# The Visualization Simulation of Remote-Sensing Satellite System

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**ABSTRACT:**

The aim of RS satellite 3D visualization is to design a system based on 3D dynamical display technology that combine orbital dynamic, attitude control, coverage and sensor with computer graphics. This system simulates the satellite track, attitude and sensor coverage, and displays the information of satellite on orbit vividly. To develop the RS satellite 3D visualization system, this paper analyzes the 3D global grid model, texture mapping and system design. Firstly, we analyze the global discrete grid thoroughly, adopt the regular icosahedrons method to build up the grid. Then the texture mapping methods are described and contrasted, the method of block texture mapping is applied. Finally, the design aim, framework and main function of system are introduced in this article.

## 1. INTRODUCTION

### 1.1 General Statement

With the advent of information age , the acquisition of spatial information gains more and more attention. Consequently, the Remote Sensing with a great ability in earth observation activities performs more and more important role both in daily life and military.

The remote sensing satellite is a kind of product which needs high input and high-tech, faces the great risk but has high-yield. As the trajectory of the satellites and its attitude that are the prime factors affecting the satellite functions are vital in engineering design process for Satellites, numerous simulations have been used to explore its law of motion. Nowadays the immense progress in Computer Graphics and Virtual Reality contribute to the progress of 3D Visualization in the realm of Space Remote Sensing: by displaying real-time interaction simulation process and result, the 3D Visualization could provide more vivid and comprehensive information to users and also can be used as a platform for experts in different areas to communicate. That the 3D Visualization could be used for operational decision of Space Remote Sensing projects, task scheduler, modelling and simulation makes the users to keep the same step with the progress of the space tasks. The reliable and scientific simulation theory and its result is indispensible to the space tasks considering its the special attribute such as the great risk and high input.

### 1.2 Main Work of this paper

Remote sensing satellite running-on-orbit dynamic visual simulation system deal with many realm and technology such as computer graphics, 3D programming, database technology, remote sensing satellite imaging technology, orbit and attitude technology of satellite, communication technology, information synthesis and so on. The main work of this article is to use the OpenGL, the latest three dimensional scene development kit—OSG(Open Scene Graph) and VC++ to get these things done: the geometrical modelling of the scene, texture mapping.The satellite demonstration platform which is the uniform formation of two-dimension and three-demonstration is also provided to users. The following are details.

(1)the 3D modelling

Utilize method of regular icosahedrons to model the earth, then partition the earth for texture mapping, thus we get a earth model with higher accuracy than models by other methods.

(2)Texture mapping
Analyze the commonly used methods of texture, and contrast their advantage and disadvantage, then choose the best one.

(3) the realization of 3D visualization system

On the basis of work above-mentioned, initial success was achieved about the 3D visualization system of remote sensing satellite. With the satellite on-orbit model, we build up the visualization system in which 2D view synchronize with 3D scene. Thus, we can simulate kinds of satellite on-orbit.

## 2. EARTH SPACE MODEL

### 2.1 The model of global discrete grids

#### 2.1.1 Overview of global discrete grids

The global discrete grids have the following attributes: it can be subdivided infinitely, it can fit the earth's surface very well and it is hierarchical and seamless. Every grid unit has unique code. There are several commonly used methods for Spherical Subdivision: grid based on latitude and longitude, grid based on regular polyhedron and self-adaptive grid.

The latitude and longitude grid causes severely deformation in the high latitude area, so grid based on regular polyhedron turn to be a better choice. We build up the grid of regular polyhedron according the following steps: firstly, projecting the side of inscribed regular polyhedron on the spherical surface, the spherical surface will be covered by spherical triangles. Secondly, we subdivide the spherical polygon based on spherical triangles to establish seamless and almost homogeneous spherical grid. The regular polyhedron grid which is seamless, stable and almost homogeneous overcome the flaws, that is heterogeneity and singularity, of latitude-longitude grid.

#### 2.1.2 Grid of regular icosahedrons

In this article, the earth is constructed according to the model of regular icosahedrons. The regular icosahedrons contain 12 vertexes and 20 surfaces. In this article, the earth is constructed according to the model of regular icosahedrons. The regular icosahedrons contain 12 vertexes and 20 surfaces. Assuming the earth's radius of 1.0, the vertexes' coordinates of regular icosahedrons is manifested in table 1.

| 顶点 | X | Y | Z |
|---|---|---|---|
| 0 | 0.420152426708710003 | 0.904082550615019298 | -0.078145249402782959 |
| 1 | 0.995009439436241649 | 0.040147175877166645 | 0.091347795276427931 |
| 2 | 0.518836730327364437 | 0.181331837557262454 | -0.83542038037823585 |
| 3 | -0.414682225320335218 | 0.630675807891475371 | -0.655962405434800777 |
| 4 | -0.515455959944041808 | 0.767200992517747538 | 0.381716898287133011 |
| 5 | 0.355781402532944713 | 0.402234226602925571 | 0.843580002466178147 |
| 6 | 0.414682225320335218 | -0.630675807891475371 | 0.655962405434800777 |
| 7 | 0.515455959944041808 | -0.767200992517747538 | -0.381716898287133011 |
| 8 | -0.355781402532944713 | -0.402234226602925571 | -0.843580002466178147 |
| 9 | -0.995009439436241649 | -0.040147175877166645 | -0.091347795276427931 |
| 10 | -0.518836730327364437 | -0.181331837557262454 | 0.835420380378235850 |
| 11 | -0.420152426708710003 | -0.904082550615019298 | 0.078145249402782959 |

Table 1. Vertexes' coordinates of regular icosahedrons

Each surface of the regular icosahedrons will be divided to 6 sub-surface as displayed in figure 1. Because the coordinates of the 12 vertexes and corresponding texture mapping coordinates are known, the coordinates of the coordinates of $V_0, V_1, V_2$ also can be calculated. The space coordinates of $e_0, e_1, e_2, c_0$ and corresponding texture mapping coordinates can also be got in light of knowledge of space analytic geometry.

$$e_{0.p} = (V_{0.p} + V_{1.p})/2 \qquad e_{0.uv} = (V_{0.uv} + V_{1.uv})/2$$
$$e_{1.p} = (V_{1.p} + V_{2.p})/2 \qquad e_{1.uv} = (V_{1.uv} + V_{2.uv})/2$$
(1)
$$e_{2.p} = (V_{0.p} + V_{2.p})/2 \qquad e_{0.uv} = (V_{0.uv} + V_{2.uv})/2$$
$$c_{0.p} = (V_{0.p} + V_{1.p} + V_{2.p})/3$$
$$c_{0.uv} = (V_{0.uv} + V_{1.uv} + V_{2.uv})/3$$

where .p represent the space coordinates of vertex(x, y, z)

.uv represent the texture mapping coordinates(u, v)

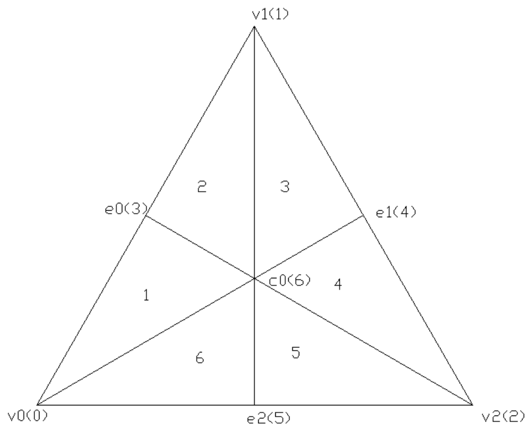


Figure 1. division of the regular icosahedrons

The 6 sub-surfaces are divided recursively as shown in the figure 2. The $\Delta c_0 v_0 e_2$ below is the triangle 6 in figure 1.

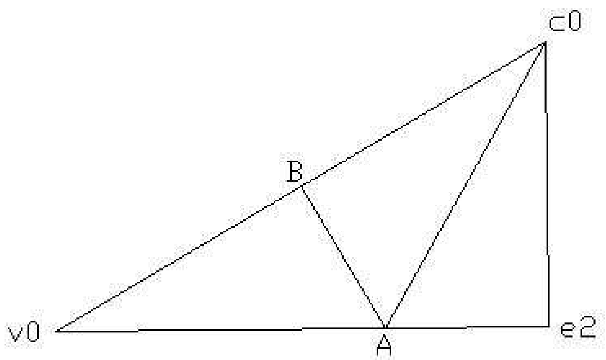


Figure2. The subdivision rule of sub-surfaces

of regular icosahedrons

the angular bisector of $\angle V_0c_0e_2$ and the side $V_0e_2$ intersect at point A, then we draw a vertical line from point A to point B which is the foot of the perpendicular. Thus, the triangle $c_0v_0e_2$ is divided into three congruent triangles. Each triangle will also be divided in the same way. The number of triangle in the grid has directly influence on the depth of recursion. The final calculated vertex coordinated should be converted to the sphere surface. The figure 3 is the global grid model we get.

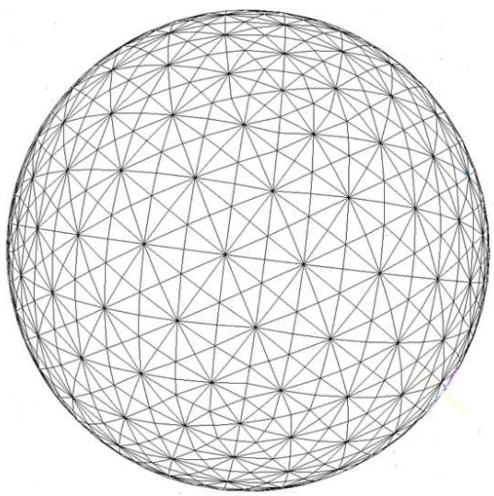

Figure 3. The global grid model

### 2.2 The texture mapping technology

#### 2.2.1 Principle of texture mapping

When finished the modelling of 3D global grids, it is necessary to do texture mapping on wire frame model to make the 3D model more realistic. The issue we concerned is 2D texture mapping which project the 2D image onto the 3D wire frame. Texture of 2D surface is always defined according to the correspondingly colour of rectangle patterns. The descriptions of all texture are called texture space whose origin locate in the lower sinister corner. The texture space of rectangle patterns is represented by the texture coordinate (u, v) where both the u and v are less than 1 and more than 0. The aim of texture mapping is to determine the coordinates of points on the model by a certain feasible method.

The texture mapping is mapping among the texture, scene and screen as shown in figure 4. The progress shown in figure 4 are mapping pixel in screen space to the surface of object and mapping scene space to texture space, thus, we determine correspondingly texture coordinate of the point's coordinate in scene space. Here we mainly concern the relationship between scene coordinates and texture coordinates.

The relationship between texture space and scene space, and relationship between scene space and screen space:

Mapping M: Scene space→Texture space
Mapping T: Screen space→Scene space

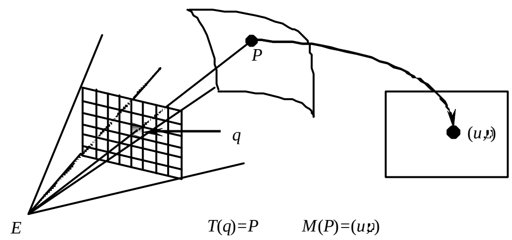


Figure 4. Mapping among the texture, scene and screen

In mathematics, mapping M could be expressed in such equation.

$$(u, v) = F(x, y, z) \quad (2)$$

where $(u, v) \in$ Texture

If F is reversible, we can get the equation (3) easily.

$$(x, y, z) = F_1 (u, v) \quad (3)$$

#### 2.2.2 Spherical texture mapping

Spherical texture mapping is mapping the rectangle to the whole sphere where the texture are expressed by rectangular coordinates. That V-axis in texture coordinate system mapping to the sphere is a parallel with the latitude $\phi$ and that U-axis mapping to the sphere is a meridian with longitude $\theta$. The algorithm of spherical mapping is to determine the function between (u, v) in texture space and latitude and longitude coordinates $(\theta,\phi)$ in scene space.

The parametric equation of latitude and longitude coordinates in object space is equation (4)

$$\begin{cases} x = R\sin\Phi\cos\theta \\ y = R\sin\Phi\sin\theta \\ z = R\cos\Phi \end{cases} \qquad (4)$$

where $0 \le \Phi \le \pi,\ 0 \le \theta \le 2\pi$

Then use the linear transformation to establish function between [0,1]*[0,1] and [0,2π]*[0,2π].

$$u = \theta/_{2\pi},\ v = \Phi/_{\pi}$$
(5)

Then spherical mapping equation can be derived from equation (4) .

$$u = \arctan\left(y/_x\right)/_{2\pi} \quad v = \arccos\left(z/_R\right)/_{\pi} \qquad (6)$$

However, the spherical mapping method will cause severely deformation which makes the method limited in practice for the reason that the remote sensing satellite simulation require high accurate global model.

#### 2.2.3 Block texture mapping based on regular icosahedrons

Divide world map according to the cylindrical equidistant projection into ten square texture image according to the method of grid construction found on regular icosahedrons, then finish the mapping of ten equilateral triangles of regular icosahedrons. Figure 5 is the block texture before mapping.

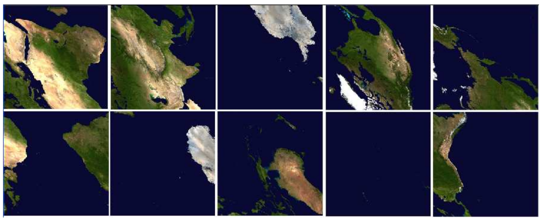

Figure 5. the block texture before mapping

As shown in figure 6, we do the mapping of ten texture image to the 20 equilateral triangles of regular icosahedrons: each square texture image to the two adjacent equilateral triangles. The rules is that the four vertexes a, b, c, and d in the left square maps to the vertexes A, B, C, and D in the right two adjacent triangles.

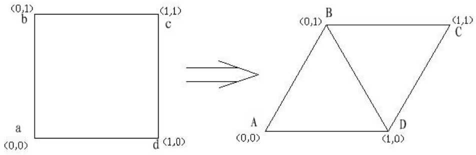


Figure 6. the rule of block texture mapping

In this article we adopt the texture mapping method based on regular icosahedrons simply because its deformation is smaller than other methods such as basic spherical mapping which cause severely deformation. Thus we could simulate the earth more precisely. Figure 7 is the earth we get by this method.

Figure 7. The view earth we get

### 2.3 Coverage Analysis

The area possibly observed by satellite at given time or certain time interval is called coverage area. The point G in the figure below that is the intersection point of the line SO between satellite and earth centre and earth surface is the sub-satellite point. The coverage area of satellite S on any point of its orbit is a cap zone which is formed by the earth surface and a right circular conical surface, as shown in figure 9, with an axis SO and $\alpha$ semi-cone angle. The size of coverage area depend on the field angle $2\alpha$. The coverage area is the earth surface with center at G and a certain radius.

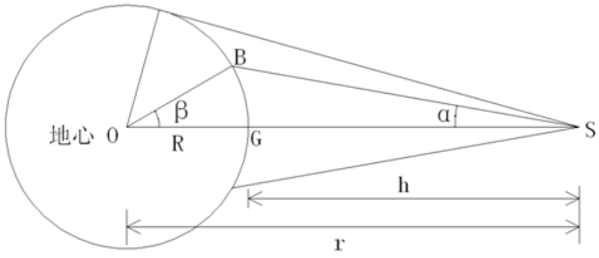


Figure 8. The satellite coverage

If we know the position of G and the observation range of satellite sensor, the coverage area can be calculated. It is necessary to assume that the longitude and latitude is $\phi_{ss}$ and $\lambda_{ss}$, the field angle is $2\alpha$, and $\beta$ is the coverage geocentric angle between the line SO and point B which is closed to the edge of coverage area.

To calculate the angle $\beta$, we could use Pythagorean Theorem in triangle OBS.

$$\left.\begin{array}{l} R/\sin\alpha = (R+h)/\sin(\alpha+\beta) \\ \beta = \arcsin\left(\sin\alpha * \frac{r}{R}\right) - \alpha \end{array}\right\} \quad (7)$$

where r= R+ h

Then we will get the N units of latitude and longitude that constitute the boundary of coverage area.

$$\begin{cases} \lambda_{SC} = \arcsin(\cos\beta\sin\lambda_{SS} + \sin\cos\Delta_i\cos\lambda_{SS}) \\ \phi_{SC} = \arctan\left(\frac{\sin\beta\sin\Delta_i\cos\lambda_{SS}}{\cos\beta - \sin\lambda_{SS}*(\cos\beta\sin\lambda_{SS} + \sin\beta\cos\Delta_i\cos\lambda_{SS})}\right) + \phi_{SS} \end{cases} \quad (8)$$

where R is the earth radius, r is the distance of satellite and earth centre, h is the satellite height, and $\Delta_i = \frac{2\pi}{N} * i \ (i = 0 \sim N-1)$

Figure 9 is the coverage image we get according to the process above.

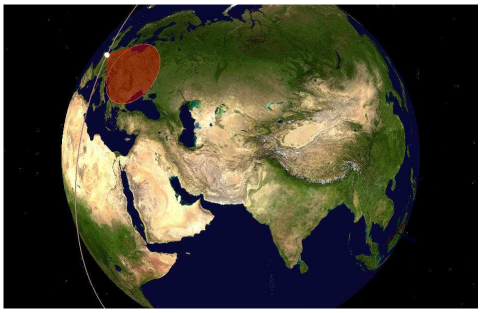

Figure 9. Satellite track and coverage area

## 3. THE DESIGNATION AND REALIZATION OF REMOTE SENSING SATELLITE SIMULATION SYSTEM

### 3.1 The system design

#### 3.1.1 The system design aim

We build the satellite demo platform with a unified view of two dimensional and three dimensional view to provide service of orbit wizard and analyze the ability of satellite observation. The system design aim of remote sensing satellite 3D visualization simulation system provides us a 3D virtual information basic system platform which could simulate the remote sensing satellite motion by mathematical modelling and visual analysis and could satisfy the need of special remote sensing satellite project.

#### 3.1.2 The general framework

We construct the system in light of modular design principles, so the system could adapt to change of functional needs and have many characteristics, such as easiness in expansibility and great flexibility.

According to the function, the system is divided into four modules: 2D view, 3D scene, engine drive and satellite motion model. The 2D view model displays satellite position and update of coverage and the 3D scene displays the satellite's motion in 3D scene. The driven engine module is the power sources of simulation and the satellite motion module model is the basis of the whole simulation system

#### 3.1.3 The main function of system

As a remote sensing 3D visualization system, the fundamental function is introduced as follows.
(1) Read, configure and control the data file of earth texture and other model files according to configuration dialog box.
(2) The system based on single document create two views the front view of which is 3D scene window

where we demonstrate the satellite around the earth in 3D scene. The other view is two-dimensional world map dialog window whose background is world map image of the cylindrical equidistant projection. The driven engine drive objects, such as satellites and sensors, in the front view and two-dimensional dialog windows, then the system dynamically display the information about satellite's position and coverage area both in two dimensional and 3D windows.
(3)Calculate the satellite's position from the initial epoch by satellite orbital dynamics, then build 3D models of satellite and orbit to simulate and predict the satellite orbit.
(4) Control the satellite's attitude by means of basic attitude control algorithm above-mentioned..
(5) Camera rotation and zoom could display result in different coordinate system and projection.
(6) The time dialog window which control the demonstrational speed of scene shows the current epoch of satellite.
(7)We can capture the location of mouse, and calculate its latitude and longitude, and display it on status bar at the same time.

## 4. CONCLUSIONS

### 4.1 Summary

The main work and results of this article are as show below. ①The 3D space environment is the one of significant segment of RS satellite simulation. We adopt the regular icosahedrons method and conduct texture mapping of the earth, thus we construct the earth model with high accuracy. ② Based on coverage analysis we simulate the satellite's coverage area at any given time in 3D scene.

Generally speaking, we have primarily construct the RS 3D visualization simulation system which could simulate different kinds of remote sensing satellite on orbit.

Finally, with the further advance of research, there will be more problems. Yet the purpose of our research is always to build an system with high sense of reality and effective operation.

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