Improved LOD Based on Quadtree and Spatiotemporal Association in SVS

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Abstract. The Synthetic Vision System (SVS) is an advanced real-time display technology of 3D terrain, which is aimed at integrated display of navigation information and 3D terrain. However, we will face two key problems in SVS development. They are spatiotemporal association of various data and real-time and effective display of terrain. Therefore, in order to solve these problems, a unified representation model is set up in this paper to uniformly express multi-source, heterogeneous and multi-scale data. Besides, LOD (Levels of Detail) based on Quadtree is improved here for the real-time and effective display of terrain. The improved method can increase rendering speed and enhance display effect at the same time. Simulation on OpenGL proves that methods in this paper can realize the integrated display between real-time 3D terrain with multi-resolution and the corresponding navigation data.

Introduction

According to statistics, worldwide, more than 30% of serious aviation accidents belong to the CFIT (Controlled Flight into Terrain) type [1]. The low visibility leads to the deficiency of situational awareness [2], which is the main reason for the CFIT accidents. The Synthetic Vision System (SVS) is a more advanced visual technology that based on the high-precision navigation information and relevant airborne databases (terrain database, obstacle database and airport database), which uses computer image processing technology to provide pilots with external terrain scene [3].

SVS that aiming at integrated display is currently faced with two problems: spatiotemporal association of all kinds of data and real-time and effective display of terrain. A spatiotemporal association model is necessary for the first problem. The model should contribute to display 3D terrain in real-time with the change of aircraft’s six degrees of freedom. In order to solve the second problem, terrain data should be efficiently processed in the system and the 3D terrain display should be intuitive.

As to solve the above problems, a unified representation model of multi-source, heterogeneous and multi-scale data is established in this paper at first. The model is aimed at unity of data types, spatiotemporal association and other issues. At the same time, the traditional Quadtree algorithm is improved. The static error analysis is introduced in LOD model for drawing in detail of ROI (Region of Interest, here means terrain-fluctuation or high-altitude region). Before error analysis, the invisible region is removed with visual cone tailoring technology. Real-time rendering of 3D terrain data will be integrated with the corresponding navigation data on the same screen.

Unified Representation Model

Establishment of Unified Representation Model

Data from navigation sensors, data from multispectral environment sensors, terrain data and other information should be fused in SVS. Therefore, a unified representation model of multi-source,
heterogeneous and multi-scale data is put forward here, aiming at the proposed problems. The 3D dynamic data model is shown as Figure 1.

![Figure 1. The unified representation model of multi-source, heterogeneous and multi-scale data.](image)

**Workflow Analysis**

According to the unified representation model in Figure 1, the data process workflow is concluded as the Figure 2.

![Figure 2. The workflow of integrated display.](image)

**Improved LOD Based on Quadtree**

LOD model is a kind of important terrain simplification algorithm. It uses the dynamic construction technology to draw different terrain blocks with different precision, according to the terrain feature, viewpoint position, posture and other related parameters. At present, the common LOD algorithms includes [8]: GeoMip mapping geometric multi-resolution algorithm, Quadtree algorithm and ROAM algorithm. The cores of these three algorithms are the same: for terrain block with short distance or distinct feature (large fluctuation or high altitude), more grids are used for rendering. Otherwise less grids are used.

**Improved Method of Quadtree**

Under the consideration of the influence of terrain geometry features on the display resolution, it is necessary to improve the traditional Quadtree structure. At the start of establishment of Quadtree model, the static error is added to each node so as to accomplish multilevel selection based on terrain features in real-time display.

Static error is a very important parameter characterizing the terrain features. Its introduction matches different-resolution terrain data with different terrain features in the multi-resolution model, in order to fully draw the terrain details of ROI region[9]. Static error is the difference between the real elevation and the interpolation average. The calculation procedure is as follows:
The elevation of each node is set as $H_x$. $x(1,2,...9)$ is the node number.

1) Calculate static errors of four sides:

$$dH_1 = \frac{|H_2 - (H_1 + H_3)|}{2}$$  \hspace{1cm} (1)

$$dH_2 = \frac{|H_4 - (H_3 + H_5)|}{2}$$  \hspace{1cm} (2)

$$dH_3 = \frac{|H_6 - (H_5 + H_7)|}{2}$$  \hspace{1cm} (3)

$$dH_4 = \frac{|H_8 - (H_7 + H_9)|}{2}$$  \hspace{1cm} (4)

2) Calculate static errors of two diagonals:

$$dH_5 = \frac{|H_1 - (H_2 + H_3)|}{2}$$  \hspace{1cm} (5)

$$dH_6 = \frac{|H_4 - (H_3 + H_5)|}{2}$$  \hspace{1cm} (6)

3) Choose the maximum of above six errors as the static error of this block:

$$dH = MAX(dH_1, dH_2, dH_3, dH_4, dH_5, dH_6)$$  \hspace{1cm} (7)

According to the fluctuation features of terrain, attitude of aircraft and viewpoint point and other parameters, dynamic selection of optimal node set in Quadtree is done for complete coverage of terrain scene. Therefore, a balance between rendering efficiency and rendering quality will be set up. It is necessary for multi-resolution terrain expression, which is shown as Figure 4. The reference for selection of the optimal node set is the screen error of each node.

Screen error (also known as dynamic error) is the screen projection error caused by the change of visual range (viewpoint position and angle). It determines the output quality of the image. Assuming the view angle is $\alpha$. The height of the projection plane is $h$. And the unit length ratio of the world coordinate system to the screen coordinate system is $\lambda$. For the node with static error $dH$, if the distance between its midpoint to viewpoint is $d$, and the angle between node's projection vector and the gazing direction is $\beta$, screen error is shown as Figure 5.
According to the principle of perspective projection transformation and spatial geometric relations, the screen error $e_{\text{screen}}$ caused by projection of $dH$ is:

$$e_{\text{screen}} = \frac{h \cdot \lambda \cdot dH \cdot \cos \beta}{2d \cdot \tan(\frac{d}{2})}$$

(8)

Consequently, in the real-time dynamic display, the screen error of each node in Quadtree can be calculated by Eq.8 unless viewpoint position and gazing direction are known. Then, a comparison between the screen error and the given threshold is made to judge whether this node should be divided again. The judging criteria is depicted as Formula Eq.9.

$$\begin{cases} e_{\text{screen}} > \varepsilon, & \text{need to be divided again} \\ e_{\text{screen}} < \varepsilon, & \text{no need to be divided} \end{cases}$$

(9)

If the screen error $e_{\text{screen}}$ of static error is greater than the given error threshold, the terrain features is obvious or distance from viewpoint is small. Hence, this node need to be divided again for higher resolution. Conversely, no need to be divided.

In fact, the selection of the multi-resolution data set is a process of nodes traversal from top to bottom. Screen error $e_{\text{screen}}$ and the predetermined threshold are compared to determine the degree of segmentation. The specific process is depicted in Figure 6.

The entire traversal process starts from the lowest level, that is, the parent node of Quadtree. Firstly, the 2D visual cone tailoring is applied to remove the invisible blocks. For visible terrain block, screen error of each node will be calculated in accordance with static error stored in the node class. Then, a comparison between the screen error and the given threshold is made to judge whether this node should be divided again. In the same way to work until every node meets the accuracy requirement or reach the highest resolution. Finally, an optimal LOD model is established under the condition of certain viewpoint position and gazing direction. It leads to the multi-resolution display base on Quadtree.
Initialization of node array, and midpoint of block is obtained. Calculating elevation of four vertices. Does this block have intersection with the visual cone? Y No, this level the highest resolution? N Calculating distance between viewpoint and midpoint of block. Is this distance greater than threshold value? Y Yes, this node needs to be divided again, then pushed into node array and created index. N No, is screen error greater than threshold value? Y Is this distance greater than threshold value? Y N N Yes, this node needs to be divided again, then pushed into node array and created index. N N No, they are marked child nodes, then pushed into node array and created index. N

Figure 6. Selection process of multi-resolution terrain data.

On the base of multi-resolution model, the multi-resolution Quadtree is drawn taking advantage of LOD algorithm based on regular grids.

Terrain rendering in this paper uses triangle mesh. A method named Triangle Fan is used here to set up triangular meshes. When increasing a triangle, it only needs to add a vertex in the original series. 3N vertices are required for N triangles in the traditional algorithm, but only (N+2) vertices in Triangle Fan. While N reaches a very large number, the improvement of new method seems more obvious. Triangle Fan can greatly reduce the number of rendering vertices and improve the speed of terrain rendering.

Simulation and Terrain Rendering

Terrain Rendering on LOD

OpenGL is widely used in picture processing and 2D/3D display. It is very suitable for exploitation of 3D terrain image. Besides, OpenGL is able to support the list display, double buffer technology and other technologies to shorten the drawing time and improve the real-time performance in display.

Hierarchical division in Quadtree is mainly based on the distance from the viewpoint, the relative altitude of aircraft and ground, as well as the pitch attitude of the aircraft. The priority relationship is shown as Figure 7. The first division for resolution is according to horizontal distance. The second division refers to the relative height in the same distance. The end is according to the current pitching angle. These three situations will be respectively analyzed in the following. The mouse is used to simulate the viewpoint movement, in order to verify the correctness of the establishment of Quadtree.

Figure 7. Organization principle of terrain data.
The Quadtree Expression Based on Horizontal Distance

According to the characteristics of visual observation, it is known that the closer the horizontal distance, the higher the resolution demand of the scene. Therefore, the terrain in different horizontal distances must be expressed with different resolutions.

In simulation, the horizontal distance is calculated firstly between each node in Quadtree and the aircraft (viewpoint). And the distance interval is judged. Then, according to the interval, the corresponding resolution is determined. Three distance intervals are established here, they are \((2000, +\infty]\), \((700, 2000]\) and \([0, 700]\). With the decrease of the horizontal distance, the resolution is changing from 1:64 to 1:8. The effect picture is shown as Figure 8 (b).

It can be seen from the Figure 8 (a) that rendering complexity of all terrain are the same in a unified resolution regardless of horizontal distance. On the contrary, the multi-resolution display based on horizontal distance is more effective. Terrain near viewpoint has high resolution, and with the increase of distance, terrain resolution is gradually decreasing. Thus, pilots will pay more attention to the closer and greater risk region. It is an effective way to reduce visual burden.

Performance Analysis of Rendering Method

In the image processing field, FPS (Frame Per Second) is usually used as a quantitative index of image display speed or refresh rate. The performance analysis of proposed rendering method will be carried on in accordance to FPS. In order to present advantages of the method in this paper, traditional terrain rendering method is made for comparison. Respectively, effect pictures with two kinds of rendering methods are shown as Figure 9.

When the number of loading terrain blocks increases from 1 to 10, the above two methods are respectively used for terrain rendering. Besides, the triangle mesh is adopted in two methods. Performance comparison is shown as Figure 10.
Figure 10. Performance comparison of two kinds of rendering methods.

It can be seen from Figure 10 that the proposed method can achieve 10%~20% speed improvements compared to traditional rendering method. It greatly contributes to real-time display. At the same time, as the number of loading terrain blocks increasing, refresh capability significantly reduces.

Conclusion and Prospect

In this paper, an integrated spatiotemporal association model and an improved LOD model based on Quadtree are put forward. They are respectively the solution for two problems in SVS: the spatiotemporal association of various data and the real-time and effective display of terrain. The simulation on OpenGL proves research in this paper achieves an expected effect. Multi-resolution rendering method based on Quadtree is an effective way to reduce pilot’s visual burden. Then 3D terrain and the corresponding navigation data are displayed on the same screen. What’s more, performance comparison shows there are 10%~20% speed improvements through proposed rendering method. Researches in this paper lay the foundation of SVS system development.

References