Advances in Engineering Software 95 (2016) 7–15

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Multi-dimensional visualization of large-scale marine hydrological environmental data

Tianyun Su[a,*], Zhu Cao[b], Zhihan Lv[c,*], Chang Liu[a], Xinfang Li[b]

[a] The First Institute of Oceanography, SOA, Qingdao 266061, China
[b] Faculty of Information Science and Engineering, Ocean University of China, Qingdao 266061, China
[c] Shenzhen Research Institute of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China

ARTICLE INFO

Article history:
Received 9 August 2015
Revised 12 December 2015
Accepted 17 January 2016
Available online 13 February 2016

Keywords:
Marine environment
GPU
3D data
OSG
NetCDF
Multi-dimensional visualization

ABSTRACT

With the constant deepening of research on marine environment simulation and information expression, there are higher and higher requirements for the sense of reality of ocean data visualization results and the real-time interaction in the visualization process. This paper tackle the challenge of key technology of three-dimensional interaction and volume rendering technology based on GPU technology, develops large scale marine hydrological environmental data-oriented visualization software and realizes oceanographic planar graph, contour line rendering, isosurface rendering, factor field volume rendering and dynamic simulation of current field. To express the spatial characteristics and real-time update of massive marine hydrological environmental data better, this study establishes nodes in the scene for the management of geometric objects to realize high-performance dynamic rendering. The system employs CUDA (Computing Unified Device Architecture) parallel computing for the improvement of computation rate, uses NetCDF (Network Common Data Form) file format for data access and applies GPU programming technology to realize fast volume rendering of marine water environmental factors. The visualization software of marine hydrological environment developed can simulate and show properties and change process of marine water environmental factors efficiently and intuitively.

1. Introduction

Currently, ocean has been closely linked with the life of people. With the rapid development and utilization of marine resources, The research on visualization of marine information plays a more and more important role. Meanwhile, multi-dimensional dynamic visualization of large-scale marine hydrological environmental data has become a hot topic of ocean research with the development of marine information technology. Digital Ocean, as a hotspot of the marine information technology, is the best way to represent its information to participants, which can convey and perform marine scenes in an intuitive way [1]. The features of 3D visualization include intuitiveness, time sharing, and regularity. Besides, it is good for displaying internal laws and different relationships in the data. It is really a challenge to integrate the visualization of massive marine data into the virtual environment organically. Beside spatial data integration, new user interfaces for interactive marine data visualization geo-database are also expected [2].

The applications of virtual and mixed-reality environments, in fields like simulation, games and education, bring in billions of dollars every year [3]. The utilization of these virtual and mixed-reality environments is under exploration for various industrial tools. Besides, with the development of marine information technology, multi-dimensional dynamic visualization of the water environment data becomes a hotpot in marine research, which is mainly reflected in simulation and emulation of the information on water environmental elements including sea temperature, ocean current salinity and seawater density. An exploratory research about 3D ocean current model rendering and multi-touch interaction [4] was conducted early. Another work visualized ocean current and airflow through Streamline Splatting algorithm [5]. The visualized analysis based on the time-space characteristic of marine environment data has been already implemented on web context [6]. The integrated virtual reality system of marine environment has been utilized for geospatial analysis on high performance computer [7–9]. Thomas Butkiewicz and Colin Ware have conducted 3D exploratory analysis on multi-point touch screen of ocean current model [10]. Sun and Ess et al. have visualized ocean current and atmospheric flow through Streamline Splatting algorithm [11]. Yawen [12] et al. have realized visualization

* Corresponding author.
E-mail addresses: sutiany@fio.org.cn (T. Su), lvzhihan@gmail.com (Z. Lv).

http://dx.doi.org/10.1016/j.advengsoft.2016.01.009

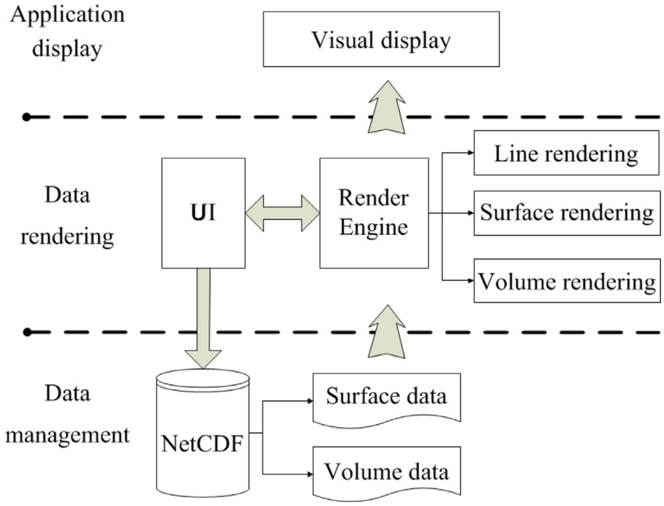

Fig. 1. The system architecture.

analysis on time-space characteristics of marine environmental data. In order to meet the requirement of marine research and development, several marine environmental visualization softwares have been developed and applied successively. Google Ocean can realize three-dimensional show of global submarine topography, but has deficiencies in three-dimensional visualization of marine water factors. IDV mainly shows value information through two-dimensional plane, section and profile in allusion to the processing of marine water factors. Vapor of USA Atmospheric Meteorological Bureau realizes three-dimensional visualization of data, but the software is mainly used for meteorological data and has its own file format. Chinese digital ocean system developed by National Marine Information Center of China, realizes visualization of ocean phenomena and their change process [13], but it mainly relies on digital sphere platform for 2D and 2.5D show of marine environmental information and lacks the analysis and display of marine environmental factors in stereo environment.

The features of marine environment can be reflected from many kinds of factors such as sea temperature, sea salinity, sea density, ocean current and so on. These data are time series, multi-dimensional, heterogeneous in structure and huge amount. The complexity of marine data and the requirements of scientific research necessitate a specific tool that can provide dynamic visualization and analysis of marine information interactively and intuitively in 3D environment. It should be generic for marine data sets and have high efficiency for mass data. This paper researches key technologies such as contour line tracing, isosurface generation, section rendering and volume rendering through point, line, surface and volume mode analysis based on features of large-scale marine hydrological environmental data, and develops a tool to realize three-dimensional simulation of large-scale marine hydrological environmental data and improves its rendering efficiency based on the application of GPU rendering technologies and NetCDF data storage technologies.

2. System framework

System framework is mainly composed of data management, data rendering and application display. Fig. 1 shows the system framework.

Data management module mainly realizes the interpretation, access and management of marine hydrological environmental data with NetCDF data access way. As a commonly used data access way, NetCDF can store, manage, obtain and distribute grid data efficiently. Due to such advantages as small memory space, fast reading data, self-description and flexible reading way, it is widely used as data storage standard in fields such as atmospheric sciences, hydrology and oceanology [14]. NetCDF provides a common C programming interface for application and supports basic data types, mainly including byte, char, short, long, float and double [15]. According to features of marine data such as dynamic and multi-dimensional nature and massive amount, target data can be obtained conveniently and rapidly according to the requirement of three-dimensional marine scene rendering with the use of NetCDF data format storage. NetCDF uses variable, dimension and property to form data storage and provides inquiry function. Therefore, it can realize unified management and share of marine data and the dynamic expression and analysis of marine water factor data.

Data rendering module uses multi-threading, integrated UI, e.g. MFC, and rendering engine to complete visualization rendering and analysis of multi-dimensional marine water factor data. 3D rendering engine is composed of a series of modules including line rendering, surface rendering and volume rendering. The modules are mainly developed with API of OpenGL underlying rendering which has become an industrial standard [16]. GLSL and CUDA are also used to improve the calculation and rendering efficiency. Detail optimizations of the rendering engine are described in Section 3.

Application display mainly responds to different operations of users, like roaming in the scene, configuring scene properties, assigning elements for analysis and display, etc., in order to realize free interaction along with data rendering module and shows visualization results.

3. Key technologies

3.1. Planar graph

The rendering of planar graph of marine hydrological environmental data is mainly realized with the use of 3D geometric rendering [17] technology and Delaunay algorithm [18]. The corresponding data value is obtained through NetCDF file operation (environmental factor value is peak elevation value). Delaunay algorithm is used to obtain triangular array and remove noneffective triangles through traversal and optimization. Vertex index mechanism is utilized to analyze data efficiently and uses drawing element to establish triangular surface object. The color of triangular vertex is interpolated according to elevation value and configurable color legend [19].

The rendering of planar graph is realized with triangular mesh method of 3D geometric rendering. Meanwhile, the effective differentiation between sea surface and land is achieved through gradient correspondence of element value and color value and the transparency of invalid value. Gradient color change algorithm is as below:

Known: minimum element value *min*, maximum element value *max*, numerical value outside data segment is an invalid value; assuming that values between the minimum value *A* and the maximum value *B* are divided into four color sections on average (step = 4), what is the numerical value (valueN) in each section?

$$Gradient = min + (max - min) * N/Step \qquad (1)$$

It can be obtained according to formula as followed.

$$\begin{cases} \text{value1} = \text{min} \\ \text{value2} = min + (max - min)/3 \\ \text{value3} = min + \dfrac{max - min}{a} * 2 \\ \text{value4} = max \end{cases} \qquad (2)$$

In this way, we can set four color values value1, value2, value3 and value4 to realize gradient change of the graph. In order to improve the planar rendering efficiency, GLSL is used to calculate the