Visualization Technique for Explosive Field

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Summary
In order to visualize the explosion field and describe the complex physical phenomena of explosion and the data from numerical simulation by multi-material in cell (MMIC), a two-dimensional visualization system(VisC2D) and a three-dimensional visualization system(VisC3D) are presented and the algorithms and the functions of ViSC2D and ViSC3D are also addressed in this paper. The overview of explosive field and some details about the transmission of shock wave in the field, such as reflection, flow over an obstacle and Mach reflection can be clearly observed by ViSC2D and ViSC3D.
Key words:
Explosive field, Visualization, Numerical simulation

1. Introduction

With the rapid development of computer science and technology, the numerical simulation on explosion and impact has made great progress. Confronted with complex physical images and huge amount of data from the result of numerical simulation, it is often no easy a task to analyze them manually, so we have to resort to the support of visualization.
Visualization in scientific computation (ViSC) turns the invisible data into physical phenomena and physical quantities expressed as visible and variable images. Users can easily observe the results of numerical simulation or invisible phenomena. At the same time, it provides interactive tools to analyze the images. However, existing visualization systems and tools are not so suitable for problems involving explosions. So the following system for visualization such as ViSC2D and ViSC3D are developed. The overview of explosive field and some details about the transmission of shock wave in the field, such as reflection, flow over an obstacle and Mach reflection can be clearly observed by ViSC2D and ViSC3D.

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2. Visualization of Two Dimensional Explosion Field

2.1 Physical Model

To simplify the complexity of numerical simulation, an ideal model shown in Fig. 1 is developed. In the physical model, the explosive source is considered as high pressure air whose original parameters are given by experience. The other media's parameters are calculated by their constitutive equations and equations of state. It is assumed that the ground and the wall are rigid, i.e., they do not absorb the energy released by the explosion through their elastic-plastic deformation. At the same time, the external force and the heat exchange (thermal conductance) are not included. So the result may be more conservative than the real ones. In addition, the explosive field is supposed to be completely axial symmetry. So the field becomes two dimensions. The main purpose of this model is to observe the effect of the wall in a far explosive field.

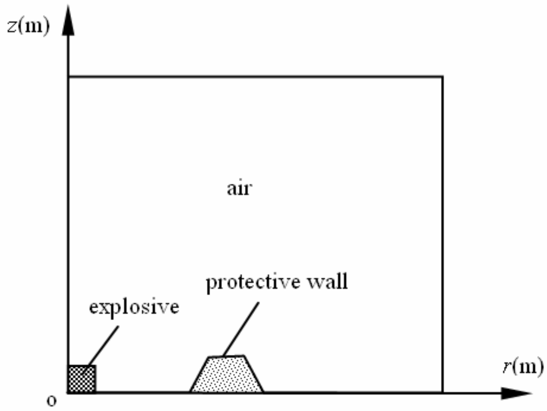


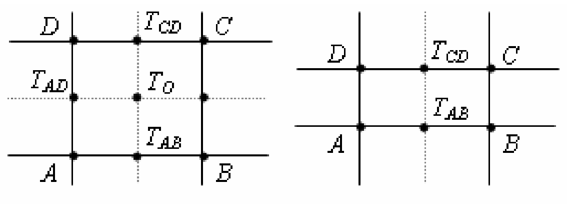
Fig.1 The physical model

2.2 Visualization Process

The main purpose of visualization is to change the physical data from numerical simulation by multi-material in cell (MMIC) into image data and display the images, from which we can get an insight into the scientific data and learn about the physical phenomena. After introducing the general procedure and technology of visualizing and considering the output of the program MMIC, the following processes are applied.

1) Normalizing the original data

In the preparation, the grids are normalized with linear interpolation. At first the smallest cell is found out and is used as a basic cell. Then the whole region is redivided by the basic cell, that is to say, a big cell is divided into one or more basic cells. The values of new grid points are calculated from the points around by the linear interpolating, as shown in Fig. 2.



(a) (b)

Fig.2 The interplolation

In the case of Fig. 2a, the cell *ABCD* is divided into 4 smaller cells and 5 new grid points are added. The new values of the added points T_{AB}, T_{BC}, T_{CD}, T_{AD}, T_O are given by the following:

$$T_{AB} = (A + B)/2\,, \quad T_{BC} = (C + B)/2$$

$$T_{CD} = (C + D)/2\,, \quad T_{AD} = (A + D)/2$$

$$T_O = (T_{AB} + T_{BC} + T_{CD} + T_{AD})/2$$

Another case is demonstrated in Fig. 2b, where a cell is divided into two. This method is fit for many other possible cases. After normalizing, the applicable data are obtained from the original data.

2) Color coding

In the mapping process, DIB bitmaps are selected to save the images. And a color palette with 256 colors is established, which the applicable data are mapped onto in segment. The advantages of DIBs are it s independence from devices and its compatibility. Considering the air and the wall in the physical model, the first color, indexed zero, is assigned to the wall, and the second to the air. The remaining 254 colors are arranged in the order of the gray degree. The brighter the gray is, the higher pressure it represents.

3) Mapping

The mapping process does the conversion from applicable data to image data. In this instance, the pressure is applicable data, and the DIB bits array is the image data. The mapping has two steps. The first is to classify the applicable data, namely, to recognize the wall, the air and the shock wave. Since the applicable data associated with the wall and the air are the constants 0 and 1.087, the classification is easy. The second is to assign a color index for each applicable data. The ones associated with the wall and the air are directly mapped onto the color index 0 and 1, respectively. For the data describing the pressure of the shock wave, its color index is given by

$$253(P - P_{\min})/(P_{\max} - P_{\min}) + 2$$

where, $P_{\max}$ and $P_{\min}$ are the maximum and minimum pressures in the data set. So the whole applicable data are parted into 254 segments, each with a different color.

4) Display of images

After finishing the mapping, the explosive field images at different moments are obtained. The images are saved as DIB bitmaps, so it is rather simple to display them by using the Windows API functions. By showing the images one by one in time order, the frame animation is formed from which the transmission of shock wave can be explicitly observed.

5) Combing the images with data

The visualized field shows us the overview of explosion and gives its development. It is helpful for us to penetrate the internal principle. However, it is not enough to accurately analyze and resolve problems. To quantitatively analyze it, the images are combined with the physical data. By right-clicking any pixel in a bitmap, the respective pressure value can be obtained.

To realize this function, the applicable data are kept in the system. The data associated with pixels are directly gotten from the applicable data, not calculated by the inverse mapping from image to data, because the applicable data and the colors are not one to one. This function not only provides a convenient way to study the problem, but also makes up for the information distorted in the visualizing process.

2.3 Implementing the Visualization

The object-oriented method is applied in implementing the visualization. The kernel model consists of the classes CBZD, CDIB and CPalette, whose relations and action are shown in Fig. 3.

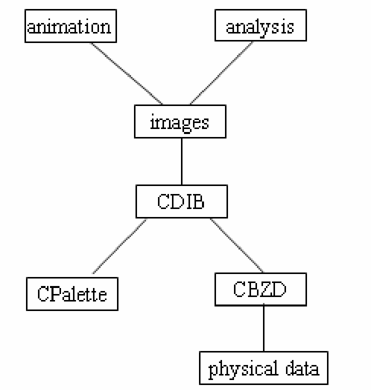
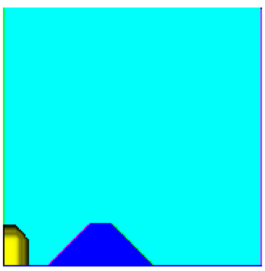


Fig.3 The system model

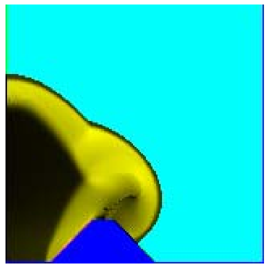
The class CBZD reads data from the stored files, departs the data describing the grids from data set and finds out the maximum and minimum one, then normalizes the original data. The class CPalette maintains a palette with 256 colors used for the color coding. Obtaining information from the CPalette and the CBZD, the CDIB is responsible for mapping as well as displaying and saving of images. In addition, the animation module is for playing the images one by one. And analysis deals with the static images, including amplifying parts of a picture and combining images with the data.

2.4 Visualization Results

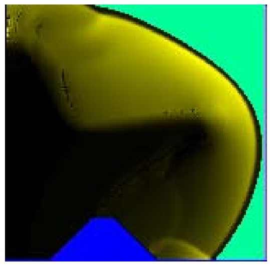
There are some visualized results of the 2D explosive field with a protective wall in Fig.4. N is calculation step. With the static analysis and the animation, some physical phenomena such as the vortex can be clearly observed. And it can be found that the peak value of pressure is at the edge of shock wave and becomes lower and lower as the time lapses. The compressed off spring of detonation forms a new shock wave (in Fig.4b). The wall makes the pressure increase after the wave goes over it and meets the ground (in Fig. 4c). All of these are valuable for study as they are hard to get by hand. The results match with what had been expected.



(a) N=500



(b) N=2000



(c) N=3000

Fig.4 Visulization results 2D explosive field with a protective wall

3. Visualization of Three-Dimensional Explosion Field

3.1 Approach to the Visualization of 3D Field of Explosive

There are two popular techniques for volume visualization, which are direct volume rendering and surface rendering. Direct volume rendering is an effective way for the visualization of shapeless data sets such as clouds, fluids and gases, and vivid images can be achieved by using it. Thus Ray-casting is one popular technique for direct volume rendering. Based on the characteristics of a field of explosion, Ray-casting is a beneficial approach.

1) Pivotal process

The visualization of 3D field of explosion involves several processes: firstly a pretreatment of data; secondly the color assignment, shading and transparency calculations; thirdly the resampling and trilinear interpolation; lastly the image composition.

In the first stage, the original data resulting from numerical simulation by MMIC need to be normalized and suitably managed. The normalized data files have two kinds of format: the text format and binary format. The former is more convenient to read out, and the latter saves more storage space. The structure of the data file is shown in Fig. 5 and Fig. 6.

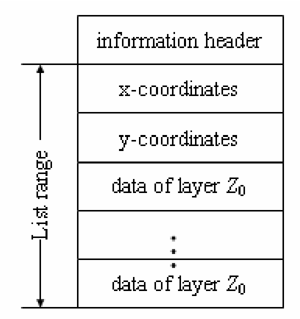


Fig.5 Structure of the data file

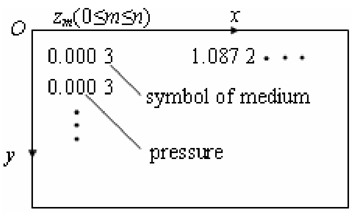


Fig.6 Format of data on each layer

The Phong Illumination Model is used for shading calculation. Brightness of a visible point on the object can be calculated by

$$I(t) = I_a(t)k_a(t) + I_1(t)[k_d(t)(NL) + k_s(NH)^s]$$

where, $t = r, g, b$, r is red, g is green, b is blue, they are tricolor ; I_a is the brightness of incident floodlight; I_1 is the brightness of lamp-house; k_a is the diffuse reflection coefficient of floodlight; k_d is the diffuse reflection coefficient of incident ray; k_s is the mirror reflection coefficient ; N is the unit normal of each visible point on the surface of scene; L is the unit vector of incident ray; H is the unit normal of ideal mirror; n is the high light exponent.

Based on the characteristics of the field of explosion, images are composed from the front to the rear. There are something to be noticed here, viz. different media should use different opacity and color, and proper steps of resampling should be used. If the step value given is too small, it will lead to samples repeatedly in a voxel, and if the step value given is too large, it will lead to lost details.

2) Algorithm

The algorithm of the visualization of 3-D field of explosive is shown below:

```
Begin
    Datasets classification;
Define viewpoint and projection mode. Build corresponding relationship between projection plane and display plane;
    For every pixel on display plane      do
    Begin
        Calculate ray L from viewpoint E through image plane pixel;
        Color = RayCasting (L);
        Set the color of pixel;
    End
End
```

3.2 Cutaway View and 2D Slice of 3D Field of Explosion

The approach to gain cutaway view of a 3D field of explosion is developed, so arbitrary sections of the 3D field of explosion can be conveniently seen. Arbitrary cutaway views can be observed in ViSC3D.

For data analysis, 3D information is often converted into 2D information. The image and data of 2D slice can be obtained easily in ViSC3D. Images of the 2D slice are shown in the right window of ViSC3D, and 2D data are saved as text files in the appointed folder. A simple interactive tool is given in ViSC3D. Users can see the value of an arbitrary point on the 2D slice by moving the mouse.

3.3 Visualization Results

1) Physical model

After explosion, shock wave is formed in the air and explosion wave is formed between the ground and slopes, and the objects are destroyed. It involves a very complicated process and a typical multi-material interacting process. In order to study the process, the physical model is shown in Fig. 7.

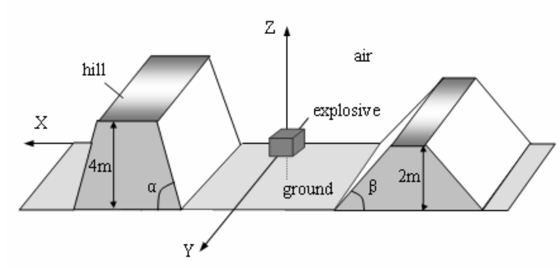
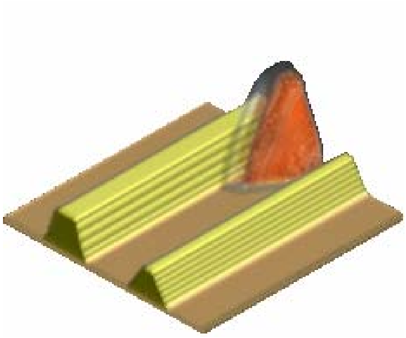


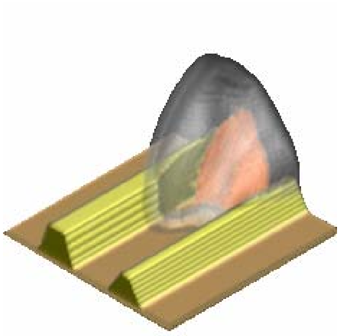
Fig.7 3-D field of explosion between the hill slopes

2) Results and Discussion

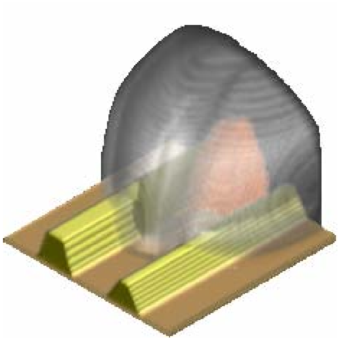
Fig.8 and Fig.9 show some results of visualization of a 3D field of explosion between hill slopes. The whole process needs the observation through ViSC3D.



(a) N=250

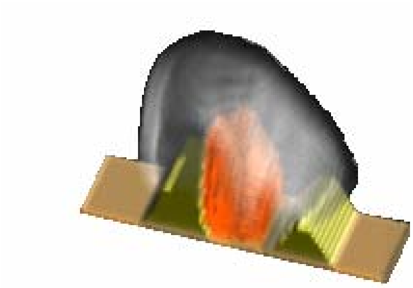


(b) N=1250

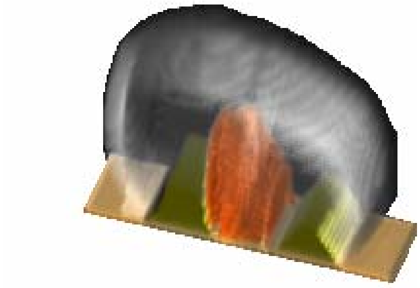


N=2750

Fig.8 The overall images of visualization of explosion field



N=1250



N=2750

N=2750

Fig.9 The cutaway views of visualization of explosion field

From these figures, we can see from some phenomena in which explosion waves and shock waves are mixed at first, and shock waves go over the slopes at last can be clearly observed. It can be found that the peak value of pressure takes place at the edge of the shock wave, becomes lower and lower as the time lapses. A vacuum is formed around the exploder at the last stage. These results are valuable for evaluating the security of explosion between the slopes and the dosage of explosives.

4. Conclusions

In this paper, the algorithms and the functions of ViSC2D and ViSC3D systems are discussed and developed to visualize the explosion field and describe the complex physical phenomena of explosion and the data from numerical simulation by multi-material in cell (MMIC). Visualization results reveal that these two systems are feasible and robust by the instances of a 2D explosive field with a protective wall and a 3D field of explosive between the hill slopes. However, explosion is too complex as a phenomenon. There are still many problems remain to be solved and problems such as computational steering, visualization of 3D vector datasets and the virtual reality of the field of explosion are all remaining to be figured out.

Acknowledgments

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