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Key Issues of Real-time Collision Detection in Virtual Reality

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Abstract: *With the rapid development of computer technology and network communication and other related fields, virtual reality has been widely used in all aspects, but there are still some problems at present. It cannot generate data information during real-time collision detection. However, the real-time collision detection system in virtual reality can accurately and quickly track and measure the target object. Therefore, this paper studies the real-time collision detection problem in virtual reality based on fast tracking of the target. To this end, this article mainly uses experimental methods, data collection methods and other methods to carry out algorithmic research and technical exploration on real-time collision detection problems. This article describes the virtual reality technology and collision detection algorithm in detail, and conducts real-timecollision experiments. Experimental results show that collision detection based on particle swarm algorithm has high real-time performance, and the time is controlled within 1 second. This algorithm is worthy of being used and explored in collision problems.*

Keywords: *Virtual Reality, Real-Time Collision, Research Review, Problem Detection*

1. Introduction

The combination of virtual reality technology and real-time motion detection system can accurately simulate real-time collision tests on instantaneous speed, three-dimensional space, and human-computer interaction interface in a virtual environment. Virtual reality is a three-dimensional visualization tool that integrates dynamics, real-time, and intelligence. It can be used to simulate the user's perception of the environment in the real world and provide various information in this system. Real-time collision detection in virtual reality refers to the use of computer technology, modern control theory and network communication technology to perform multi-dimensional data analysis on different scenarios, so as to achieve accurate tracking of the target's trajectory and get the most accurate response at the target location.

There are many research results on collision detection in virtual reality. For example, Wang Jia proposed that the collision detection algorithm as one of the key issues of virtual reality technology has been extensively researched and developed, and the algorithm has great significance and broad prospects [1]. Yu Wenfei believes that collision detection is an important technical difficulty in graphics, simulation, artificial intelligence, and virtual reality. The industry has conducted more in-depth research on collision detection algorithms [2]. Pan Renyu said that the virtual assembly system can simulate the assembly of electromechanical products and generate assembly sequence and assembly trajectory. The collision detection technology is to verify the correctness of the assembly sequence and assembly trajectory [3]. Therefore, this article studies some related overviews and methods of real-time collision detection in virtual reality. In industry and other fields, this research is of great significance.

This article first studies some basic knowledge of virtual reality technology, and then has an in-depth understanding of collision detection technology. Afterwards, the collision detection algorithm and the collision detection in the virtual assembly system are studied. Finally, the particle swarm optimization optimization collision detection is analyzed and experimented, and the data results are obtained.

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2. Real-Time Collision Detection Technology in Virtual Environment

2.1. Virtual Reality Technology

Virtual reality technology is a kind of simulation of the real world in a virtual environment, so as to realize the function of human-computer interaction. Using virtual reality technology for image processing can greatly improve work efficiency and reduce human-computer interaction interfaces. Virtual reality technology can provide users with a colorful, lively and interesting experience, and can process various information through a computer network system. In this process, it is necessary to establish a complete function with strong operability, easy to understand and easy to use [4-5].

(1) Basic features

Virtual reality technology is a human-machine interface technology that is truly simulated in a natural environment. It has three basic attributes:

1) Immersion: It refers to immersing the user's body and mind in the created virtual environment and experiencing the immersive feeling.

2) Interactivity: Users no longer receive passive information or watch, but can manipulate virtual objects through interactive input devices.

3) Conceptualization: This means that through the use of virtual reality systems, users can obtain perceptual and rational knowledge of the integrated environment, thereby deepening concepts and germinating new ideas.

(2) Classification of virtual reality systems

1) Immersive virtual reality system

The immersive virtual reality system disconnects the user from the outside world through closed images and sounds, so that the user is placed in the virtual world [6-7].

2) Non-immersive virtual reality system

The non-immersive virtual reality system can run on a desktop computer. It has the characteristics of relatively free users, allowing multiple users to log in at the same time.

3) Superimposed virtual reality system

The superimposed virtual reality system enables users to observe the real world while superimposing a virtual image on the observation point.

(3) Classification of design systems

1) Enhanced visualization system

The improved visualization system should use the existing CAD system for modeling, and input into the virtual environment system after the correct data format conversion. Use interactive 3D equipment to view models from different angles in a virtual environment.

2) CAD system based on virtual reality

CAD systems can prompt users to perform activities in a virtual environment. Designers can design and modify directly.

(4) Key technology

1) Collision detection

Real-timecollision detection is a basic part of the virtual construction system and a prerequisite for virtual assembly and virtual maintenance. In order to avoid confusion, it is necessary to be able to accurately determine whether there is a collision between virtual objects in real time. In addition, the collision detection algorithm in the virtual environment must be real-time [8-9].

In order to improve the reliability and efficiency of the detection algorithm, collision detection can be carried out in two aspects: rectangular bounding box space test and space projection.

2) Constraint recognition

The detection of boundary conditions in the virtual construction environment mainly involves the

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detection of geometric boundary conditions. The geometric boundary conditions between components during virtual assembly or maintenance can be roughly divided into five categories. If a part is in motion, the system will detect the dependency between the part and its neighboring parts, analyze it according to the dependent type and parameters, and then standardize the freely moving parts to a certain extent, thus realizing mobile navigation [10-11].

3) Precise positioning

In the virtual reality system, the system first identifies all collisions before drawing the frame of each assembly scene, and then recognizes the possible assembly relationship between the parts to be assembled and the assembled parts in real time according to the rules of identification constraints. At the same time, users can also express assembly intentions through voice or gesture interaction.

4) Real-time exploration

The discrete collision detection algorithm is a method that continuously detects whether a collision occurs between various geometric bodies at each discrete time point in the entire time period. The continuous collision detection algorithm refers to a method of judging whether there is a collision between various geometric bodies in a continuous period of time. Most real-time algorithms are discrete collision detection algorithms.

First, use the cuboid intersection theory to detect whether the vertices of the colliding bodies collide. For the cuboid intersection theory, no rotation matrix is needed, and only a coordinate system with a point in the geometry as the origin of the coordinate system needs to be established. This method reduces the dot product between vectors and saves a lot of time. When a collision between geometric bodies is detected, the detection stops, and the real-time collision detection ends.

2.2. Collision Detection Technology

(1) Overview of collision detection technology

In essence, collision detection is to check whether two objects collide in the virtual environment. In a complex environment, you may need to pay attention to more detailed issues than whether or not a collision occurs, such as when and where two objects collide [12-13].

(2) Enclosure

The bounding volume is usually a simple volume space containing one or more complex objects. This simple bounding volume has an obvious property: if the bounding volume of the object does not intersect, the object must not intersect; only when the bounding volume intersects, further collision detection is required.

The performance function of the bounding box technology can be expressed as:

$$T = W_{\mathrm{c}} \times M_c + W_{\mathrm{d}} \times M_d + W_{\mathrm{e}} \times M_e \tag{1}$$

Enclosure characteristics: easy to construct. The enclosure can be constructed quickly through the original object. Fit objects tightly. The enclosure should wrap the object as tightly as possible, with as few gaps as possible and low memory footprint. The data structure of the bounding volume should occupy as little memory as possible. The intersection test is simple. The enclosure is easy to update. When the object moves, the position of the enclosing body also changes, and the corresponding data must be updated.

(3) Update of bounding box tree after space object collision

The matrix generated by the rotation around the axis, the axis and the axis respectively, and the object space rotation matrix is synthesized.

$$U(a,\alpha) = \begin{bmatrix} 1,0,0 \\ 0,\cos\alpha,-\sin\alpha \\ 0,\sin\alpha,\cos\alpha \end{bmatrix}, U(b,\beta) = \begin{bmatrix} 0,1,0 \\ \cos\beta,0,\sin\beta \\ -\sin\beta,0,\cos\beta \end{bmatrix}, U(c,\lambda) = \begin{bmatrix} 0,0,1 \\ \cos\lambda,-\sin\lambda,0 \\ \sin\lambda,\cos\lambda,0 \end{bmatrix} \tag{2}$$

Through the formula, we can find that the translation transformation does not change the characteristics of the bounding box in the fixed direction.

(4) Space division method

The space division method is very suitable for the environment where the position of objects in the virtual space does not change much and is evenly sparsely distributed. It can easily exclude disjoint objects from a large number of objects. Based on the uniform position arrangement characteristics of uniform grid division, the coordinate value of the grid single selection can be quickly obtained. Based on the consideration of the performance of the partitioning algorithm, the size selection of the uniform grid becomes very important. When the size of the object is large and it is divided by different grid units, once the object is displaced, the update of the data will become very complicated. The octree space division method is a typical adaptive space division method. The BSP tree collision detection algorithm is the most common type of space division algorithm.

(5) There are two main schools of research on collision detection algorithms: the field of graphics and the field of computational geometry. The commonly used collision detection algorithms are as follows:

1) Collision detection algorithm based on the geometric representation of the object

The collision detection algorithm of polyhedron can be classified as a linear programming problem. The preprocessing algorithm can establish the hierarchical representation structure of the polyhedron within a certain period of time. The implicit surface is a surface represented by an implicit function, that is, an implicit function is used to represent the internal and external functions of collision detection. The collision detection algorithm of structural solid geometry only needs to see whether the intersection of the corresponding geometries of the two CSG models is empty. The non-polygonal model must accurately calculate each point in the intersection curve of the two surfaces, and the stability of the algorithm must also be taken into account.

2) Continuous collision detection algorithm based on time zone

The so-called space-time body is a four-dimensional concept. Given an object P, there is a position function Γ, given time as a parameter. $\Gamma(t)$ returns a transformation matrix. That is to say, at time t, the geometry P becomes:

$$\{e | \ni w, w \in P, e = \Gamma(t) w\} \tag{3}$$

This mathematical expression allows us to make a formal definition of the so-called "push" operation. Define the corresponding "push operator" as:

$$P_o(\Gamma, S) = \{(e,t) | e \in \Gamma(t)(S)\} \tag{4}$$

3) Trajectory parameterization

If the trajectory of the object is expressed as time, it can be determined whether a collision has occurred. Assuming that the starting point is Q and the end point is Q, whether this point intersects the triangle Q_0, Q_1, Q_2 that is the vertex, only a vector equation needs to be solved, namely:

$$Q + (Q - Q)t = Q0 + (Q_1 - Q_0)s + (Q_2 - Q_0)r \tag{5}$$

2.3. Collision Detection in Virtual Assembly System

(1) Virtual assembly

Virtual assembly technology uses the virtual environment provided by virtual reality technology to put assembly engineers in a virtual environment. The assembly designer can directly verify the assemblability of the product, or consider the maintenance of the product.

The virtual assembly system is a computer-aided design tool. Like various general CAD systems, designers can use this system to model and assemble products, and can also assist designers in making reasonable evaluations of product designs.

In addition to rigid parts, the parts in the virtual assembly system also have flexible parts, such as plastic parts or rubber parts. At the same time, there are also objects that have the properties of rigid bodies and do not deform, but the overall shape can be changed.

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The basic composition of the virtual assembly system is shown in Figure 1:

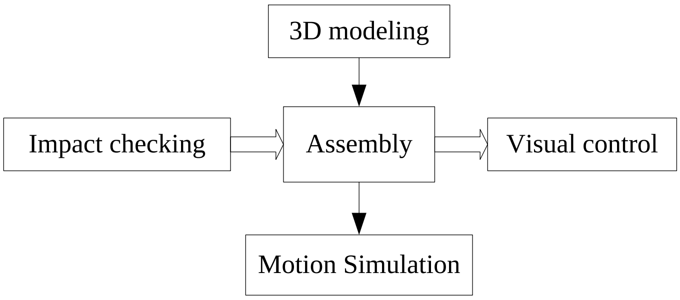

Figure 1: Virtual Assembly System Process

The first step of virtual assembly is to construct a virtual model of the part in the virtual assembly system, and its construction is generally completed through a specialized CAD system. X3D is a new generation of WEB 3D graphics standard, which can be used to create interactive 3D virtual scenes. The operating system library is a general operating system library. After the solid model is established with 3D software, the data needs to be imported into VC.

(2) Collision detection

In the process of virtual assembly, the correctness of the product structure or part structure and size design and the rationality of the assembly sequence of the parts are judged by checking whether the parts collide. There are two kinds of collisions in the virtual assembly process: collisions between parts and collisions between assembly tools and parts.

(3) Realization of collision detection in virtual assembly system

After establishing a three-dimensional model of the part, the model information is obtained through the interface module, and the collision detection algorithm of the previous study is used to perform collision detection on the part in the virtual assembly process

2.4. Random Collision Detection Algorithm Based on Particle Swarm Optimization

(1) Particle swarm optimization algorithm

The particle swarm algorithm regards the individual as a particle without mass and volume in the S-dimensional space. The optimal position of the particle at the current moment can be determined by the following equation:

$$S(\mathrm{t}+1)=\begin{cases} S(t), if, g(A_i(t+1) \geq g(S_\mathrm{i}(t) \\ A(t+1), g(A_i(t+1) \prec g(S_i(t) \end{cases} \quad (6)$$

The user can set the limit of the maximum speed and position of the particles according to different needs.

(2) Application of particle swarm in random collision detection algorithm

The key issues that need to be solved when applying particle swarm optimization algorithm to collision detection are the establishment of particle swarm search space, the determination of fitness function, and the adjustment of particle flight speed and position update. Each particle in the search space has its own position and velocity before the optimization search is performed. When the initial position before the search optimization starts, the current best position of the particle is the first position it will move. In the random collision detection algorithm, the position of the particles needs to be updated in real time, and each particle has a fitness value. The speed of the particles is constantly changing in the virtual scene, and the particles will change with changes in the global or individual optimal positions.

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3. Performance analysis of Collision Detection Algorithm

3.1. Development Environment

(1) Hardware platform:

CPU: T6400

Memory: 6G

Hard disk: 1000G

Graphics card: NVIDIAFX/4400

(2) Software platform

Operating system: windows XP

Development tools: Visual Studio 2018

Development platform: Open SQ

3.2. Experimental Scenario

This article will test the cuboid in motion. Use moving objects to detect collisions in real time. In the course of the experiment, the number of moving objects is kept within 1000, which is used to compare the time consumption of collision of objects. Collect experimental data and perform statistics on moving objects, number of collisions, and time spent. Finally, analyze the performance of the algorithm from the data.

4. Performance test of Collision Detection Algorithm Based on Particle Swarm Optimization

The cuboid collision data sorted by experiments, and the collision information between objects based on the particle swarm collision detection algorithm are shown in Table 1:

Table 1: Object Collision Information Based on Particle Swarm Algorithm

	Number of objects	Number of collisions	Number of frames executed	Time Per Image
Group1	60	11265	1355	0.01625
Group2	120	35611	1065	0.01764
Group3	180	65482	1156	0.02546
Group4	240	237163	1457	0.05463

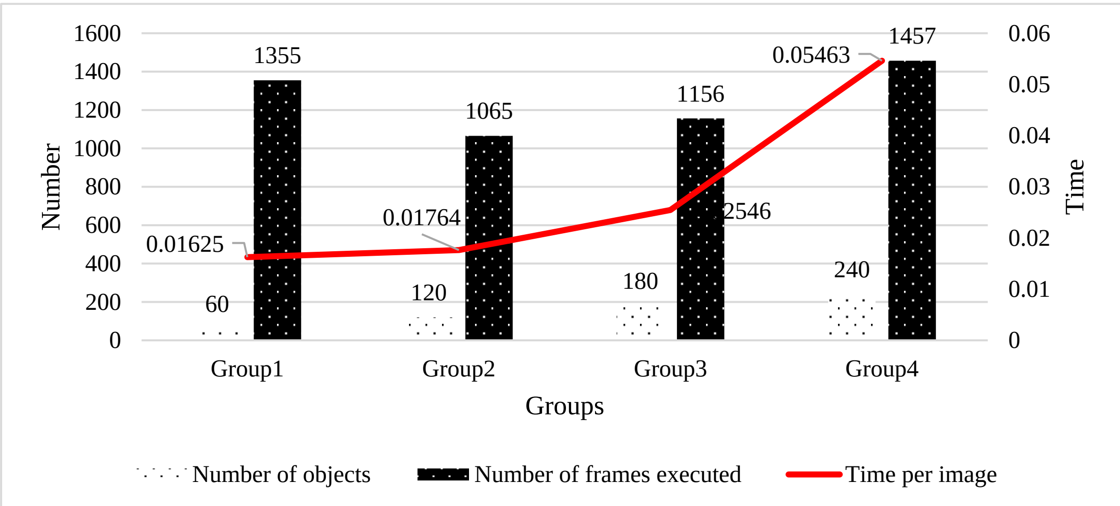

Figure 2: Object Collision Information Based on Particle Swarm Algorithm

As shown in Figure 2, when there are a large number of moving object models in the virtual scene,

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the average time consumption of collision detection per frame increases. The collision time of the data obtained by using the particle swarm algorithm is controlled within 1 second, which shows that the improvement of the particle swarm algorithm makes the bounding box play a great role in the timeliness of collision detection.

5. Conclusion

This paper studies the key issues of real-time collision detection, that is, the research on collision detection algorithms and methods. From the related theories of virtual reality technology and systems, this paper finds that collision detection is a key link in virtual technology. Collision detection algorithms can be studied from the geometric representation of objects, continuous collision detection algorithms based on time regions, and trajectory parameterization. The experiment in this article is mainly to test the optimization method of particle swarm algorithm in collision detection. The experimental results prove that the timeliness of the particle swarm optimization algorithm in real-time collision detection experiments can be guaranteed. Therefore, for collision detection in a virtual environment, particle swarm algorithm and other methods can be used to make judgments. Although the research in this article is not precise enough, it can still provide a reference for collision detection research.

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