Research on Collision Detection Algorithm of Tankin Virtual Battlefield

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Abstract. In order to solve the contradiction between real-time and accuracy of collision detection in virtual battlefield, we divided the terrain into three types according to its average curvatureand different matching algorithms were used in different types of terrain. In virtual battlefield, collision detection internal 3D solid modelwas put forward to avoid the untrue phenomena that tank gun barrel penetrated the rear auxiliary fuel tank. Mixed bounding box algorithm was used to solve the problem of collision detection between tank and other solid models perfectly. The application has a good performance in a simulation training system.

1.Introduction

Simulation training hasrisengreat attention in the military affairs all overthe world and it has become an important wayto improve thecombat effectiveness.Buildingrealistic virtualbattlefieldisone of the keysectors to achievesimulation training.Virtualbattlefieldis the battlefield environment displayedoncomputerbyusing computer technology, graphics technology, virtual reality technology and so on[1]. Tankand otherarmored equipmentarean important part in virtualbattlefield. To ensure itsrealism,matchingbetweentankandterrain and collisiondetection betweentankandother objectsarekey issuesthat must be addressed.

2.Terrain Matching

Terrain matching is collision detectionbetweentankandterrain. It is the fact that invirtual battlefieldtankis alwaysclose to the ground and changesposture to be consistent with the undulatingterrain. The phenomenon that tank penetratesinto the groundorflies in the air are not allowed to appear.Due to the limitedprocessing power ofcomputerhardware, using only one terrain matching algorithm cannot resolve the conflictbetween timelinessand accuracy ofcollision detection. So we divide the terrain into three types according to its average curvature, i.e. flat,general anduneven. Different matching algorithmsare used in different types of terrain.

2.1The Concept of the Mean Curvature

On the surface, every point has two mutually perpendicular directions on its section, which make the corresponding normal curvature $\frac{1}{R_1}$ or $\frac{1}{R_2}$ to the minimum and maximum value. $\frac{1}{R_1}$ and $\frac{1}{R_2}$ arethe principal curvature of PointP. In most cases, what plays a great role istheir average value. That is

$$H = \frac{1}{2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right). \quad (1)$$

H is the mean curvature of a point on the surface[2].

2.2 Calculation Method of Mean Curvature

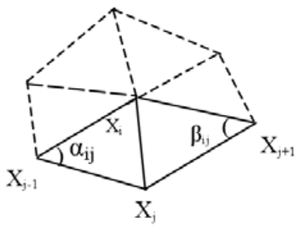

Fig.1: Diagram of Average Curvature Calculation

As shown in Fig.1, in order to obtain the mean curvature ofPoint X_i, we need to use a few discrete points around this point to make it. We take N points called $X_j(1 \le j \le N)$ around X_i and put them together into a vertebral body to obtain the mean curvature of X_i approximately. Weobtainthe points near around X_i by using Voronoi diagram. Voronoi diagram is also calledDirichlet graph, which was first proposed in 1850 by Dirichlet [3].

The arithmetic equation of mean curvature is

$$k_H(X_i) = \frac{1}{A_{Mixed}} \sum_{j \in N_1(i)} [\frac{1}{8}(\cot\alpha_{ij} + \cot\beta_{ij}) \| X_i - X_j \|^2] k_{i,j}^N \tag{2}$$

Where, A_{Mixed} is the area of the Voronoi diagram of Point X_i.

$$k_{i,j}^N = 2\frac{(X_i - X_j)\cdot n}{\| X_i - X_j \|^2} \tag{3}$$

$$R_{ij} = \frac{\| X_i - X_j \|^2}{2(X_i - X_j)\cdot n} \tag{4}$$

So

$$k_{i,j}^N = \frac{1}{R_{ij}}. \tag{5}$$

We can get the value of R_{ij} according to the fact that any four non-coplanar points determine a sphere. The coordinate of the center of the sphere is$P(x, y, z)$. We can obtain the following equations based on a formula of spherical.

$$\begin{cases} (x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2 = R_{ij}^2 & (a) \\ (x_{i-1} - x)^2 + (y_{i-1} - y)^2 + (z_{i-1} - z)^2 = R_{ij}^2 & (b) \\ (x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2 = R_{ij}^2 & (c) \\ (x_{j+1} - x)^2 + (y_{j+1} - y)^2 + (z_{j+1} - z)^2 = R_{ij}^2 & (d) \end{cases} \tag{6}$$

(b) - (a), (c) - (a), (d) - (a), and then we have the following equations.

$$\begin{cases} 2(x_{j-1} - x_i)x + 2(y_{j-1} - y_i)y + 2(z_{j-1} - z_i)z \\ = (x_{j-1}^2 + y_{j-1}^2 + z_{j-1}^2) - (x_i^2 + y_i^2 + z_i^2) \\ 2(x_j - x_i)x + 2(y_j - y_i)y + 2(z_j - z_i)z \\ = (x_j^2 + y_j^2 + z_j^2) - (x_i^2 + y_i^2 + z_i^2) \\ 2(x_{j+1} - x_i)x + 2(y_{j+1} - y_i)y + 2(z_{j+1} - z_i)z \\ = (x_{j+1}^2 + y_{j+1}^2 + z_{j+1}^2) - (x_i^2 + y_i^2 + z_i^2) \end{cases} \tag{7}$$

The Equations (7) can be expressed in matrix form as $AP = L$. The Coordinate$P(x, y, z)$can be derived by the following formula.

$$P = A^{-1}L \tag{8}$$

The value ofR_{ij}can be got byFormula (8) and any formula of Equations (6). Then mean curvature is got.

2.3 Steps of Match Terrain

We divide the terrain into three types according to the mean curvature and processing ability of the system: flat, general and uneven.Two points terrain matching algorithm (TPTMA) is used in flat areas; fourpoints terrain matching algorithm (FPTMA) is used in general areas; and six points terrain matching algorithm (SPTMA) is used in uneven areas. The matching process between tank 3D model and terrain is as shown in Fig.2.

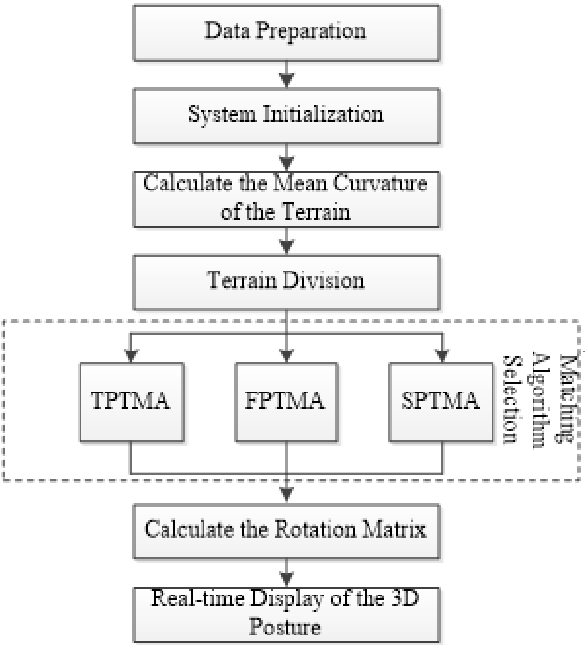

Fig.2: Matching Process Between 3D Models and Terrain

Step 1: Data Preparation. Establish terrain model and tank 3D model by using a variety of modeling tools and modeling method. Establish the model coordinate system.

Step 2: System Initialization. Read in terrain data and tank 3D model data, complete the situation construction, and determine the initial posture of tank in the world coordinate.

Step 3: Calculate the Mean Curvature of the Terrain. Calculate the mean curvature of the terrain according to the method in Section 2.2.

Step 4: Terrain Division. According to the mean curvature divide the terrain into three types: flat, general, uneven.

Step5: Matching Algorithm Selection. As shown in Fig. 2, different algorithms are used in different areas.

Step6: Calculate the Rotation Matrix. Calculate the rotation matrix of tank 3D model according to terrainmatching algorithm and relationship between model coordinate system and the world coordinate system.

Step 7: Real-time Display of the 3D Posture.

TPTMA is also called line matching algorithm, which selects two key points to represent the 3D model, and then projectthese two key points onto terrain surface. Here, we choose the midpoint in front at the tank body bottom and the midpoint at the rear at the tank body bottom asthe two key points. As shown in Fig.3, Point aand Point b are these two key points.The two projection line andterrain intersect at point P_1 and point P_2 respectively. P_1 and P_2 are located at Vector L. Take Vector N_2 which is perpendicular to vector L in the plane defined by Vector L and Z-axis of the world coordinate system. Vector K 、 L and N_2 constitute the model coordinate system. We can get the rotation matrix M_1 according to the relationship betweenthe model coordinate system and the world coordinate system. Rotate tank 3D model around the normal vector at the point A at an angle, which generates a rotation matrix M_2.Matrix $M_1 \times M_2$ is the rotation matrix we want get from the model coordinate system to the world coordinate system. Chose the elevation value of the midpoint of P_1 and P_2 as the height of tank 3D model and then we can get the translation matrix of tank 3D model. TPTMAhas a very fast calculation speed, but in general areas and uneven areas it will make the tank 3D model off the terrain, appearing unreal situation.

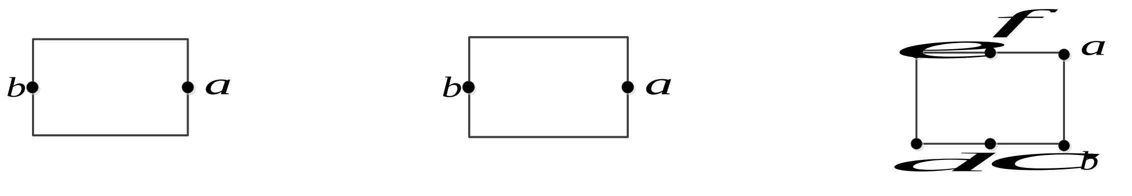

Fig.3: Two Key Points Selection

Fig.4: Four Key Points Selection

Fig.5: Six Key Points Selection

FPTMA selects four key points to represent the 3D model. Point a、b、c and d are these four key points, as shown in Fig.4. While ad and bc are equal to the length of the track closing to the ground. While ab and cd are equal to the distance between two tracks. We use the projection information of these four points to adjust the posture of tank. Because terrain is always complex, these four projection points are probably not on the same plane. Therefore,we need to determine which projection point is the floating point.We can calculate its elevation by using plane defined by other three points. If this elevation is larger than the original elevation of this projection point, then it is the floating point. This algorithmcan reflect the actualgesture of tank more accurately,but italso only applies tothe generalarea.When tank goesthrough thecrater, ditches, moundsand otheruneven areas, its actual gesture is difficult to be reflected by this algorithm.

SPTMA selects six key points to represent the 3D model. Like FPTMA, in this algorithm we also need to find out which three projection points are the floating points. That is we need to select three projection points to define the supporting plane. Wehave20 kinds ofselection methods. To reduce thecomplexity of calculation, wefirst select four points depending onterrainfeatures, and then determine which three points to define the supporting plane from these four points. We have 15 kinds ofselection methods.Point c and Point f are added to reflect the real posture of tank, therefore, twopoints should be selected each side. Here we have 9 kinds of selection methods. Specificselection methodcan be determinedaccording to the terrain and the actualmotionsituationof thetank. Document [4] has analyzed very clearly onSPTMA, so this paper will not repeat them.SPTMA can reflect tank postureaccurately, but it is more complex and has higher requirement forcomputer processing power.

3.Collision Detection of 3D Solid Model

In actual combat process, because of long range maneuveringtank always needs to add two auxiliary fuel tankson the rear of its body. In the tank turret rotation process, if the gun barrel has a large depression angle, it may be blocked by auxiliary fuel tank. In the virtual battlefield environment, if we do not consider this situation, then the phenomenon that gun barrel penetrates auxiliary fuel tank may occur, which is not consistent with the actual situation. So we should consider the collision detection inner tank 3D solid model. There are other 3D solid models in virtual battlefield environment, such as cones and buildings, etc. So we also need to take into account collision detection between 3D solid models.

Bounding box collision detection algorithm is a commonly used method, whose basic idea is to use a slightly larger volume to instead complex geometric object approximately for collision detection. The most common bounding box includes sphere, axis-aligned bounding box (AABB), oriented bounding box (OBB), discrete orientation polytopes (k-DOPs) and so on.

4. 1Inner Collision Detection of 3D Solid Model

Establish tank model coordinate system as shown in Fig.6, where$x$-axis, y-axis and z-axisare orthogonal and intersect at Point o. Because the tank gun barrel and the auxiliary fuel tank are generally cylindrical,we can use two corresponding cylinders to instead them. Project these two cylinders to Plane xoy and Planeyoz, if projections of these two cylinder in both projection plane is not intersect, then gun barrel and auxiliary fuel tank don’t collide. Otherwise they collided.

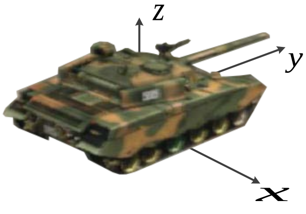

Fig.6: Model Coordinate System

4.1 Collision Detection Between 3D Solid Models

Bounding box collision detection algorithm is also used in collision detection between models, but using only one bounding box algorithm is difficult to resolve the contradiction between real-time and accuracy of collision detection. AABB-k-DOPs hybrid collision detection algorithm is used in this paper [5].

This algorithm includes two stages: preprocessing and real-time collision detection. Establish bounding box binary treeof 3D modelinpreprocessing stage. Binary bounding box uses two-layer structure, the top using AABB, other layers using k-DOPs. The feature of AABBis simple, and it can be used to quickly exclude non-intersecting objects. Surrounding tightness of k-DOPs is good and it can detect colliding objectsmore precisely. Mixed use of two kinds of bounding box can make full use of both advantage to make collision detection quick and accuracy. In real-time collision detection stage, depth-first traversal is used for two bounding box treessynchronously [6]. The same layer subtasks of task tree can be executed in parallel in order to reduce thecomputingtime.Intraversal process we need to detect collision between both AABB-AABB and k-DOPs-k-DOPs. Here we use a top-down approach to building hierarchical bounding box binary tree. First, establish bounding box of 3D model. Second, divide 3D modelinto two disjoint subsets by using splitting plane, and put these two subsets as the root to establish corresponding bounding boxes. Third, new root node is divided again, until the child nodes are basic elements. Hierarchical bounding box binary tree is as shown in Fig.7.

Real-time collision detection method uses task tree to detect collision between AABB and AABB of the root nodes first. If AABBs intersect, then detect collision between k-DOPs. Practical application shows that the use of hybrid bounding box collision detection algorithm can not only improve the real-time but also improve the accuracy of collision detection.

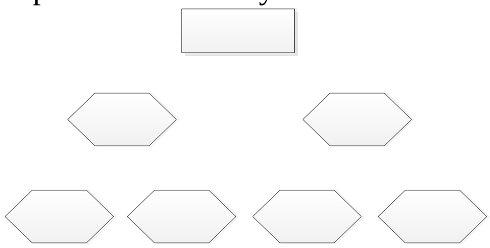

Fig.7: Hierarchical Bounding Box Binary Tree

Conclusion

This paper divided the terrain into three types according to its average curvature, and different matching algorithms were used in different areas. It took into account the processing power of computer and accuracy and real-time requirement of collision detection. Collision detection internal 3D modelwas put forward to avoid the phenomena inconsistent with the actual. Using AABB-k-DOPs hybrid bounding box algorithm could both exclude disjoint objects and detect collision quickly. It enhanced the sense of immersion in the practical application, achieving the expected purpose.

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