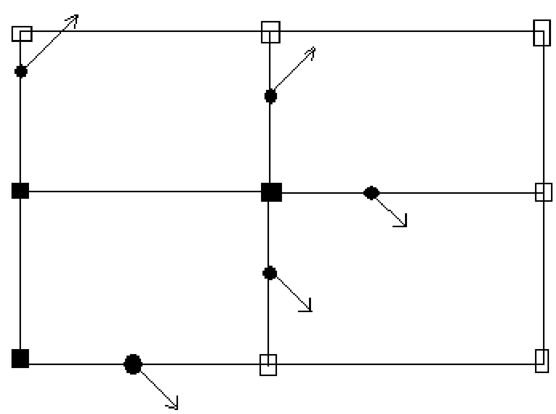


Fig 2. A sign valued grid with Hermite data

Dual Contouring method is composed of two main steps. For each non-uniform grid cell compute an iso-vertex and connect the adjacent vertices to generate the surface. To determine the location of isoverex we need to use the intersection points p_i and normals n_i. Position x of the isovertex can be obtained at the minima of the following quadratic error function (QEF).

$$\mathbf{E[x] = \sum_i (n_i \,.\, (x - p_i))^2}$$

This function $E[x]$ can be expressed as the inner product $(Ax\text{-}b)^T (Ax\text{-}b)$ where A is a matrix whose rows are the normals n_i and b is a vector whose entries are $n_i \,.\, p_i$. Typically, the quadratic function $E[x]$ is expanded into the form

$$\mathbf{E[x] = x^T A^T Ax - 2x^T A^T b + b^T b}$$

Because of the normal direction there is a chance that the matrix can be rank deficient and hence we need to use **svd** to solve for x. Also, in case we have multiple solution for E[x], we add one more constraints that isovertex x, will also minimize the distance from the centroid c of intersection. Thus the objective function becomes –

$$\mathbf{F[x] = E[x] + (x - c)^2}$$

In order to solve for the minima of F[x] , we augment A by adding one more rows of ones and augment b by appending sum of the components of centroid c.

We solve the above optimization for each non-uniform grid cell [grid cube or grid square] and obtain an isovertex. Then we connect adjacent iso-vertices which gives us the approximation of the iso-surface in the form of quad mesh.

Experimental Result

The dual contouring method has been implemented in MATLAB. Implementing the algorithm in MATLAB helped to solve the minimization of x using in built library function. The implantation has been tested by extracting iso-contour of four implicit functions in 2D and 3D and 3D MRI scan of brain. For brain model, we also report some comparison.

Implicit functions for 2D are circle and square. Figure 3 and 4 shows isocontour of these two implicit functions.

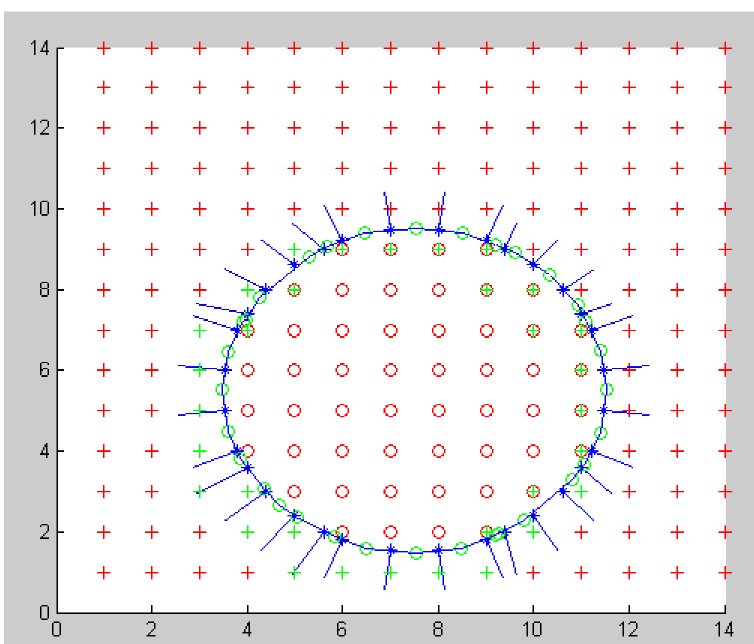


Fig 3: isocontour of the circle. Normal direction and point of intersection is also drawn.

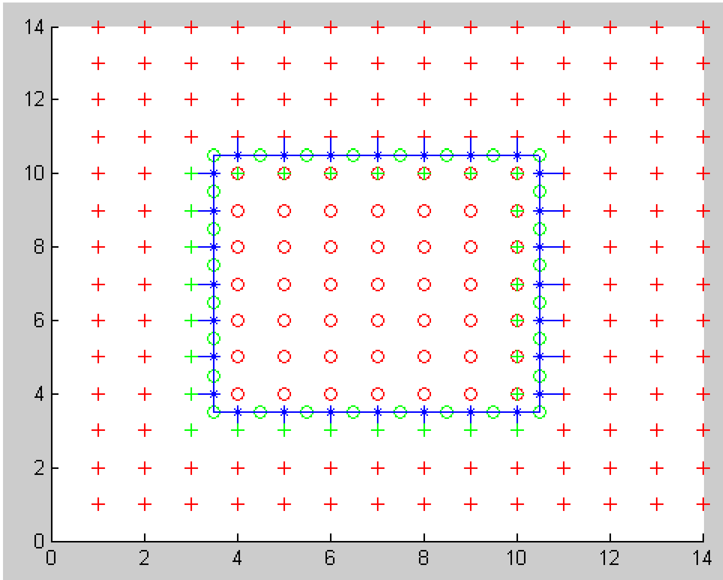


Fig 4: isocontour of the rectangle. Normal direction and point of intersection is also drawn.

We also implement marching cube algorithm to compare with the dual contouring method. We compare three 3D models. Following table shows number of vertex and triangles obtained using marching cube algorithm.

Marching Cube

Model	Input size	Number of Vertices	Number of Triangles
Sphere	25 X 25 X 25	414	824
Cube	25 X 25 X 25	216	428
MRI Head	128 X 128 X 27	18604	37072

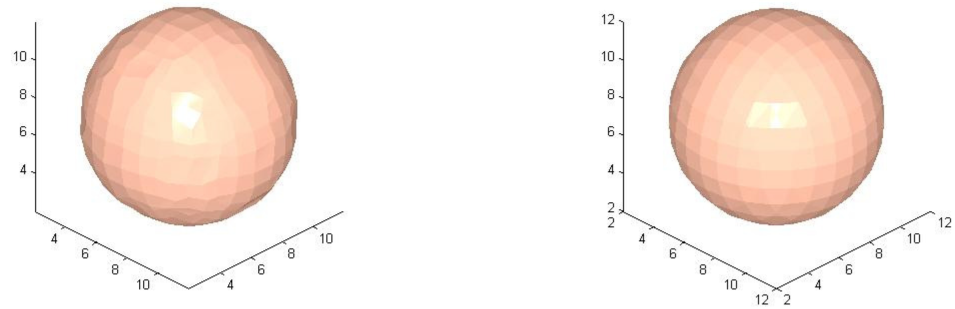
Following table shows number of vertices and quads we get using dual contouring method.

Dual Contouring

Model	Input size	Number of Vertices	Number of Quads
Sphere	25 X 25 X 25	416	414
Cube	25 X 25 X 25	218	416
MRI Head	128 X 128 X 27	19216	19717

From the following table it seems that number of vertices obtained using both the models are roughly same since we did not apply any mesh simplification techniques.

We also give some visual comparison of these 3d models. First consider the sphere model (Fig 5).

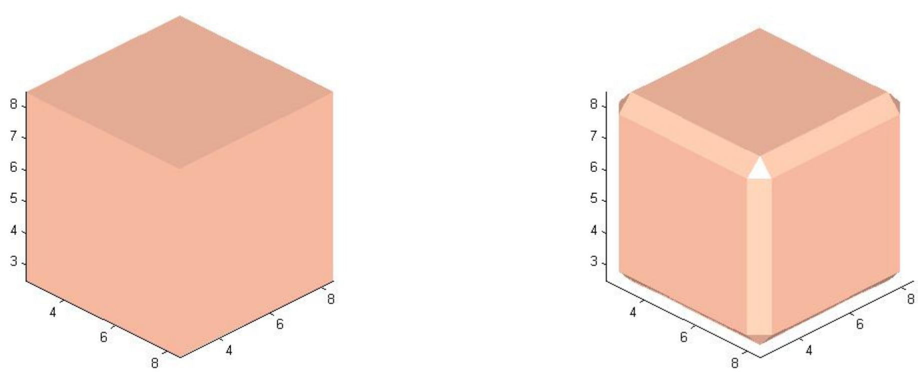


Dual Contouring   Marching cube

Fig 5. Rendering of sphere in dual contouring and marching cube algorithm

Since sphere is a very simple models we don’t find any visual difference between the two surfaces.

Then we show the result for 3D cubed surface rendering. Fig 6 shows the comparison.

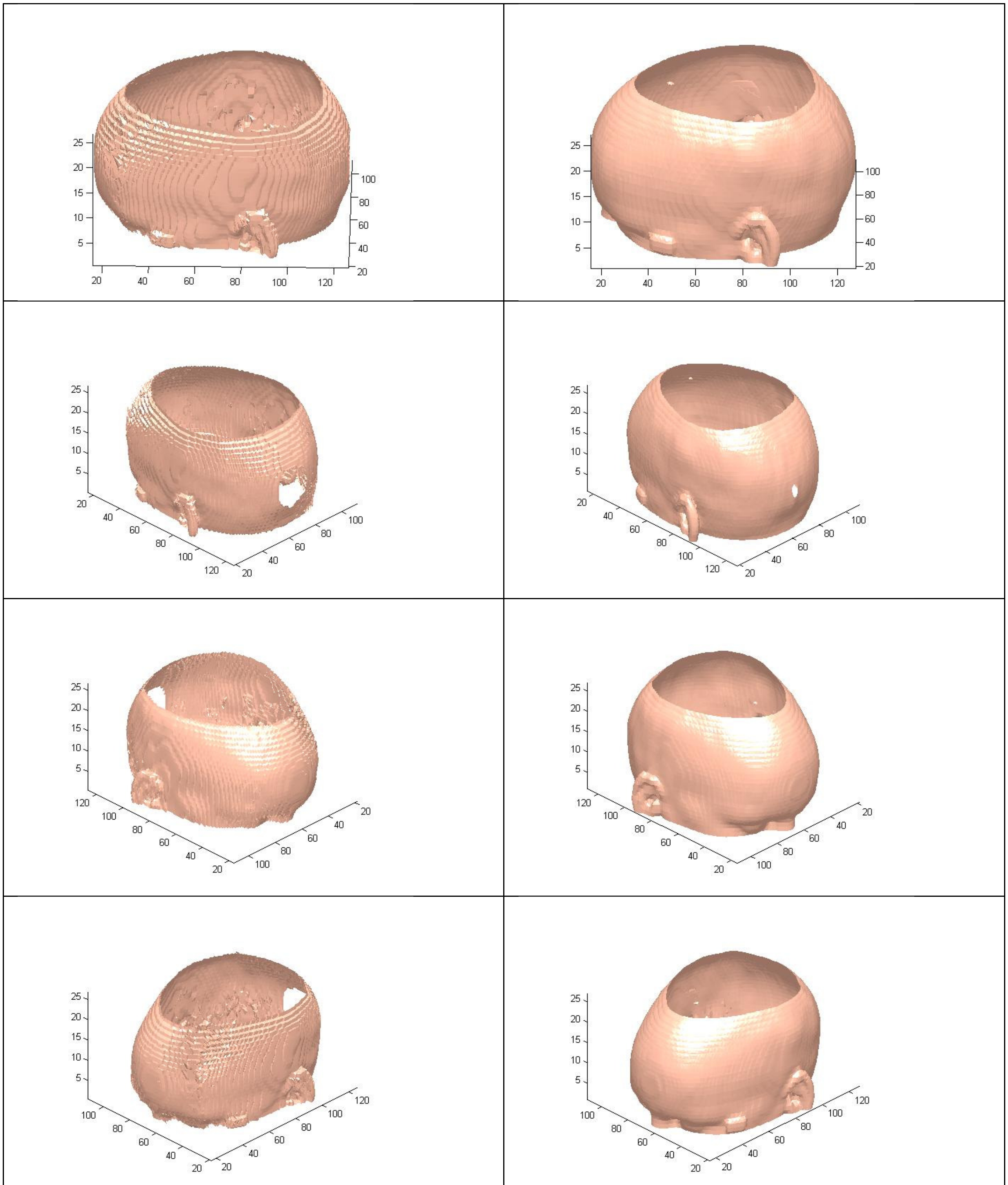


Dual Contouring   Marching cube

Fig 6. Rendering of cube in dual contouring and marching cube algorithm

From this rendering we find the necessity of using dual contouring algorithm as dual contouring method correctly reconstructs the corners and edges of the surface correctly. On the other hand marching cube algorithm could not recovered the sharp features from sampled data.

Now we present the result of surface reconstruction of MRI head dataset in Figure 7.



Dual Contouring | Marching Cube

Fig 7. Surface reconstruction of MRI Head dataset

From the result of MRI head dataset it showed that quality of surface obtained using marching cube algorithm is better than dual contouring method. This can be due to the fact that because of the data normal calculation may not be accurate. Normal vector were calculated using the sampled values on the grid only. More precise normal may give us better result.

Discussion

If we look at the extracted contours in the experimental result section, we will see the dual contour method has successfully extracted the iso-contour of the functions. Moreover, it has recovered the corner of cubes and rectangles from Hermite data which is the main motivation of using dual contouring methods. Although in this project the positions of the iso-vertices are computed independent of each other, one can make a linear system to solve for all the iso-vertices and thereby can make the implementation faster.

Conclusion

By doing this project I became familiar with dual contouring methods and its potential advantage over direct contouring methods and it was a good learning experience for me.

References

[1] Ju, T. et al, *Dual Contouring of Hermite Data*, ACM Transactions on Computer Graphics (SIGGRAPH 2002 Proceedings), pp 339-346, 2002

[2] Schaefer S. and Warren J. *Dual Contouring: The Secret Sauce*

[3] Contouring Implicit Surfaces Principles and Practice -- Ronen Tzur

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