A New K-DOPs Collision Detection Algorithms Improved by GA*

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Abstract. In collision detection algorithm based on bounding volume hierarchies, the update cost of the bounding volume hierarchies tree when the collision detection object motion or deformation directly influenced speed of collision detection. According to this trait, the update of bounding volume hierarchies was optimized by utilizing temporal-spatial coherence in virtual environment, to reduce the cost when the collision detection object motion or deformation that coused the update of the bounding volume hierarchies tree by using the genetic algorithm instead of traditional approximate method and improve the speed of collision detection greatly. The emulation experimental of the collision between cars show that this algorithm can solve the complexity and improve the property of the collision detection algorithm effectively.

Keywords: collision detection, bounding box, K-DOPs, genetic algorithms(GA), virtual reality.

1 Introduction

The collision detection is the base of interaction between dynamic objects and static objects or dynamic objects and dynamic objects in virtual environment. Collision detection is such an important issue in the fields of computer animation, physical simulation, computer graphics, virtual reality, and so on. The fast and precise collision detection has a vital role in improving the authenticity and increase customer immersed sense of the virtual environment. And the virtual environment own

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complexity and real-time, that put forward higher request for collision detection. The key problem of the collision detection is that how to improve the real-time and accuracy whom are contradictory, need to consider the equilibrium relationship of them according to the need. Many experts and scholars come from home and abroad have already had a productive research and application for collision detection problem[1-2].

The frequently-used algorithm of the collision detection fields can be mainly divided into three categories: bounding box algorithm, distance algorithm and space subdivision algorithm[3].The bounding box algorithm is the most widely used, such as: AABB, spherical hierarchies, OBB, K-DOPs algorithm etc. The tightness of AABB is poor, but the overlap test is simple; The tightness of spherical hierarchies is worst, seldom use; The tightness of OBB is good, but the randomicity of OBB direction makes the overlap test complex; K-DOPs' tightness is better than AABB, and it's complexity of overlap test is less than OBB, so K-DOPs has already admittedly been the better collision detection method that had been widely used.

Yingmei Wei [comes from NUDT (National University of Defense Technology)] used the temporal-spatial coherence of the virtual environment object to accelerate collision detection on the basis of bounding box algorithm. She puts forward a kind of traverse tracking strategy: track the traverse process of the current object in other active object tree last time point, then make sure the traverse way of the active object current time. Optimized the K-DOPs tree using the temporal-spatial coherence of the virtual environment object, reduced the bounding box number greatly, thus improved the efficiency of collision detection effectively[4]. Later, a collision detection algorithm based on parallel is presented by Wei Zhao, Jilin Agricultural University, which mainly uses the partition strategies to build the balanceable bounding box tree, traverse the assignment tree comprises the bounding box tree, using the pipelining to accelerate the collision detection, and this algorithm can be in common used on both monoprocessor and multiprocessor[5]. In this paper, it can reduce the cost when the collision detection object motion or deformation that coused the update of the bounding volume hierarchies tree by using the genetic algorithm instead of traditional approximate method and improve the speed of collision detection greatly.

2 Rationale

2.1 Definition of K-DOPs

K-DOPs (Discrete Orientation Polytopes) bounding box is a kind of convex polyhedron, it's surface is composed of a set of half space Hi determined, these half space can so said: $H_i=\{x\in Rm|nTix\leq b_i,n_i\in N,b_i\in R\}$, type: n_i are the outer normal vectors of the half space, which are discrete, and they constitute the set N= $\{n_1, \ldots, n_k\}$. In order to detect overlapping polyhedra into simple interval test, usually choose k/2 vector pairs , collinear and opposite in direction, as the element of set N, therefore, actually there are only k/2 direction in K-DOPs, thus it just need k/2 times interval test in 2 K-DOPs' detect overlapping[6]. Because of that these k/2 directions are settled and foreseeable,

it's needless to save these directions when we should save a K-DOPs, only k numerical values should be saved, every numerical value corresponds to the position of one plane.

There are four K-DOPs (6-DOPs, 8-DOPs, 14-DOPs, 18-DOPs) of different direction vector listed in figure 1.

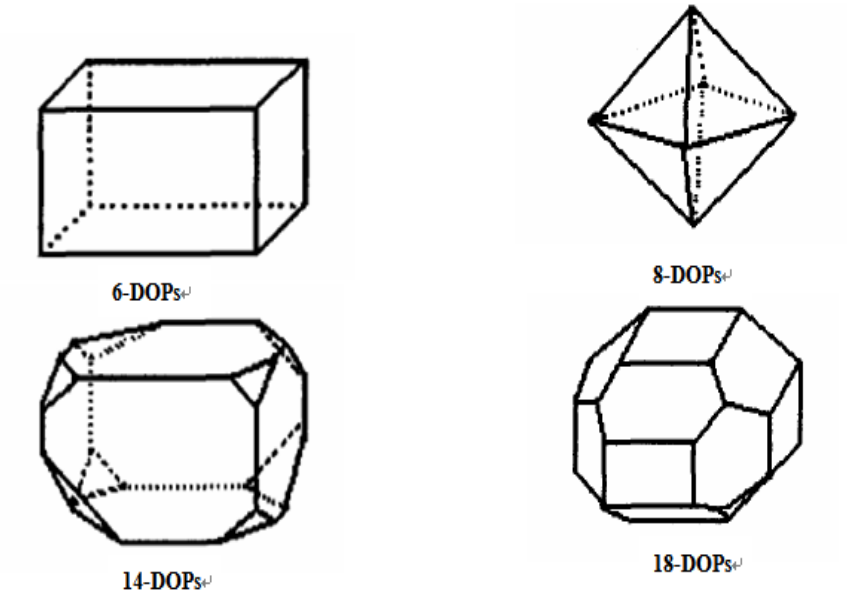

Fig. 1. K-DOPs of different direction vector

2.2 Intersection Test of K-DOPs Bounding Box

The intersection test of K-DOPs bounding box can be accomplished by overlap testing of the projections, we can determine the 2 K-DOPs bounding box are not intersectant if their projections in a certain direction of N are not overlapping; if all of the projections in any direction of N are overlapping, consider conservatively them are intersectant[7].

Presume that we had built two bounding box trees for objects A and B respectively. In the bounding box tree, the bounding box on every node correspond to a subset of the set which is comprised of the basal geometrical element of the object, the root node is the bounding box of the whole object[8]. Through traverse the two trees effectively in order to make sure whether some parts of object B collide with some parts of object A current location. This is process of double traverse. Algorithm let the root node of the object B's bounding box tree traverse object A's bounding box tree firstly, if reach a leaf node, then let this leaf node traverse object B's bounding box tree. If it can reach object B's leaf node, then do the intersection test of the basic geometrical element further. The basic idea is that use the bounding box of simple geometric characteristic symbols instead of the complicated geometry object to intersection test, if the bounding boxes of the two nodes are not intersect, the subsets of their basic geometrical element are not intersect, thus it has no use for intersection test to the elements of the subsets further.

The implementation algorithm of K-DOPs collision detection is under: (for example while K=2)

```
Void CollisionDetection(K-DOPs Tree)
{
  if (p_Root->angle< π /2)
     {
    return;
   }
   else
   {
    if (p_Root->p_FirstChild->angle> π /2)
    {CollisionDetection (p_Root->p_FirstChild)
    }
    if (p_Root->p_SecondChild->angle> π /2)
{CollisionDetection (p_Root->p_SecondChild)
    }
    if(*p_Child1=Max(p_Root->p_FirstChild->angle,p_Root->p_SecondChild-
>angle)<= π /2&&*p_Child2=SecondMax(p_Root->p_FirstChild->angle,p_Root-
>p_SecondChild->angle)<= π /2)
      CollisionDetection(p_Child1,p_Child2);
    }
   }
```

2.3 Updating of K-DOPs Tree

Because of that the shape of deformable objects would vary continually in the simulation process, the creating bounding box tree quondam would be disabled after every simulation time step and it's need to update. There are two methods to complete the updating for the bounding box tree:

(1) Rebuilding. Rebuild bounding box tree on the basis of the new position of the basic geometric element, the combination condition of these elements would vary if we use the top-down generator function. The generative process is time-consuming especially when the model is meticulous, so the weakness of this method is obvious, the calculation burden is too hard to be fit for real time application and interactive application.

(2) Updating. Saving the element's combination condition of the current bounding box tree is just that update the bounding box which is contained in the all nodes of the tree, thereby update the total bounding box tree. The speed of this method is very fast but it also has a shortcoming: it would make the bounding box incompact and affect the efficiency of collision detection[9-11].

2.4 Genetic Algorithms(GA)

Genetic algorithm is presented by an American scholar Holland J H. The GA is a computation model that simulate the evolutionaryprocess of biological in nature. Its essence is parallel, it does not require derivation or other auxiliary knowledge, only

need to determine the objective function of search direction and the fitness function of response, it emphasizes that transform probability to rule, but not determinate rules of conversion.

When solving problems by genetic algorithm, at first create a group of initial candidate solutions of the problem randomly, namely the initial population; Every individual in a population (each solution) should be transformed to binary code, such a binary code is called a chromosome; then calculate each individual's fitness, eliminate the individuals of smaller fitness. Then must inject the same numbers of population, what is copied the population of bigger fitness, to ensure the number of population is stable. In order to that the population should create new individuals to make the population evolve endlessly, two operators crossover operator and mutation operator are presented. Crossover operator imitates the hybridize theory of biology, interchange saome chars (gene) between two individual chromosomes, it's the main tool to create new individuals; Mutation operator is another method to create new individuals in GA, it's a complementation operation to the chars means that the mutation of certain gene in the chromosome, change 0 to 1,or 1 to 0. The GA is a searching method of reiterative iteration, it approaches optimal solution step by step through evolving repeatedlily, not equal to the optimal solution exactly, so it need to make sure termination conditions. For the termination conditions, some rule the evolution (iteration) times, the iteration should be stop when the iteration times was bigger than the specified value; another some estimate the optimal individuals, the iteration should be stop when the maximum fitness of the population should be invariable[12-14].

Genetic algorithm takes the methods of exchange, duplication, mutation and so on without calculating the derivate of function to get the global optimal solution of search. In a sense, it's a kind of black box problems which just considers the input and output of it that is suitable for dealing with all kinds of complicated problems. For its unique characteristic, the genetic algorithm has been widely used in every field.

3 Algorithm Analysis

In the complex virtual environment, objects are constantly moving, when objects were changing in space position, it need to make corresponding conversion for the object bounding box to real-time update K-DOPs tree. For rigid object speaking, it's movement is divided into two categories: translation and rotation. When the object translation moves and you do the same translation conversion for the bounding box, you will get the bounding box in a new position[15]. Occurred when the object rotation, the new position can't get through simple rotation transformation. If you recalculate the object bounding box ,it will spend a very long time. As for the K-DOPs tree of the update, the traditional method is to use a kind of approximation method: calculate the bounding box of the object's when the object would rotated to get the current condition of K-DOPs object bounding box an approximate. Then the approximate form for the new K-DOPs bounding box tree, it need to use the current activity objects from the roots of a tree node to traverse other activities object tree. There would often be some repetitive traverse process that increase unnecessary spending to collision detection algorithm.

The Motion Paths of the kinetic object in virtual environment is consecutive: when one object collide with another object at a certain time point, they should still possibly

collide at next time point, the point of colliding should be nearby the last[16]. According to the temporal-spatial coherence in virtual environment, this paper proposes that the GA is applied to update process of K-DOPs bounding box tree when the object would been athletic, it can reduce the cost when the collision detection object motion or deformation that coused the update of the bounding volume hierarchies tree, thus improve the speed of collision detection greatly. The specific solving process is as follows:

① Initialize the controls parameter of GA, such as: the scale of population N, the probability of mutation pm, the probability of crossover pc.
② Randomly engender the initial solution population p(t)={p0 p1 p2…pn}, the number of individuals is definite, every individual expressed as the gene coding of the chromosome.
③ Calculate the fitness of every individual in population. Search by utilizing the fitness of every individual. The solution is dependent on the fitness, the fitness larger means to the solution better.
④ Choose to copy the individual according to the fitness, the fitness larger means that the probability to copy should be larger.

The choosing process is a kind of select the superior and eliminate the inferior process that based on fitness, it means that select the superior and eliminate the inferior from the population on the basis of fitness, in order to make sure the group or intersectional individual and how many offspring should be copied from the individual had been chosen.

⑤ Do intersecting operation to the existing solution population to get new individual according to certain mutation probability and mutation method.
⑥ Do mutation operation to the intersected individual according to certain mutation probability and mutation method.
⑦ Get a new population by intersecting operation and mutation operation, end the evolutionaryprocess if it settles for the convergence prerequisite, else turn to step ③.

By using this algorithm, when the collision detection object motion or deformation result to update the K-DOPs bounding box tree, just need to traverse from the parent node of the current node in the active object tree, not must to traverse from the beginning of the root node just like the traditional approximate method. Such that we should avoid some repeating and same ergodic process, reduce the dispensable cost, and improve the speed of K-DOPs greatly.

4 Experimental Result and Performance Analysis

An emulational testing scene of the collision between two cars (figure 2、3 shows) is built to analyse the algorithm's performance and characteristic. The experiment uses a PC (Pentium(R)Dual-Core/CPU, E5300, 2.60GHz, 2.0GB), the operating system is Windows XP professional, the simulation program was developed using Microsoft Visual C++6.0 and OpenGL was used for 3D scene rendering and animation to simulates collision detection, self collision detection and collision response of cars. The simulation testing and verify that firstly the collision detection arithmetic

improved in this paper is viable, secondly the real-time and the veracity of collision detection had been improved, in addition, the simulation realizes the interactivity in virtual environment preliminarily.

Fig. 2. The collision detection of cars Ⅰ

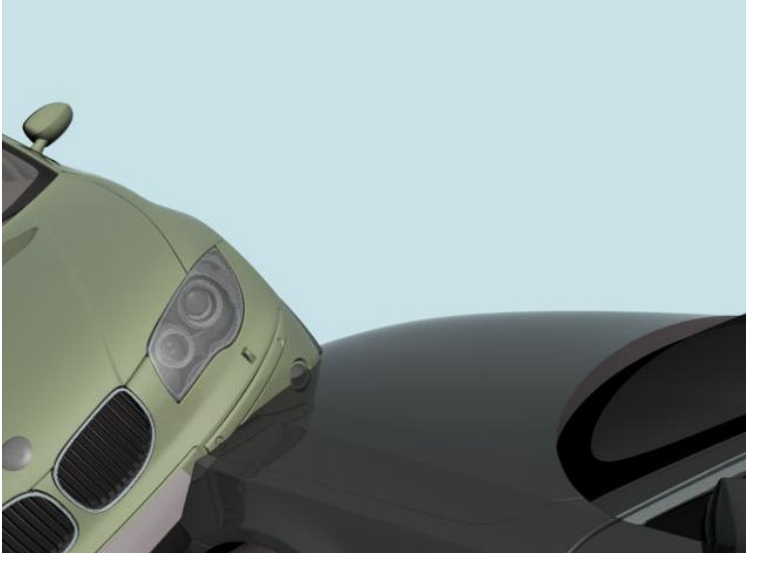

Fig. 3. The collision detection of cars Ⅱ

Figure 4 and figure 5 displayed the areal models of the cars front and back whether the collision happened by using anomalous polygons to indicate the plane projection of the two cars' model.

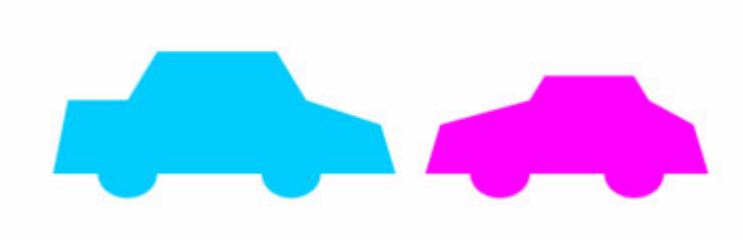

Fig. 4. The areal models of the cars before the collision happened

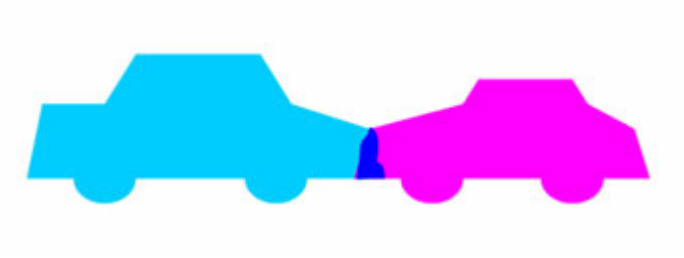

Fig. 5. The areal models of the cars after the collision happened

In order to test and verify the effect of the improved algorithm before, the cars' simulated-time of collision process had been contrasted in front and back of improved. The specific method n front and back of improved just as table 1 shows.

Table 1. The instruction for the methods in front and back of improved

	update policy of bounding box tree
the former algorithm	nearness algorithm
the improved algorithm	genetic algorithm

Describe the complexity of the collision detection object in the number of geometric element (triangle facets), table 2 shows the average collision detection time of deal with one frame of patterning with the two methods of different complexity objects, for collision detection, self collision detection and collision response.

Table 2. The average collision detection time of deal with one frame of patterning

Complexity (the number of triangle facets)	1000	1400	1800	2200	3000
The former algorithm	15.823	18.572	19.341	20.457	21.690
The improved algorithm	15.535	18.164	18.761	19.896	20.974
The percentum between the former algorithm and improved algorithm	98.2%	97.8%	97.0%	97.3%	96.7%

The two methods' change situation of average collision detection time ,with the complexity increasing in the emulational testing scene of the collision between cars, in front and back of improved algorithm, had been displayed in figure 4. Figure 5 had display that the contrast of the collision detection time between the algorithm was presented in this paper and the classic hill-climbing algorithm. The ascensional velocity of the algorithm was presented in this paper is slower, it means that the algorithm was presented in this paper, the improved K-DOPs collision detection algorithms based on genetic algorithms, has biggish increase, in the same complex scene.

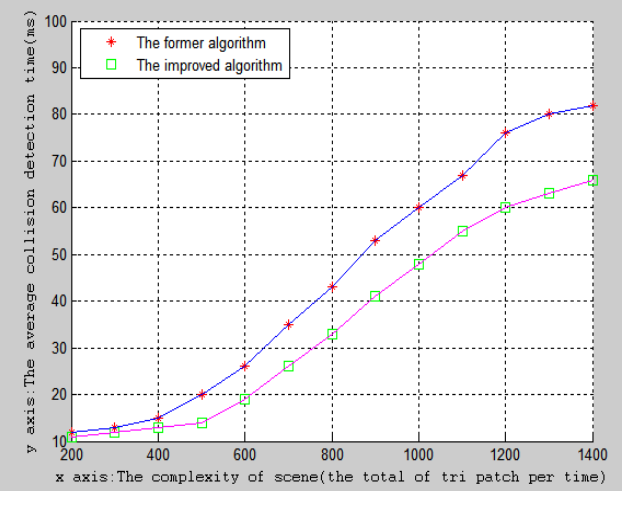

Fig. 6. the contrast of the collision detection time in front and back of improved algorithm. X axis: the complexity of scene (the total of tri patch per time); Y axis: the average collision detection time (ms).

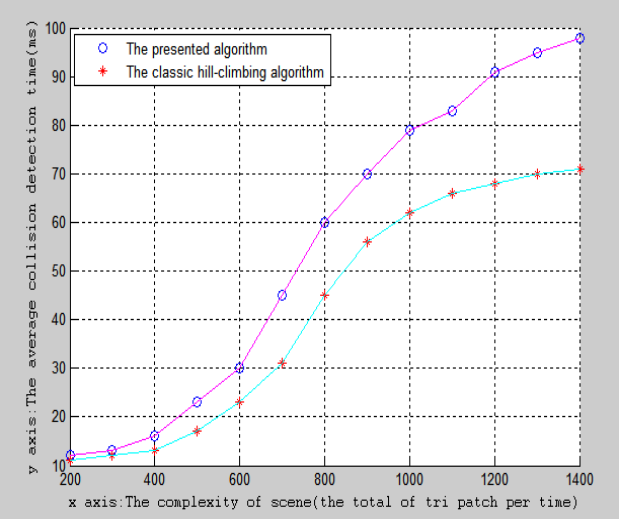

Fig. 7. the contrast between the algorithm that presented in this paper and the classic hill-climbing algorithm. X axis: the complexity of scene (the total of tri patch per time); Y axis: the average collision detection time (ms).

5 Peroration

The paper find illumination in the temporal-spatial coherence in virtual environment, using the genetic algorithm instead of traditional approximate method when the collision detection object motion or deformation that coused the update of the bounding volume hierarchies tree, thereby improve the speed of collision detection greatly. The experiment attests that this algorithm could handle arbitrary variform polyhedron efficaciously, it should cut the collision detection time down by using the GA to update the bounding box tree, and it's suitable for dynamic, complex, interactive scene for real-time collision detection.

Of course, this algorithm still exist some disadvantages and await perfection further. The major future job is to improve the algorithm further aim at crossover rate and mutation rate, to get better balance between fast convergence and global optimum, in order to settle the computational complexity problem of the collision detection and ameliorate the performance of the collision detection more effective in the virtual environment.

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