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Collision Detection of High Density Point Set Based on Convex Hull

Peihe Tang，Lianyuan Jiang，Hao Liu
Department of Computer Engineering,
Guangxi University of Technology
Liuzhou Guangxi 545006, China
E-mail:tangpeihe@163.com, jly_jly_jly@163.com, lqzh505@163.com

Abstract—**This paper presents a collision detection algorithm of high density point set based on convex hull. According to the characteristics of the point set tightness, a fast speed convex full algorithm is designed. If extremums can't define un-collision, convex hull of the await collision detection point set and intersection of the convex hulls are calculated. If they disjoint, the two point sets don't collide; if they intersect, we search for the collision point set in the intersection set region of the two convex hulls. The algorithm is simple, high-efficiency and reliable. It has the certain application value for education, defense and art.**

*Key words—**collision detection; convex hull; high density point set; extremum***

I. INTRODUCTION

Virtual environment has become an important research field of computational science, it is applied in many fields such as, education, national defense, medicine，art, entertainment and so on. Virtual environment modeling is more complex than traditional CAD and animation modeling, because it is not enough only geometric modeling to virtual objects, its behavior rule and physical property have to be described. The collision detection between virtual objects is the key problem in behavior rule and physical property, for increasing immersion and realistic of virtual environment the fast and efficient collision detection is essential and important.

In the mass, collision detection algorithm could be divided into two sorts which are space partition technique and hierarchical bounding boxes, and hierarchical bounding boxes is applied more widely, it suits in complex environment collision detection. The basic idea of collision detection based on bounding box is using simple geometrical bodies to replace complex and various geometrical bodies, first of all simply detecting objects’ bounding boxes, only when their bounding boxes intersect then geometrical bodies could be intersecting, otherwise geometrical bodies could not be intersecting, then great deal geometrical bodies not intersecting can be quick eliminating. Typical bounding boxes types are listed below: axis-aligned bounding boxes[1], sphere[2], oriented bounding box[3], fixed directions hulls[4], discrete orientation polytopes[5] and so on. In this paper, convex hull is applied into collision detection of high density point set, and a collision detection algorithm of high density point set based on convex hull is presented.

II. PRINCIPLE OF COLLISION DETECTION

Collision detection is to detected the collisions between various objects in virtual environment, and the key point is solving the conflict between teal-time and accuracy in collision detection. And different application situation, the requirement of real-time and accuracy are different.

In term of considering time parameter, collision detection can be separated into continouslly collision detection(CCD) and discrete collision detection(DCD). The algorithm of sequential collision detection is too complex, in reality collision detection algorithm always be simplified by sacrificing the calculation accuracy to increasing the calculation speed, only some discrete points in time axis be considered. The specific methods are as

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follows: calculating out the next time position, direction and so on moving state of all objects in environment, and don't move objects into new state, but detecting if there is object overlapping with others in new state, then judge if collision happens, and that is called discrete collision detection. This method only detects the potential collision in the discrete time point, if objects moving too fast or time point distance is too long, an object could absolutely cross another one, which is called penetration phenomenon. Ways to figure it out are: ①Restraining object speed, ② Reducing time interval of discrete sampling, ③ Restraining objects motion state (speed, direction, acceleration and so on), detecting objects motion track.

If intersecting could be detected immediately and adjust two objects position, then collision can be eliminated when it happens, therefore adding collision detection functions when objects moving is the basic method of collision detection. Following example presents the algorithm of objects moving with collision detection:

while *system is running*

  for *every entity of virtual environment*

    e.old_position= e.current_position;

    according to e speed and other factor adjust e.current_position;

    if *e collides with other entity then*

      e.current_position= e.old _position;

      adjusting position.

III. CALCULATING CONVEX HULL OF HIGH DENSITY POINT SET

This paper uses convex hull as a bounding boxes in high density point set collision detection and the minim time complexity of convex hull algorithm of a planar set as O(nlogn)[6,7]. In order to described easier, definition has been given as below. As Fig. 1 displays, in minim set of abscissa of point set, the maxim point of ordinate is V_{xY}, the minim point of ordinate is V_{xy}; in maxim set of point set of abscissa, the maxim point of ordinate is V_{XY}, the minim point is V_{Xy}; in the minim set of point set of ordinate, the minim point of abscissa is V_{yx}, the maxim point of abscissa is V_{yX}; in the maxim set of point set of ordinate, the minim point of abscissa is V_{Yx}, the maxim of abscissa is V_{YX}; these eight points are called convex hull of the set. Anticlockwise arraying vertex sequence of the convex hull, videlicet $P=\{V_{xy},V_{xy+1},\ldots,V_{yx-1},V_{yx},\ldots,V_{Xy-1}, V_{Xy},\ldots,V_{YX-1},V_{YX},\ldots,V_{xY-1},V_{xY}\}$, then property below can be easy given.

property 1: The slope of beeline sequence of edge of Convex hull P $V_{xy}V_{xy+1},V_{xy+1}V_{xy+2},\ldots,V_{yx-1}V_{yx},\ldots,V_{Xy-2}V_{Xy-1}, V_{Xy-1}V_{Xy}$ monotone increasing, the slope of beeline sequence of edge of $V_{XY}V_{XY+1},V_{XY+1}V_{XY+2},\ldots,V_{YX-1}V_{YX},\ldots, V_{xY-2}V_{xY-1},V_{xY-1}V_{xY}$ monotone increasing either.

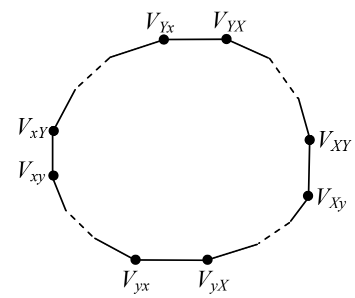


Fig. 1. Eight extreme points

Proof: Denote the coordinate of V_i by (V_{ix},V_{iy}), to any three border upon points $V_iV_jV_k$ of peak sequence $V_{xy},V_{xy+1},\ldots,V_{yx-1},V_{yx}$, there must be $V_{ix}<V_{jx}<V_{kx}$ 、 $V_{iy}>V_{jy}>V_{ky}$, through property of convex polygon. As $V_{ix}<V_{jx}<V_{kx}$ 、 $V_{iy}>V_{jy}>V_{ky}$, it can be known that the inclination angles of line V_iV_j、V_jV_k must in the area of $(\pi/2,\pi)$, and the inclination angles of V_iV_j must less then line V_jV_k, then the inclination angles of line sequence of $V_{xy}V_{xy+1}$, $V_{xy+1}V_{xy+2}$, …… ,$V_{yx-2}V_{yx-1}$, $V_{yx-1}V_{yx}$ monotone increasing in turn. Moreover in range of $(\pi/2,\pi)$, slope increasing as the inclination angles, so the slope of line sequence of edges $V_{xy}V_{xy+1},V_{xy+1}V_{xy+2},\ldots,V_{yx-2}V_{yx-1},V_{yx-1}V_{yx}$ monotone increasing and all be negative numbers. Proving by the same methods, the slope of line sequence of edges $V_{yX}V_{yX+1}$, $V_{yX+1}V_{yX+2}$, … ,$V_{Xy-2}V_{Xy-1}$, $V_{Xy-1}V_{Xy}$ monotone increasing and all be positive numbers. But(→And) if line $V_{yx}V_{yX}$ exists, its slope must be zero, therefore the slope of line sequence of edges $V_{xy}V_{xy+1},V_{xy+1}V_{xy+2},\ldots,V_{yx-1}V_{yx},\ldots, V_{Xy-2}V_{Xy-1},V_{Xy-1}V_{Xy}$ monotone increasing.

Proving by the same methods, the slope of line sequence of edges $V_{XY}V_{XY+1}, V_{XY+1}V_{XY+2}, \ldots, V_{YX-1}V_{YX}, \ldots, V_{xY-2}V_{xY-1}, V_{xY-1}V_{xY}$ monotone increasing. Therefore proposition is true. Justified.

The algorithm of convex hull of high density point set R as shown below:

STEP 1: *Calculating out the minim abscissa r_{xmin} and maxim abscissa r_{xmax} of point set R, let $Maxlen=r_{xmax}-r_{xmin}+1$.*

STEP 2: *Defining array point[Maxlen][4], the point value of row of array subtracts r_{xmin}; the 1(2) column of array stores all the abscissa(ordinate) of points with the same abscissa which ordinate is the maxim. The 3(4) column stores the abscissa(ordinate) of points with the minim ordinate.*

STEP 3: *Orderly link the points with maxim ordinate of apiece abscissa and the points with minim ordinate, a polygon can be drew. If some maxim or minim points of abscissa corresponding ordinate don't exist, then skip.*

STEP 4: *On the basis of property 1, the convex hull of set can be figured out by orderly comparing the line slope of adjacent sides of polygon and removing the points not in convex hull and backtracking at the same time.*

According to the above convex hull algorithm calculations to a great deal of high density point set, all can be figured out quickly.

IV. COLLISION DETECTION ALGORITHM OF HIGH DENSITY POINT SET

Definition 1: Set two point sets are $R=\{r_0, r_1, \ldots, r_{k-2}, r_{k-1}\}$ and $S=\{s_0, s_1, \ldots, s_{l-2}, s_{l-1}\}$, if point r_i exists in R, point s_a exists in S, and r_i is the 8-neibourhood point of s_a or r_i overlap with s_a, then point R collides with S, otherwise not.

Following example depends on the collision detection of two point sets R and S that explains the collision detections of more point sets are the same. Set the whole system detecting time of collision detection of two point sets R and S is t_e, time alternation of detection is Δt, the initial value of current hour t is zero, recording the convex hulls of point sets R and S are P and Q, C is the intersection of P and Q, the subset of point set R in C presented by R_c, the subset of S in C presented by S_c, the minim abscissa of point set $R(S)$ recorded as $r_{xmin}(s_{xmin})$, the maxim abscissa recorded as $r_{xmax}(s_{xmax})$, the minim ordinate recorded as $r_{ymin}(s_{ymin})$ and the maxim ordinate recorded as $r_{ymax}(s_{ymax})$, these four value are called as 4 extreme value of point set $R(S)$.

If situations below exist, $r_{xmax}<s_{xmin}$、$s_{xmax}<r_{xmin}$、$r_{ymax}<s_{ymin}$ or $s_{ymax}<r_{ymin}$, then point set R doesn't collide with S. Otherwise, calculating the convex hull P and Q of two point sets, using marching method to judge the intersection of P and Q[8], if they don't intersect that tells there isn't collisions between two point sets, otherwise searching collision sets in the field of intersection of two convex hulls.

The algorithm of collision detection of high density point set shown as below:

STEP 1: *If t is less than t_e, goto STEP 2; else detection finish, algorithm is over.*

STEP 2: *Updating the 8 extreme value of two point set and comparing them, if no collision, goto STEP 5; else, goto STEP 3;*

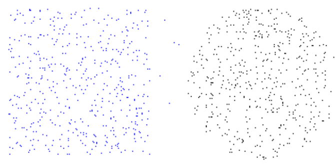
STEP 3: *Updating convex hull P and Q, running intersection operations to P and Q. If P intersects with Q, then updating C、R_c and S_c, goto STEP 4; else no collision between R and S at time t, goto STEP 5;*

STEP 4: *Judging 8-neibourhood and overlap to every point in R_c with every point in S_c. If 8-nerbourhood or overlap happens, recording these points as collision point set, system goes into collision response processing, goto STEP 5;*

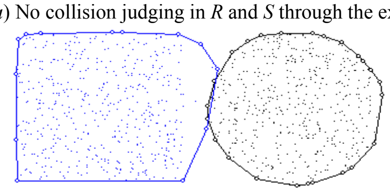
STEP 5: *$t=t+\Delta t$, system goes into collision detection at the next time, goto STEP 1.*

V. Experimental Results

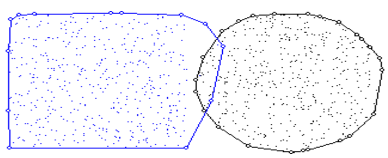
To verify the effectiveness of the algorithm in this paper, a huge deal of simulation experiments have been done, and the results of experiments shows that the experimental results indicate that the algorithm has a high efficiency. Due to the limited space, only an example has been given. Fig. 2(*a*) shows the situation of no collision judging in two point set *R* and *S* through the extreme value comparison, Fig. 2(*b*) shows the situation that convex hull *P* intersects with *Q* but *R* doesn't collide with *S*, Fig. 2(*c*) shows the situation that *R* collide with *S*.



(*a*) No collision judging in *R* and *S* through the extreme



(*b*) convex hull *P* intersects with *Q* but *R* doesn't collide with *S*



(*c*) *R* collide with *S*

Fig. 2. Experimental results of collision detection

VI. Conclusion

This paper gives the researching of collision detection of high density point set, an algorithm of collision detection of high density point set based on convex hull is given. Using the storage space with length of $Maxlen=r_{xmax}-r_{xmin}+1$ to store the point set that could be the vertex of the convex hull, calculating this point set to find the requisite convex hull. When $r_{ymax}-r_{ymin}<r_{xmax}-r_{xmin}$, the method which classifying the same ordinate point into one side, could be used to calculate the convex hull of point set, which is the same as the method of classifying the same abscissa point into one side. Now $Maxlen=r_{ymax}-r_{ymin}+1$, storage space and the times of slope comparison calculation are reduced, but the time of calculating r_{ymax} and r_{ymin} is increased. This algorithm, which can be applied to education, national defense, art, entertainment and so on fields, also suits to the collision detection of three dimensional high density point set. As the development of computer and the further study of collision detection algorithm, new problems and treatments of collision problems will show up ceaselessly, the main content of research focus on how to figure problems out, how to increase detecting speed, reduce the engagement of memory and increase the precision of detection. The next step is to research the collision response of high density point set.

Innovation as follows: (1) A fast speed convex hull algorithm which depends on the good properties of high density point set tightness is designed. (2) Calculating intersect to the convex hull of point set, if intersection exist, no collision of two point sets can be judged, otherwise, searching the collision points set in the intersection field of two convex hulls, it reduces a lot of calculations and ensures the real-time of detection.

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