3D SEABED: 3D MODELING AND VISUALIZATION PLATFORM FOR THE SEABED

Tianyun Su[1*], *Zhihan Lv*[2*], *Shan Gao*[1], *Xiaolong Li*[4], *Haibin Lv*[3]

1. First Institute of Oceanography, The State Oceanic Administration, Qingdao, 266061, PRC
2. Shenzhen Institutes of Advanced Technology, Chinese Academy of Science, Shenzhen, 518055, PRC
3. North China Sea Branch, The State Oceanic Administration, Qingdao, 266033, PRC
4. CNOOC Deepwater Development Co. Ltd., PRC

* Both author are the first author and corresponding author.

Email: sutiany@fio.org.cn, lvzhihan@gmail.com

ABSTRACT

We are building a 'virtual-world' of a real world seabed for its visual analysis. Sub-bottom profile is imported in the 3D environment. "section-drilling" three-dimensional model is designed according to the characteristics of the multi-source comprehensive data under the seabed. In this model, the seabed stratigraphic profile obtained by seismic reflection is digitized into discrete points and interpolated with an approved Kriging arithmetic to produce uniform grid in every strata layer. The Delaunay triangular model is then constructed in every layer and calibrated using the drilling data to rectify the depth value of the dataset within the buffer. Finally, the constructed 3D seabed stratigraphic model is rendered in every layer by GPU shader engine. Based on this model, two state-of-the-art applications on website explorer and smartphone prove its ubiquitous feature. The resulting '3D Seabed' is used for simulation, visualization, and analysis, by a set of interlinked, real-time layers of information about the 3D Seabed and its analysis result.

Index Terms— Virtual reality, seabed, GPU

1. INTRODUCTION

'Digital Seabed' has become a hotspot of the marine information technology. Virtual Reality is quite popular in computer simulation as it provides participants with a true feeling of realism. Visualization technology takes an advantage of the computer graphics and image processing theory to express the laws and the relationships hidden in the vast amounts of data. Therefore, to display Digital Seabed information to participants the most effective way is by expressing and rendering marine scenes in an intuitive ways[1].

Virtual reality has the characteristic of interactivity, imagination, and illusion of immersion, and imagination, and it has the advantage of a real-time display of the dynamic virtual environments. Whereas, visualization has the characteristic of intuitiveness, time sharing, and regularity, and it has the advantage of revealing internal laws and various relationships in the data. When integrating visualization of massive marine data into the virtual environment, it is difficult to combine them organically. So the 3D seabed system, on one hand, has finished the intuitive display of sub-bottom profile and on the other hand, it has reserved the real-time features of interactive roaming and analysis.

Virtual and mixed-reality environments make billions of dollars in revenue every year, in applications like simulation, games and education[2]. So, we are exploring the use of these virtual, augmented, and mixed-reality environments for various industrial systems and research-aided tools. We are also interested in understanding the appropriate methods for communicating and collaborating with these environments, which will aid us to import the real-world data from variety of sensors to these virtual, augmented and moxed environments.

Because the seabed is a special environment, people cannot observe and analyze the geological features and phenomenon directly. So multi-disciplinary marine investigations are required to obtain comprehensive information under the seabed, which include not only direct sampling data (such as subsurface sampling and drilling sampling) but also indirect survey data (such as geophysical data and remote sensing images). Furthermore to visualize these multi-dimensional data to make a comprehensive understanding of seabed is always a hot issue raised by many experts and scientists. Traditional visualization in marine geosciences is mainly focused on the plane maps, the horizontal profiles and the vertical sections, etc. These are displayed in two-dimensional environment, and it is hard to read marine geological structure and features in detail in these 2D environments. Therefore, with the development of visualization technology, the elevation of seafloor can be displayed in $2.5D$ view by several arithmetic models such as Digital Elevation Model (DEM), Digital Terrain Model (DTM), Digital Slope Model (DSM). But such models can only show the topographical and geomorphological features of the seafloor surface and can not reveal the internal geological structure under the seabed. Extensive amounts of accumulated and diverse marine data sets need to be commonly organized, accessed, and queried by marine scientists[3]. 3D visualizations can contain more information at once and are therefore more suitable for presenting large data sets.

GIS-related visualization works can be divided into three categories: visualization tools, visualization of geographicaly models, and visualization-aided 3D GIS system. Over the past decades some experts tried many ways to do research in virtual reality-based simulations. Applying virtual reality, a 3D diffusion scene management subsystem[1] was developed, and a new method is proposed for the simulation of rock crushing[4] in a virtual environment. Many $3D$ data models [5][6], which can model the internal structures and attributes of $3D$ objects, are issued to meet different application requirements. Additionally, study in the aspects of $3D$ visualization[7], $3D$ topology [8][9], $3D$ analysis and $3D$ web services also have made great progress and several high performance $3D$ commercial software have been designed, such as IVM, $LYNX$, EVS [10][11][12]. Based on the existing achievements in research of $3D$ visualization, this paper studies the $3D$ modeling methods and presents an interactive analyzing applications for seabed geological objects with drilling data and seismic profiles, aiming at displaying geological structures and features of the seabed directly and completely in the $3D$ environment.

Rather than simply building a virtual environment which replicating the seabed, our aim is to create an ubiquitous platform, that platform can capture data from the variation of strata under the seabed, and then find useful ways (i.e. for analysis and visualization) for using and displaying that information for different phenomena. So far, we have developed several applications based on this infrastructure, optimized for data modeling, simulation, data visualization, and lightweight analysis. Web and mobile based applications are client part of the information stack; so is a 'virtual world' 3D representation of the seabed. These visualization layers each focus on different data and functions for both expert and non-expert users. We developed a list of missions and then experimented with several web-based or smartphone-based virtual environment platforms. The main contribution of this paper is proposed and developed a ubiquitous client for seabed modeling and visualization, which is one kind of state-of-the-art prototype and proof of the concept 'Digital Seabed'. The sub contributions include: The data source is multi-source geological sensors but not traidtional video, this is the nature for challenge of digital seabed system; The novel modeling and visualization method is ubiquitous and suitable for both website explorer and smartphone; "section-drilling" three-dimensional model is a novel multi-source data fusioin and correction linear method, which is the preparation to tackle the augmented demand on ubiquitous context of digital seabed system.

2. DATA PREPARATION

Because of the inconsistent raw format and spatial references, these data need to be processed and converted in advance with uniform format and spatial reference in order to be integrated and visualized in $3D$ environment. Bathymetric data and sub-bottom profile data are converted/written into (x, y, z) text format that could be used for interpolation and surface modeling. Drilling data are converted into text file formatted to record longitude, latitude, water depth, aperture, length, stratums depth, stratas description, and so on. These drilling data are used to calibrate the spatial model constructed with bathymetric data and sub-bottom profile data. Geomorphology map, which is stored in $ESRI$ shape file format, can be produced by processing and analyzing the sub-surface sampling data. Side-scan images data are saved in $Geo-TIFF$ format. All spatial data are converted with uniform spatial reference ($Beijing-54$ coordinate system, $Gauss-Kruger$ Projection).

3. LIGHT-WEIGHT 3D GEOLOGICAL MODELING

As described above, drilling data can directly reveal the strata structure of the drill location and further lab experiment of the drilling samples can show the physical and chemical characteristics of the seabed in detail. Because of the complex geographical environment of the seabed, it is very difficult and costly to get drilling data, and the spatial coverage density of the drilling samples is very low. If the geological spatial model of seabed is constructed only based on those limited drilling data, the internal structure and features cannot be revealed accurately and completely, especially in complex areas between the drilling samples. In order to obtain more data about seabed geological structure and characteristics, a lot of sub-bottom profiles and seismic sections have been acquired by marine geophysical exploration. These geophysical exploration data are obtained by indirect manners and need to be interpreted by scientists to reflect the strata information between the surrounding of the drilling locations, where there exists a great uncertainty. Our proposed platform takes advantage of direct drilling data and indirect geophysical data to generate $3D$ model of seabed geological objects by a low-cost (light-weight) 3D geological modeling approach in order to enhance the accuracy and performance of $3D$ seabed visualization and its visual analysis on the ubiquitous context.

3.1. MODELING PROCESS

The process of $section-drilling$ $3D$ modeling is shown in Figure1, which mainly includes discrete points preparation, $3D$ data interpolation, Delaunay triangulation generation, model calibration, side face generation, model optimization, attribute assignment and data fusion.

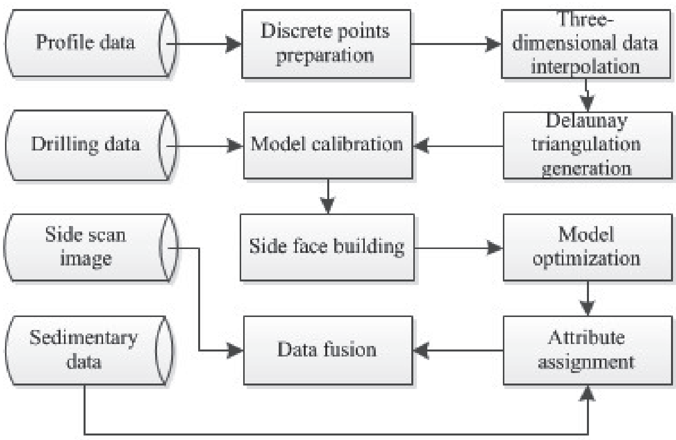

Fig. 1. Modeling process

Discrete points Preparation: For the sub-bottom profiles and seismic sections, all of interpreted stratum layers are digitized into (x, y, z) $ASCII$ format and stored in the text file.

3D data interpolation: Reasonable interpolation can compensate for the lack of raw data and obtain extra smoothing data. Within the inputted regional spatial parameters such as $[X_{min}, X_{max}]$ and $[Y_{min}, Y_{max}]$ the discrete points in the spatial range are read into memory and made Kriging interpolation by pre-defined interval values to get regular grid points. This method mainly considers the variability of the attribute values in the spatial area and determines influential distance range within which the value of the point waiting to be interpolated will be calculated by the values of sampling points. Kriging is a method to compute the interpolated Best Linear Unbiased Estimator (BLUE) value [13]. After considering the geometric characteristics of samples, such as shape, size and spatial distribution between segments to be estimated, and the spatial structure of grade, this method gives a certain coefficient to every sample and estimates the segments grade by weighted average in order to make linear, unbiased and minimum-variance estimation.

Delaunay triangulation generation: Based on $Bowyer/Watson$ algorithm[14][15], Delaunay triangulation can be generated using grid points dataset, which are written in geometry objects and inserted into scene root. Delaunay triangulation can ensure that every triangles angle is close to regular triangle abiding by the graphics optimization principle of minimum internal angle is the best in triangulation. Additionally, Delaunay triangulation network generated from irregular distributed discrete points dataset is unique.

Model calibration: Control point dataset consists of drilling data and the radiation area of every control point which is computed by circular buffering algorithm. Interpolated height values of data points are calibrated by the control point dataset. Suppose control point $V_0(x_0, y_0, z_0)$ and interpolated point from sub-bottom profile $V_1(x_0, y_0, z_1)$ then the correction error H is given in (1).

$$H = z_1 - z_0 \tag{1}$$

Supposing that the radius of the round buffer A_0 of control point V_0 is R_0 and the two-dimensional distance value R_{0i} from control point V_0 to the point V_i waiting to be corrected as in (2).

$$R_{0i} = \sqrt{(y_i - y_0)^2 + (x_i - x_0)^2}, V_i(x_i, y_i, z_i) \in A_0 \tag{2}$$

The corrected height c_{zi} as in (3), which is a normalized X-Y plane Euclidean distance-weighted formula .

$$c_{zi} = z_i + \lambda \times H \times (1 - R_{0i}/R_0), \lambda > 0 \tag{3}$$

For the condition of buffer overlapping, the geometric mean of the difference values between the point to be corrected and each control points will be computed for correction. After correction, the corrected points will be inserted into the grid dataset and rebuild Delaunay triangulation by Lawson algorithm.

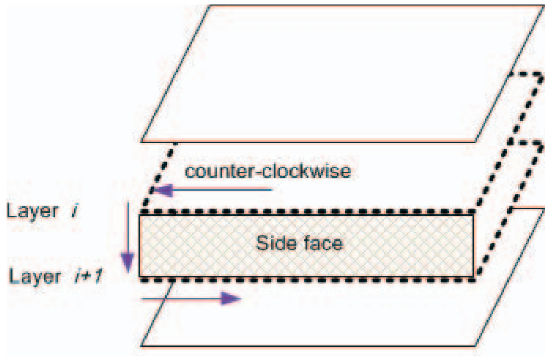

Fig. 2. Side Building Diagram

Side face building: Firstly, all boundary points of every layer will be selected. The points in the same side of adjacent layers i and $i+1$ will be written in a vector $V < i, i+1 >$ by counter-clockwise direction, as shown in Figure2, this direction is suitable for light rendering based on GPU, otherwise, the generated mesh is invisible. The method of counter-clockwise vector generation is described as followings. Take the boundary of the minimum X for example, the data set of layer i s boundary point are written into vector $V < i, i+1 >$ in decreasing order. And then the data set of layer $i+1$s boundary point are written into vector $V < i, i+1 >$ in increasing order. After that, the polygon is generated using the vertices in $V < i, i+1 >$. For the side face of concave polygon caused by topographic relief, tessellator processing will be implemented in order to display completely. The generated side face is stored in geometric data structure and inserted into the scene root for visualization.

Model optimization: Triangle strips[16] are built for each layer generated by Delaunay triangulation model in order to manage and index the triangular cells, which can cut down the frequency of I/O and improve the efficiency of the model. Strata geometry is simplified by edge collapse method[17] and will occupy less system resources when rendered.

Attribute assignment: Attribute assignment is a very important step for fusion and partitioning of multi-source data. Firstly, special color or texture will be rendered on the surface of each layer according to its geological type. Secondly, according to the sediment classification generated from sedimentary data, special effects can be rendered by GPU shaders, such as specular effect, marble effect and so on. Thirdly, dynamic wave effect can be rendered by GPU shaders.

Data fusion: In order to observe the topography and geomorphology in detail, side scan images are stored in $Geo-TIFF$ format and attached to the relief of seafloor and the sediment data are stored in $ESRI$ shape file format and imported to the model for rendering on the seafloor.

3.2. UBIQUITOUS VISUAL ANALYSIS

Different view modes can be generated from the 3D model to reveal internal characteristics of the seabed by fast linear algorithm on ubiquitous context. It's obvious that ubiquitous visual analysis is becoming the important and popular approach in both industrial application and scientific research.

Profile rendering: Strata profile rendering is done by seismic profiles, in which each strata is rendered with defined color or texture according to it's lithological type. With such render mode, seismic profiles, especially in intersecting lines, can be visualized to reveal the internal phenomenon of the seabed model. It's also helpful for scientists to rectify the interpretation of the seismic profile.

Section analysis: Section analysis mainly extracts spatial information of a profile from 3D seabed model with a random line defined by users. User clicks twice in the layer in order to define start point and end point of the cutting line. The platform will then extend the cutting line and make it cut the bottom to obtain points of intersection. Suppose the start and the end points are $(x0, y0)$ and $(x1, y1)$ respectively, then the cutting line formula is in (4).

$$(Y_1 - Y_0) \times X + (X_0 - X_1) \times Y + Y_0 \times X_1 - Y_1 \times X_0 = 0 \quad (4)$$

To see the inside profile of the surface, the outside portion of the profile, which faces the frustum, is cut. After that, the profile map is generated based on the points of intersection between the profile and the boundary of each layer. The height value of each point of intersection is interpolated in every layer, then the points of intersection is obtained in $3D$ space and the profile is generated. The visual result is made up of the geologic entity and profile after secion analysis.

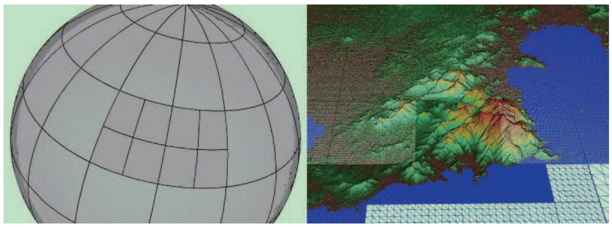

Fig. 3. Quadtree block

4. THE KEY ISSUES

4.1. GRAPH-BASED SCENE TOPOLOGY

The scene graph is managed by hierarchical bounding boxes, by bounding spheres and bounding boxes to achieve the scene bounding volume. The information is stored by a directed acyclic graph structure. A scene graph includes a root node, multi-level interior of the side nodes, and multiple terminal leaf nodes. The root and side nodes take charge of the construction of the level of the nodes, and the completion of certain functions, whereas the leaf node is saved to one or more object information. Each node maintains its own bounding volume, and so on, hence constitutes a distinct level. This hierarchical bounding box diagram can speed up the correction information, reduction of the scene objects, intersection tests, collision detection and a series of operations. This structure allows each node to have multiple parent nodes. When the same geometric object needs to be repeatedly referenced by more than one parent node pointing to the same child node, with each parent node pointing to a new child node of the tree than the total number of nodes, memorizing utilization and scene traversal steps reduced, rendering the final results remain unchanged[18].

4.2. DATA FILE PARTITION

The nodes in the scene graph include terrains, objects and different data types. Different partition methods are adopted for them. Geographic data includes terrain model using Tin Triangulation, the real image in the terrain covers the surface and the vector data. Furthermore, these geographic data are the surface data with little overlap in the vertical direction. So to evenly split the region based on quadtree classification and index structure, each quadtree level represents a level of precision. An example of mature application is worldwind [19]. Quadtree construction processes the whole terrain as root, starting from the root node, checking whether the partition meet certain conditions. If it is not satisfied; not partitioned then it will be preserved as a leaf node. Otherwise, recursively the root node is continuously divided into four equal

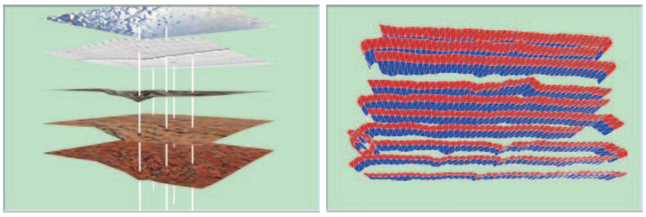

Fig. 4. 3D Visualization; Left. Drilling Correction; Right. Strata Profile Rendering

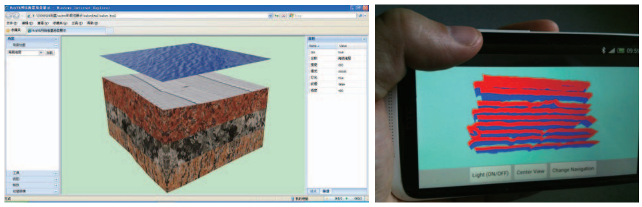

Fig. 5. 3D seabed UI on ubiquitous context: Left. Website Explorer; Right. Smartphone

sub-regional nodes, until minimal unit. The last step is drawing and rendering all the leaf nodes. The greater the depth of the division is, the higher the resolution. Which means, for each raising separate layer of depth, the sampling density is doubled. Figure3 shows the quadtree-based multi-scale geographic data block.

The scene contains a variety of object nodes as unit data block, including the following ones. A. Construction information extruded from attributes information with a high degree of vector data; B. $3D$ model information imported from $3DsMax$; C. Geometry data. In the traversal of scene, each node of the outermost layer under the root is considered as a unit.

4.3. MULTI-SCALE DATA PREPROCESSING

The topographic data according to the different quadtree levels is divided into the LOD data and stored to external memory. For object nodes, each one is generated from the refined precision of the data LOD $L1$ to $L4$. In which $L1$, $L2$ and $L3$ are generated by collapse of law on the simplified model. Whereas, $L4$ impostor is generated by the image cache node. The texture object node is based on cell aspect ratios of $2:1$ which is generated by three simplified texture memory to external memory. The texture data is compressed as $DTX3$ by $GPGPU$ by using $CUDA$ library. External memory models in different scales in turn are called, for more efficient file transfer as compared to single $MIPMAP$ file to be transferred[20].

4.4. WRAPPER COMPONENT

The client of the platform is wrapped into two components extending to ubiquitous context: website explorer and smartphone. The component on website explorer is encapsulated by Microsoft ATL library. The security certificate is packed into the component with style of CAB. The component is communicated with the website explorer by the way of JavaScript calling interfaces. The component of smartphone is implemented in C++, Java with Android SDK/NDK and the 3D visualization rendering tasks were realized using OpenGL ES. Our test device was an HTC one X phone equipped with a 1GHz processor, 1GB RAM.

5. VISUALIZATION

This paper adopted Visual Studio 2010 and OpenGL to realize "$section - drilling$" modeling and developed the prototype application of $virtualdigitalseabed$. The data used for testing is located in the region whose latitude range is from $38.2N$ to $38.3N$ and longitude range is from $118.8E$ to $118.9E$. Regional interpolation is north latitude $38-39$, east longitude $118-119$ from a typical sea area near DongYing city, ShanDong province, China which includes multi-beam bathymetric data, side-scan sonar images, sub-bottom profile, drilling data and sub-surface sampling data. The right of Figure 4 shows strata profile rendering generated by initial data. In order to show the data clearly, the effect is rendered by GPU. The left of the Figure 4 shows the effect which correct the strata data after drilling data written in. $X-axis$ coordinate is longitude, $Y-axis$ coordinate is latitude, $Z-axis$ coordinate is depth from seafloor. Figure 5 demonstrates the ubiquitous capability of the platform on both website explorer and smartphone application which developed by eclipse and OpenGLES. The left of Figure 5 shows the rendering effect by attaching the side scan image onto the seafloor and sticking special texture to each layer. $Z-axis$ is scaled to 0.01 times in 4.

6. CONCLUSIONS

This paper issued a 3D seabed platform based on "$section - drilling$" model which can realize the modeling, visualization and analysis of the comprehensive data under the seabed in $3D$ virtual environment. The developed prototype application is a useful tool for the scientists and public for browsing and analyzing seabed information directly, and is agreed upon as being both immediately useful and generally extensible for future applications. The platform can be adopted to build many interesting applications through multimodal interaction. $3D$ or multi-dimensional visualization of spatial information is a hot and difficult topic. The spatial model and prototype application studied in this paper are only an elementary research and discussion. There are many key problems such as visualization of dynamic data, expressing the special geological phenomenon of faults and folds, etc., which need to be studied and solved in the future. Our 3D seabed platform is state-of-the-art solution in this developing field, and we believe there is value in this space for wider field, particularly in a versatile seabed monitoring device that allows ongoing multi-source and multi-dimensional integration of virtual and ubiquitous applications.

Acknowledgments.

The authors are thankful to the sub-project 2011ZX05056-001 of The Important Project of Science and Technology in Developing Great Oil & Gas Field and Coal Bed Gas, National Natural Science Fund for the Youth of China(41301439).

7. REFERENCES

[1] Chen, G., Wang,Z.Z., Qian,C.C., Lv,C.J., Han, Y., 2010. Seasonal-to-decadal modes of global sea level variability derived from merged altimeter data.Remote Sensing of the Environment 114(11),25242535.

[2] Back M., Kimber D., Rieffel E., Dunnigan A., Liew B., Gattepally S., Foote J., (...), Vaughan J. The virtual chocolate factory: Building a real world mixed-reality system for industrial collaboration and control (2010) 2010 IEEE International Conference on Multimedia and Expo, ICME 2010, , art. no. 5582532 , pp. 1160-1165.

[3] Su, Y., Slottow, J., Mozes,A., 2000. Distributing proprietary geographic data on the World Wide Web: UCLA GIS database and mapserver. Computers and Geosciences 26,741749.

[4] Wu, D.L., Hu,Y., Fan,X.M., 2009. Visual simulation for granular rocks crush in virtual environment based on fractal geometry. Simulation Modelling Practice and Theory 17,12541266.

[5] Bak P., Mill A. Three Dimensional Representation in a Geoscientific Resources Management System for the Minerals Industry. In: Three Dimensional Applications in Geographic Information Systems. London: Taylor and Francis, 1989, pp. 155-182

[6] Zlatanova, S. 3D GIS for urban development. PhD dissertation, ITC Netherlands, 2000

[7] Yoshida, T. Three-dimensional object modelling in a three-dimensional urban map. Proceedings of UM398. Tokyo, Japan, 1998, pp. 55-62

[8] Arnaud. S., and Bernard, C. 3D topological modelling and visualization for 3D GIS. COMP GRAPH, 1999, pp. 469-478

[9] Pfund, M. Topological data structure for a 3D GIS. In Proceedings of T he 3rd ISPRS Workshop on Dynamic and Multi-dimensional GIS, 34, Part 2W2, 23rd25 May, Bangkok, Thailand, 2001, pp. 233-237

[10] ESRI, ArcView 3D Analyst (Redlands, California: Environmental Systems Research Institute Inc), 1997

[11] Zlatanova, S., and Gruber, M. 3D GIS on the Web. In Proceedings of ISPRS, Commission. IV, Stuttgart, Germany, 1998, pp. 691-699

[12] Coors, V. 3D GIS in networking environments. In Proceedings of International Workshop on 3D Cadastres, 28-30 November, Delft, Netherlands, (Denmark: International Federation of Surveyors), 2001, pp. 159-169

[13] M. A. Oliver and R. Webster "Kriging: a method of interpolation for geographical information system", INT. J. Geographical Information Systems, 1990, vol. 4, No. 3, pp. 313-332

[14] D. F. Watson. Computing the n-dimensional Delaunay tessellation with application to Voronoi polytopes. The Computer Journal (1981) 24 (2): 167-172.

[15] A. Bowyer. Computing Dirichlet tessellations. The Computer Journal (1981) 24 (2): 162-166.

[16] Regina Estkowski, Joseph S. B. Mitchell, and Xinyu Xiang. Optimal decomposition of polygonal models into triangle strips. In Proceedings of the eighteenth annual symposium on Computational geometry (SCG '02). ACM, New York, NY, USA, 2002, 254-263.

[17] Michael Garland and Paul S. Heckbert. 1997. Surface simplification using quadric error metrics. In Proceedings of the 24th annual conference on Computer graphics and interactive techniques (SIGGRAPH '97). ACM Press/Addison-Wesley Publishing Co., New York, NY, USA, 209-216.

[18] Lv, Z., Yin, T., Han, Y., Chen, Y., Chen, G.. WebVR–Web Virtual Reality Engine Based on P2P network. Journal of Networks, Vol 6, No 7 (2011), 990-998, Jul 2011.

[19] David G. Bell, Frank Kuehnel, Chris Maxwell, Randy Kim, Kushyar Kasraie, Tom Gaskins, Patrick Hogan, Joe Coughlan, NASA World Wind: Opensource GIS for Mission Operations. New York, 2007

[20] Lv, Z., Rhman, SU., Chen, G.. WebVRGIS: A P2P Network Engine for VR Data and GIS Analysis. ICONIP 2013, Daegu, Korea, 2013 (LNCS: Neural Information Processing).