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 curvature and different matching algorithms were used in different types of terrain. In virtual battlefield, collision detection internal 3D solid model was 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 way to improve the combat effectiveness. Building realistic virtual battlefield is one of the key sectors to achieve simulation training. Virtual battlefield is the battlefield environment displayed on computer by using computer technology, graphics technology, virtual reality technology and so on[1]. Tank and other armored equipment are an important part in virtual battlefield. To ensure its realism, matching between tank and terrain and collision detection between tank and other objects are key issues that must be addressed.

2. Terrain Matching
Terrain matching is collision detection between tank and terrain. It is the fact that in virtual battlefield tank is always close to the ground and changes posture to be consistent with the undulating terrain. The phenomenon that tank penetrates into the ground or flies in the air are not allowed to appear. Due to the limited processing power of computer hardware, using only one terrain matching algorithm cannot resolve the conflict between timeliness and accuracy of collision detection. So we divide the terrain into three types according to its average curvature, i.e. flat, general, and uneven. Different matching algorithms are used in different types of terrain.

2.1 The 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 \( \frac{1}{R_2} \) are the principal curvature of Point P. In most cases, what plays a great role is their average value. That is

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

(1)

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

2.2 Calculation Method of Mean Curvature

![Diagram of Average Curvature Calculation](image)

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

The arithmetic equation of mean curvature is

$$k_{hj}(X_i) = \frac{1}{A_{mixed}} \sum_{j=N_{i}(i)} \left[ \frac{1}{8} \left( \cot \alpha_{ij} + \cot \beta_{ij} \right) \|X_i - X_j\|^2 \right] k_{ij}^{N}$$  \hspace{1cm} (2)

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

$$k_{ij}^{N} = 2 \frac{(X_i - X_j) \cdot n}{\|X_i - X_j\|}$$  \hspace{1cm} (3)

$$R_y = \frac{\|X_i - X_j\|}{2(X_i - X_j) \cdot n}$$  \hspace{1cm} (4)

So

$$k_{ij}^{N} = \frac{1}{R_y}.$$  \hspace{1cm} (5)

We can get the value of $R_y$ 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.

$$\begin{align*}
(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2 &= R_y^2 \hspace{1cm} (a) \\
(x_{i-1} - x)^2 + (y_{i-1} - y)^2 + (z_{i-1} - z)^2 &= R_y^2 \hspace{1cm} (b) \\
(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2 &= R_y^2 \hspace{1cm} (c) \\
(x_{j+1} - x)^2 + (y_{j+1} - y)^2 + (z_{j+1} - z)^2 &= R_y^2 \hspace{1cm} (d)
\end{align*}$$  \hspace{1cm} (6)

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

$$\begin{align*}
&2(x_{j+1} - x_i)x + 2(y_{j+1} - y_i)y + 2(z_{j+1} - z_i)z \\
&= (x_i^2 + y_i^2 + z_i^2) - (x_{j+1}^2 + y_{j+1}^2 + z_{j+1}^2) \\
&2(x_i - x_j)x + 2(y_i - y_j)y + 2(z_i - z_j)z \\
&= (x_j^2 + y_j^2 + z_j^2) - (x_i^2 + y_i^2 + z_i^2) \\
&2(x_j - x_{i-1})x + 2(y_j - y_{i-1})y + 2(z_j - z_{i-1})z \\
&= (x_{i-1}^2 + y_{i-1}^2 + z_{i-1}^2) - (x_j^2 + y_j^2 + z_j^2)
\end{align*}$$  \hspace{1cm} (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.

$$P = A^{-1}L$$  \hspace{1cm} (8)

The value of $R_y$ can be got by Formula (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; four points 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.

**Step 5:** Matching Algorithm Selection. As shown in Fig. 2, different algorithms are used in different areas.

**Step 6:** Calculate the Rotation Matrix. Calculate the rotation matrix of tank 3D model according to terrain matching 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 project these 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 as the two key points. As shown in Fig. 3, Point a and Point b are these two key points. The two projection lines and terrain 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 between the 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 to 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. TPTMA has 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
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 algorithm can reflect the actual gesture of tank more accurately, but it also only applies to the general area. When tank goes through the crater, ditches, mounds and other uneven 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. We have 20 kinds of selection methods. To reduce the complexity of calculation, we first select four points depending on terrain features, and then determine which three points to define the supporting plane from these four points. We have 15 kinds of selection methods. Point \( c \) and Point \( f \) are added to reflect the real posture of tank, therefore, two points should be selected each side. Here we have 9 kinds of selection methods. Specific selection method can be determined according to the terrain and the actual motionsituation of the tank. Document [4] has analyzed very clearly on SPTMA, so this paper will not repeat them. SPTMA can reflect tank posture accurately, but it is more complex and has higher requirement for computer processing power.

3. Collision Detection of 3D Solid Model

In actual combat process, because of long range maneuvering, tank always needs to add two auxiliary fuel tanks on 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. Inner Collision Detection of 3D Solid Model

Establish tank model coordinate system as shown in Fig. 6, where x-axis, y-axis and z-axis are 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 Plane \( yoz \), 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.
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 tree of 3D model in preprocessing stage. Binary bounding box uses two-layer structure, the top using AABB, other layers using k-DOPs. The feature of AABB is simple, and it can be used to quickly exclude non-intersecting objects. Surrounding tightness of k-DOPs is good and it can detect colliding objects more 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 trees synchronously [6]. The same layer subtasks of task tree can be executed in parallel in order to reduce the computing time. 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 model into 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.

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 model was 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.

References

