Volume Rendering of 3D Borehole Data Based on GPU

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Abstract: Taking 3D borehole data for research object, an algorithm flow of volume rendering based GPU is given. According to the limited and discrete characteristics of 3D borehole data, Kriging interpolation algorithm is used to construct a regular grid data model. Ray-casting algorithm based on GPU is realized with the Visualization Toolkit (VTK). The results show that after the application of volume rendering technology, it is easy to practice the functions of arbitrary section displaying, volume clipping and volume data extracting which are practicalities.

Introduction

Volume rendering [1] is a technology to generate 2D image from 3D data field directly. This technology doesn't construct geometrical graphic items. All sampling points of the data body contribute to the image, the panorama and internal details of data field are showed clearly. Volume rendering technology can accurately express the panorama of complicated geological phenomenon and all kinds of geological structure in geological body. It fully improves the visualization and accuracy of geological analysis [2].

Most traditional visualization methods of borehole data construct model based on surface firstly, such as multilayered DEM, TIN surface generated from Delauney method, and then after the operation of shearing and suturing, a 3D geological body can be obtained. Another method is to construct model based on body, such as Tetrahedral Element Model, Octree Model, Bock Model, etc. All these models adopt surface rendering technology under which the image is isolated and unilateral; at the same it cannot reflect the integral tendency of data. The process of constructing model is complex, too [3].

Compared with other volume rendering algorithms, such as Splatting algorithm, Shear-warp algorithm, Volume element algorithm and Frequency domain volume rendering algorithm, the main advantage of Ray-casting algorithm [4] is that it can generate high quality image, furthermore it has good calculation parallelism. The calculation speed of Ray-casting algorithm based CPU is slow and the interaction of is poor. Since GPU has more cores than CPU and can process many data parallel at one time, Ray-casting algorithm based GPU is used widely.

The theory of Ray-casting algorithm based GPU[5]

In Ray-casting algorithm based GPU, as 1D texture, transfer function and opacity function are loaded into GPU, at the same time, 3D volume data is loaded into GPU as 3D texture. The calculation of resampling and image synthesis will be processed by fragment shader [6] of GPU.

2.1 Resampling and image synthesis in GPU

Set the position of ray entering data volume is p_{in} , the position of ray running out it is p_{out} . pos, the ith resampling point of ray is expressed as ,

$$pos = p_{in} + i * \text{rayDir} * normalize(p_{out} - p_{in}) \qquad i \in N \qquad (1)$$

In (1) rayDir is the distance of resampling point, $normalize(p_{out} - p_{in})$ is the normalization of vector $p_{out} - p_{in}$. If $|pos - p_{in}| > |p_{out} - p_{in}|$ is true, then the resampling point is out of volume data.

Set the color value of ith volume element is color, the opacity value of it is opacity, the color value of entering into ith volume element is destColor_{i-1} , and the opacity value is $\text{remainOpacity}_{i-1}$ .After pass through the ith volume element, the color value is destColor_{i} ,the opacity value is emainOpacity$_i$. The calculation of image synthesis from front to back is, $destColor_i = destColor_{i-1} + color * remainOpacity$

$$\text{remainOpacity}_i = \text{remainOpacity}_{i-1} * (1.0 - opacity) \qquad (2)$$

The flow of fragment shader algorithm

Fragment shader can be divided into the following sections:

(1)Calculate incident point of current direction of line sight, the most distant point, and then convert them into the coordinates of volume texture.

(2)Calculate sampling step rayDir according to volume data.

(3)Sample volume texture and accumulate the value of color synthesis and opacity.

(4)Decide whether the sampling distance is greater than the maximum distance or the accumulation of opacity is more than 1.

(5)Output the value of color.

Ray-casting algorithm base on GPU is shown as follows:

```
//shader    version 110
Function    trace(void)
Begin
destColor←initialColor();        // initial color value of ray entering into volume data
remainOpacity←1.0-destColor.a;                 //residual transparency
While inside==TRUE                    //the flag of whether the sampling point is in volume data
   While inside==TRUE
      value←texture3D(dataSetTexture, pos);
            //obtain property value of pos of current position through volume data
       scalar←scalarFromValue(value);
           //get corresponding color value of property value from transfer function
      opacity←texture1D(opacityTexture,scalar);      //opacity
      If opacity>0.0    then
         color←shade(value);           //calculate of light on current point
         color←color*opacity;
         destColor←destColor+color*remainOpacity;    //color synthesis
         remainOpacity←remainOpacity*(1.0-opacity);    // opacity synthesis
      End if
      pos  ←pos+rayDir;           //position of next sampling point
      t←t+1.0;                 // counts of sampling point plus 1
        //decide whether the sampling point is in the valume data,
        // in the expression, tMax is the total number of sampling points
      inside←t<tMax && (remainOpacity>=0.0039); // 1/255=0.0039
   End while
End while
gl_FragColor←destColor;                   //output color value
gl_FragColor.a←1.0-remainOpacity;           //output transparency
End
```

Construct 3D volume data

Define borehole data

3D borehole data set can be expressed as two-tuples K= (U, R), in which U is an object (i.e. sampling point) set, R is a property set. For $\forall r \in R$ exist $r: U \rightarrow V_r$ in which V_r is the numerical range of property r, that is to say, $\forall p \in U$, $r(p) \in V_r$ .If R={x,y,z,a}, in which x,y,z are properties of coordinate, a is property of data, furthermore there is one to one correspondence between p and <x(p),y(p),z(p)>, then $f:\{x, y, z\} \rightarrow V_a$ is equivalent to $a: U \rightarrow V_a$,i.e.

$f(x(p), y(p), z(p)) = a(p)$. Data set $K = (U, \{x, y, z, a\})$ is 3D borehole data. In 3D borehole data, the property of each sampling point of borehole is the formation NO. of this point.

Preprocess data—Construct formation level NO. of borehole

As figure 1, stratiform deposit or rock formed in a certain geological period is called formation. After analysis the borehole, give level NO. to every formation according to its sedimentary sequence, and then establish sedimentary sequence table on which give each borehole formation level NO.s. All these numbers belong to property set R.(In order to make the borehole horizontal alignment, layer 0 and layer 6 are appended.)

Construct volume data of borehole

The advantage of modeling method [7] proposed by Luo Zhiyong is the small computational amount. The disadvantage of it is that formation level NO. cannot be determined in complex terrain as shown in Figure 2. It is difficult to interpolate formation automatically. Data of borehole is only limited discrete data, so common Kriging interpolation algorithm [8,9] can be used to generate volume data required by volume rendering.

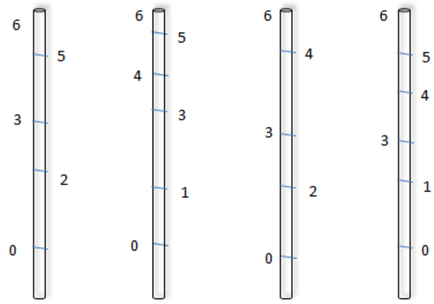

Figure 1 formation level NO. of borehole

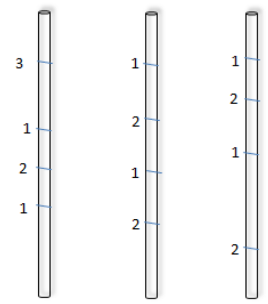

Figure 2 complex formation

Modeling method fitting for any geologic body

(1)Gridding. Set the range of grid according to the data position in database, at the same time, the size of grid needs to be set according to the user's requirement.

(2)Calculate the estimated point's coordinates(x,y,z), that is p_0.

(3)Select the appropriate reference point p_i according to search strategy (near distance search, position search).

(4)Calculate the coefficients K, λ, D of equation set according to obtained variation function.

(5)Solve equation set(use LU method) to get weight coefficient λ_i .

(6)Calculate the property value R' of estimated pointed through $R^*(p_0) = \sum_{i=1}^{n} \lambda_i R(p_i)$, and then round R' to R. In the equation set, n is the number of interpolation points.

(7)Repeat step (2) to step (6) until all the values of grid points are found out.

(8) Output the result.

Realize volume rendering of 3D borehole data

Volume rendering method based VTK [10]

VTK(Visualization Toolkit) is a free open source 3D visualization tools. Many foreign universities and laboratories take VTK as teaching and research tool which has been widely used in the field of medicine, petroleum exploration, rock and soil engineering. Compared with other similar software, VTK not only supports displaying and rendering of geometry but also supports many visualization algorithms and some common operation of human computer interaction. VTK adopts pipeline mode to program and its basic component are Source, Filter, Mapper, Actor and Renderer.

Data source is the beginning of the whole visualization process. With Kriging interpolation algorithm, borehole data will be interpolated to volume data format of vtkImageData which include origin, dimension and sampling interval. To avoid the discrete borehole data being interpolated while starting every time, the interpolated volume data vtkImageData is saved into data file. vtkXMLImageDataWriter and vtkXMLImageDataReader provide the methods to save vtkImageData. Though VTK provides many methods to save vtkImageData into file, vtkXMLImageDataWriter can only save data compressed by zlib. VTK provides Ray-casting algorithm based on GPU acceleration: vtkOpenGLGPUVolumeRayCastMapper, furthermore, it proides such class as vtkColorTransferFunction, vtkColorTransferFunction, vtkVolumeProperty to set color value, opacity and shade separately.

Figure 3 is the pipeline of borehole data visualization.

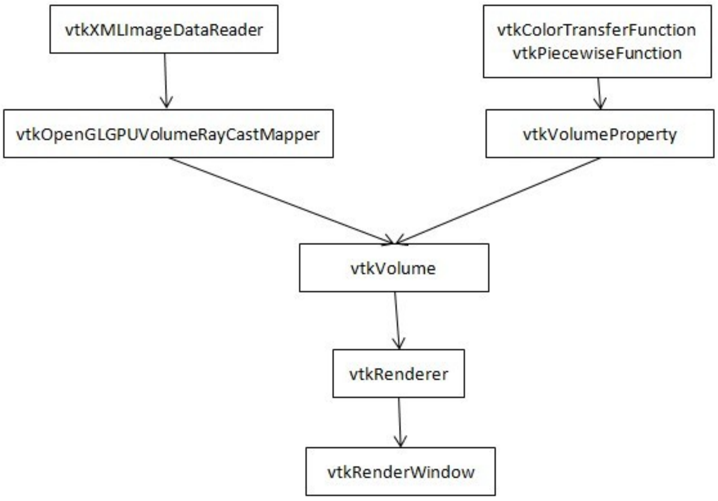

Figure 3 Pipeline of borehole data visualization

Experiment

500 borehole data under the area of 11500×10000 saved in ACCESS database is handled under the method above. The size of interpolation grid reaches 1146×1000×340. The environment consists of Win 7.0, i5 processor, NVIDIA NVS 4200M graphics card, cross platform QT and VTK graphics library.

Rendering results of kriging interpolation algorithm is shown in Figure 4. Rendering results of inverse distance interpolation algorithm shown in Figure 5.

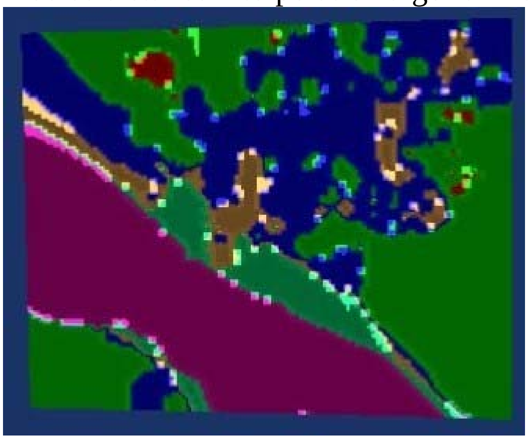

Figure 4 Kriging rendering

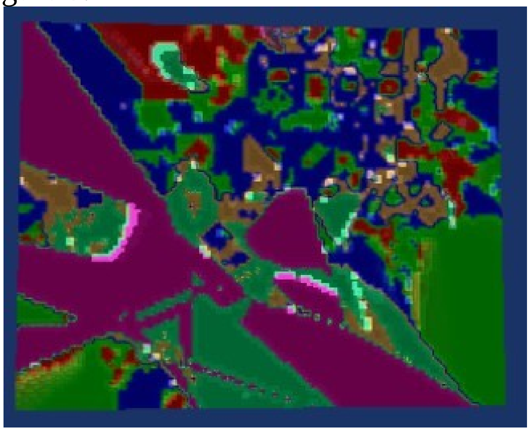

Figure 5 Inverse distance rendering

1)Display arbitrary section[11]

Arbitrary section can be displayed by vtkImagePlaneWidget, the result is shown as Figure 6.

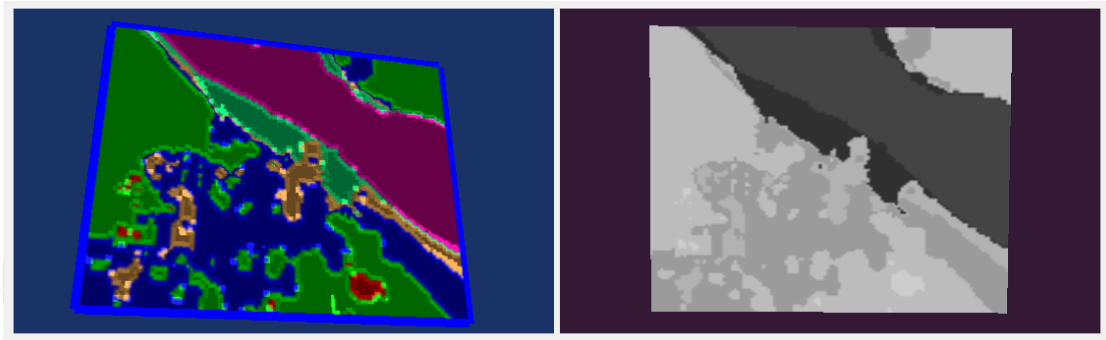

Figure 6 arbitrary section

2)**volume data extracting**

Volume data extracting can be realized by vtkImagePlaneWidget, the result is shown in Figure 7

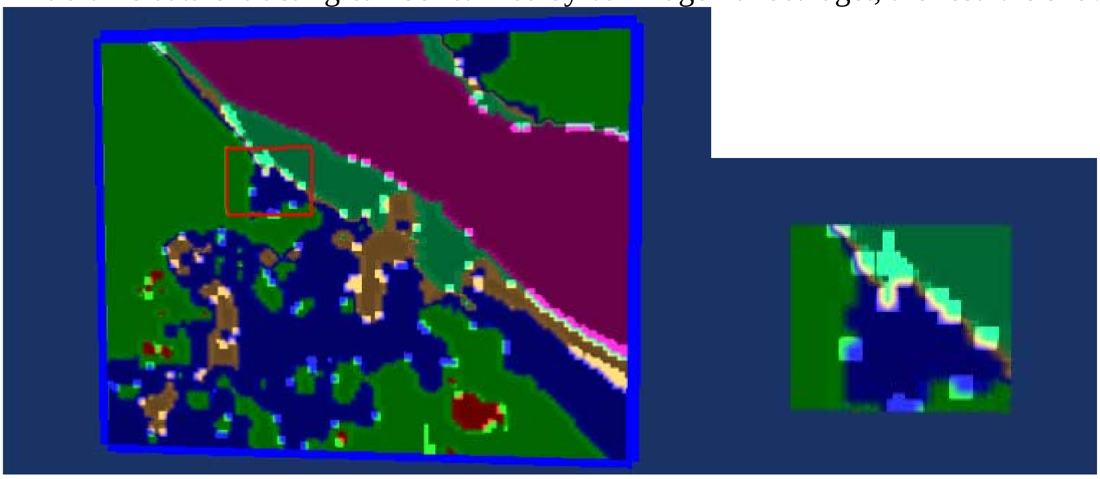

Figure 7 volume data extracting

Summary

In order to make 3D modeling method based borehole widely used in engineering, the modeling method must be simple and practical. In this thesis, the method and theory of GPU acceleration concerning with volume rendering of 3D data field is summarized on the basis of the definition and separation of data body. The visualization of borehole data shows the distribution principle of data. It overcomes the disadvantage of drawing methods to 2D cross-section, section and surface rendering. Modeling process of borehole data is so simple as to adapt to any complex terrain. Experiment results show that, this method is rapid, simple and effective, it is suitable for modeling stratiform geology structure,too. Kriging interpolation is better than inverse distance interpolation in this field.

[1] Tang Zesheng,The three-dimensional data field visualization[M]. Tsinghua University press 1999.1~8.

[2] ZHAO Yue,YIN Ziming,WANG Zhiqiong,GUO Shijia. Research and Implem ent of Interactive Cutting Based on VTK[J], Journal of Chinese Computer Systems, vol.30 No.12 pages 260-266, 2009.

[3] Levoy M. Display of surface from volume data [J].Computer Graphics and Applications, 1988, 3(8): 29-37

[4] M Hadwiger, C Sigg, H Scharsach Real - Time Ray - Casting and Advanced Shading of Discrete Isosurfaces[D] computer graphics forum, Volume 24, Issue 3, pages 303–312 2005

[5] S Stegmaier, M Strengert, T Klein A simple and flexible volume rendering framework for graphics-hardware-based raycasting[D], Volume Graphics, 2005 Fourth International Workshop on:

187 – 241. Stony Brook,NY,USA

[6] The OpenGL Shading Language Specification[E]. 2012.

[7] LUO Zhi yong, YANG Wunian 3D modeling and visualization of geological bodies based on borehole data[M] Science of Surveying and Mapping Vo l.33 No.2 Mar pages 130-132.

[8] Fan Minghui,Chen Chongcheng, Chi Tianhe Research and Application on the Continuity of Monitoring Data Using Kriging Interpolation Computer Engineering and Applications[J] 2005 pages 210-212.

[9] Su Shu, Lin An-wen, Liu Qinghua Ordinary Kriging Algorithm Applied for Interpolation[J] Journal of Southern Yangtze University(Natural Science Edition) Vol.3 No.1 Feb. 2004 pages 18-21.

[10] The VTK user's guide[E]. [Clifton Park, New York] : Kitware, Inc., 2010

[11] Zhao Yue,Yin Ziming,Wang Zhiqiong,GUO Shijia Research and Implem ent of Interactive Cutting Based on VTK[J] Journal of Chinese Computer Systems vol130 No. 12 2009 pages 2465-2467.