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A virtual globe-based three-dimensional dynamic visualization method for gas diffusion

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Three-dimensional dynamic visualization of the long range gas diffusion contributes to disaster forecasting and assessment. Existing three-dimensional visualization methods, which calculate the gas concentration without considering the terrain and display the gas concentration in the local range by isosurfaces, cannot meet the demand for intensive calculation and dynamic visualization of gas diffusion over a wide range. This study proposes a virtual globe-based three-dimensional dynamic visualization method of the long range gas diffusion, consisting of a voxel-based multi-scale data model, a terrain-dependent multi-scale concentration field calculation method using graphics processing units (GPU), and a GPU-based multi-scale spherical ray-casting algorithm. The method is then applied to the long range natural gas diffusion and is evaluated according to the efficiency of the concentration calculation and dynamic visualization. The results show that the proposed method can achieve dynamic visualization of the long range gas diffusion above 30 frames per second.

1. Introduction

Leakage of gas transmission pipelines covering large areas and long distances can easily cause the long range gas diffusion; this is affected by meteorological conditions, gas properties, and complex terrain (Hu et al., 2015). Visualization of dynamic processes of long range gas diffusions can intuitively demonstrate changes in concentration distribution during gas diffusions and aid in the assessment and prediction of environmental impacts (Cheng et al., 2009; Koussoulakou, 1994). Therefore, it is necessary to research the dynamic visualization for long range gas diffusions, which can support the auxiliary analysis of the environmental impact caused by gas diffusions.

The accuracy of the concentration distribution when dynamically visualizing gas diffusion depends on the accuracy of the gas concentration calculation. Contemporary soft computing technology solves uncertain problems in different fields through neural network (Chen and Chau, 2016; Gholami et al., 2015; Taormina et al., 2015), fuzzy logic (Sefeedpari et al., 2016), intelligent computing (Fotovatikhah et al., 2018) and other computing models (Zhang and Chau, 2009), and does not insist on high accuracy. In order to exhibit a more accurate gas concentration distribution during dynamic visualization, it is necessary to establish a mathematical model of the gas diffusion process to calculate the exact gas concentration. The existing three-dimensional visualization of gas diffusion models the gas diffusion process through the Gaussian diffusion model and displays the gas concentration in the form of three-dimensional isosurfaces (Jian and Fan, 2014; Wang et al., 2013; Zahran et al., 2013). The Gaussian diffusion model is one of the most important methods that are widely used to estimate pollution levels. This model has been applied extensively in the study of emissions from large industrial operations as well as a variety of other applications (Chen and Qi, 2010; Ebrahimi and Jahangirian, 2013; Liu et al., 2012), and is suitable for concentration estimation under flat terrain conditions (Chang and Weng, 2013). The limitations of the existing three-dimensional visualization of gas diffusion include three aspects: first, it is an idealized simulation within a local range. The effect of terrain on the gas concentration is not considered when calculating the gas concentration; second, the concentration calculations within the local range are based on central processing units (CPU), which lead to low computational efficiency; in addition, they can only achieve static visualization because the extraction efficiency of the three-dimensional isosurface is affected by the amount of data (Hou and Chen, 2016; Newman and Yi, 2006). Therefore, the existing three-dimensional visualization method for gas diffusion cannot meet the demand for intensive calculation and dynamic visualization of gas diffusion over a wide range.

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1364-8152/

Software availability

Name of software Virtual Globe based Gas Diffusion Visualization
Contact address State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
Year first required 2018
Hardware required tested on DELL PC
Software required MS Windows (tested on Windows 10)
Programming language MS visual studio 2010 C++, GLSL version110
Program size 97MB(compressed)
Availability and cost https://github.com/CHENGRUOZHEN/GasDiffusionVisualization.git
Maintenance Contact via e-mail

Three-dimensional dynamic visualization of the long range gas diffusion must consider 1) a large range of terrain and 2) the high calculation and dynamic visualization requirements of a massive concentration dataset. For the first requirement, virtual globe software supports the access and visualization of a large range of three-dimensional terrain (Goodchild, 2008), providing efficient methods for presenting the long range geographical processes on the Earth's surface (Gong et al., 2010; Yu and Gong, 2012). For the second requirement, the programmable characteristics of graphics processing units (GPU) allow its application to general computing (Owens et al., 2007); its simulation speed and performance is substantially higher than that of CPU-based computing (Jr. Molnar et al., 2010; Yang and Wu, 2010). Further, GPU parallel computing power supports intensive calculations of gas concentration (Owens et al., 2008).

GPU-based volume rendering techniques based on a virtual globe have been widely used in the visualization of three-dimensional meteorological fields (Li et al., 2011; Liang et al., 2014; Liu et al., 2015a, 2015b), and can effectively represent the internal structure of three-dimensional or four-dimensional phenomena (Li et al., 2013). Furthermore, the parallelism of volume rendering techniques can realize the migration to GPU and support three-dimensional or four-dimensional visualizations of real-time interactions (Du et al., 2015; Su et al., 2016). These characteristics enable the three-dimensional dynamic visualization of massive gas concentration datasets. However, the visualization of the above-mentioned three-dimensional meteorological field is based on a multi-scale data model within the meteorological field, which makes it difficult to match with the global terrain on the virtual globe. In addition, in the volume rendering of a three-dimensional meteorological field, a large number of sampling points outside the field are introduced and frequent coordinate transformation calculations are executed.

Thus, this study integrates the gas diffusion model and the data organization characteristics of the virtual globe and proposes a virtual globe-based three-dimensional dynamic visualization method for gas diffusion. This method is designed to meet the calculation demands of massive concentration datasets, consider the effect of terrain, and perform dynamic visualization of the long range gas diffusion. In the method presented in this study: (1) a voxel-based multi-scale data model under a global framework is proposed to organize gas concentration fields. This overcomes the fact that the multi-scale data model in a certain range in previous studies is difficult to match with the global terrain on the virtual globe and is difficult to express the time characteristics of the three-dimensional field; (2) a GPU-based calculation method for multi-scale gas concentration fields, which considers terrain, is proposed for the rapid calculation of gas concentration. This solves the problem of low efficiency and lack of consideration of terrain when calculating the gas concentration field based on the CPU, and the calculation results can be directly applied to the subsequent visualization; (3) a GPU-based multi-scale spherical ray-casting algorithm is proposed for spherical visualization of the concentration field. This algorithm avoids the introduction of sampling points outside the field and improves the ray casting process; and (4) the temporal properties of voxels are updated in the concentration field, and the concentration calculation and visualization of the concentration field are repeated, thus achieving dynamic visualization of the long range gas diffusion.

The structure of this paper is as follows. Section 2 describes the virtual globe-based three-dimensional dynamic visualization method of gas diffusion. Section 3 uses an example of the long range natural gas diffusion to conduct experiments, and then evaluate and analyze the proposed method. Section 4 presents the conclusions and proposes further research directions.

2. Methodology

Our virtual globe-based three-dimensional dynamic visualization method of gas diffusion includes three parts (Fig. 1). (1) To organize the gas concentration field, the three-dimensional global space is divided into multi-scale blocks. Based on these, the voxel-based multi-scale data

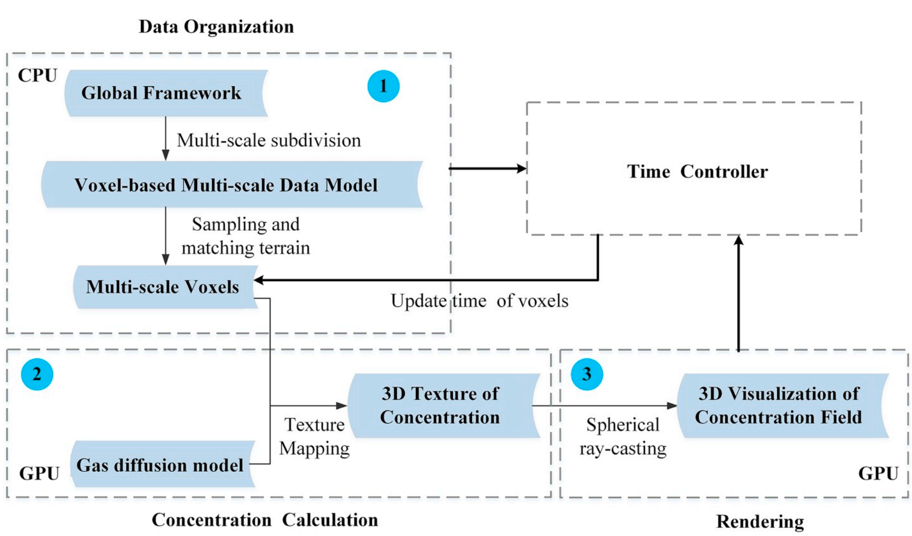

Fig. 1. Workflow of the proposed method.