Realistic Group Behaviors Based on Visibility-Voronoi$^{(c)}$ Diagrams

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Abstract. In virtual crowd simulation, group behavior is very important, and its authenticity directly affects the authenticity of crowd behavior. This paper presents a group trajectory planning method based on visual-voronoi$^{(c)}$ diagram(VV$^{(c)}$-diagram) in which *c* represents the expected distance between group and obstacle, and VV$^{(c)}$-diagram represents the visual-voronoi diagram with gap value of *c*. In this method, VV$^{(c)}$-diagram is used to generate path diagrams with different gap information. The advantage of VV$^{(c)}$-diagram is that it can balance the length of the supporting path with the gap information and generate the required path based on the gap value c specified by the user. Simulation results show that the method based on VV(c)-diagram can generate real group behavior.

1. Introduction

Crowd behavior simulation is an important research direction in the field of computer graphics, which studies virtual human intelligence behavior from the perspective of individual emotion, psychology and group social behavior [1]. An agent group is a collection of several agents that have a certain relationship. The corresponding expression of agent group is "Group/Flock", and its behavior is also known as group behavior or flocking behavior. It is possible to have multiple groups in any one type of population.

No matter in daily life or other events, as human beings are social animals, the proportion of independent pedestrians in the crowd is small, so group behavior is universal. In virtual crowd simulation, group behavior is very important, and the authenticity of group behavior directly affects the authenticity of crowd behavior [2,3]. At present, most group behaviors lack authenticity, so how to generate various group behaviors is worth further research.

In terms of group motion planning, many researchers generate the motion trajectory of the whole group through decoupling trajectory planning for multiple leaders. However, these methods do not consider the gap information between tracks and obstacles, so the group behavior separation phenomenon is too serious [4]. To address the above problem, some researchers used a sampling strategy based on the central axis to build paths, generating paths with maximum gap information. The path diagram method based on medial axis uses the retraction method to shrink the random sampling points to the center axis of free space [5]. Other researchers use Voronoi diagrams of first or second order to plan group paths. For example, literature [6] proposed the use of second-order Voronoi diagram to generate the motion path of the intelligent group. In its method, each intelligent group can only move in its own Voronoi region, so the collision between groups can be minimized, but the authenticity of crowd movement is reduced.

In fact, "large gap" and "short path" are two conflicting indicators [7-8]. If the "path with maximum clearance" is only satisfied without paying attention to the length of supporting path, the group can move towards the target according to the central axis or Voronoi diagram, but the movement path of the group may be too long. If only the "shortest path" is satisfied , the group can move to the target according to the viewable node, but the viewable node is the vertex of the obstacle, resulting in the smallest gap with the shortest movement path, which not only looks unnatural, but also is unacceptable for the group's motion planning. Therefore, in order to give consideration to the length and gap information of the support path, this paper proposes to construct the path diagram by combining the visibility graph and Voronoi diagram in the pre-processing stage.

In our work, the visual-voronoi diagram is used to generate group motion trajectories, and the evaluation function is modified by the gap information on the edge of visual-voronoi diagram, so that the gap between groups and obstacles and the length of group motion trajectories can be balanced. It not only guarantees that the group will minimize the influence of obstacles on the group's movement, but also guarantees that the group can move to the target position as soon as possible. The method in this paper is based on the visual-voronoi diagram proposed by Ron Wein and Van den Berg[9-10] to represent the gap value of the expected group path to the obstacles, and the VV(c)-diagram represents the visual-voronoi diagram with the gap value c.

In summary, the proposed $VV^{(c)}$-diagram based group behavior generation process is mainly divided into the following three main steps:

1. First, calculate the visibility graph and voronoi diagram of the virtual environment and calculate the average clearance value of the whole environment according to the voronoi diagram. Then, according to the average gap value, the gap value c between the group and the obstacle is computed by non-uniform random methods or specified by the users.

2. $VV^{(c)}$-diagram is built using user-specified c value. Together with the visibility graph and voronoi diagram. This step is used to take into account both the length of the group path and the gap value of the group path.

3. The c value is introduced into the evaluation function to modify the evaluation function, and the modified evaluation function is used to conduct path query, and finally the query path is smoothed and the final trajectory is generated by using trajectory planning.

2. Visibility-Voronoi Diagrams

2.1. Computing the Voronoi Diagram of the Obstacle Space

We use C_{obs} to represent the obstacle space of the virtual human. The Voronoi Diagram divides C_{obs} into several Voronoi regions (VR) in which all points are less distant from one object than from another. For any element $e_i \in C_{obs}$, Its corresponding VR is:

$$VR(e_i) = \left\{ q \in \mathcal{C}_{free} \,|\, D(q,e_i) \le D(q,e_j),\ i \ne j \right\} \tag{1}$$

Voronoi diagram is the common edge of all these areas, that is, the set of equidistant points to more than two contour elements. For the vertex-vertex, edge-edge element pairs in, the Voronoi diagram generated is a straight line. For vertex-edge element pairs, the Voronoi diagram generated is a parabola. So the Voronoi diagram consists of straight lines and parabolas.

The smaller the c value, the more inclined the $VV^{(c)}$-diagram is to be Visibility Graph. When c value equals 0, $VV^{(c)}$-diagram is Visibility Graph.

2.2. Calculating the Average Gap Value of the Environment and Generating the c Value

Since the Voronoi diagram $\mathcal{V}$ consists of line segments and parabola, we represent each line segment and parabola as an object. Then $\mathcal{V}$ can be represented as:

$$\mathcal{V} = \{o_1, ..., o_K\} \tag{2}$$

in which $o_i \; i=1,\ldots,K$ represent the i-th object, K represents the number of objects. Therefore, the maximum gap value can be calculated according to the following equation:

$$c_{\max} = \max(\mathcal{V}) = \max_{i=1,\ldots,K}\left(clerance\left(o_i\right)\right) \tag{3}$$

$\max\left(clearance\left(o_i\right)\right)$ Is the maximum gap value of object o_i. The average gap value $\bar{c}$ of the whole environment can be calculated according to the following equation:

$$\bar{c} = \frac{\sum_{i=1}^{K}\left(\int_0^{L(o_i)} clearance(x)\mathrm{d}x\right)}{\sum_{i=1}^{K} L\left(o_i\right)} \tag{4}$$

in which $L\left(o_i\right)$ is the length of o_i, $clearance(x)$ is the gap value of any point on o_i.

We use non-uniform random number generation method and continuous distribution sampling method (χ^2) to generate gap values c. In order to ensure the probability of c falling within a range $\left[0, c_{\max}\right]$(set this probability as 0.9). We use $c_{\max}$ to find a degree of freedom $n_{c\_\max}$.

$$n_{c\_\max} = \arg\min_{n\in\mathbb{Z}^+}\left(\left|\chi^2_{0.1}(n) - c_{\max}\right|\right) \quad \chi^2_{0.1}(n) \le c_{\max} \tag{5}$$

Similarly, the degree of freedom $n_{c\_average}$ is obtained according to the average gap value $\bar{c}$ of the whole environment. Finally we obtain the degrees of freedom of the distribution, the mathematical expectation:

$$E\left(\chi^2\right) = \left\lceil \frac{n_{c\_average} + n_{c\_\max}}{2} \right\rceil \tag{6}$$

The aim is to take into account the influence of average gap value and maximum gap value on the generation of non-uniform random numbers. After obtaining the freedom of distributed degrees χ^2, we can use the non-uniform random number generation method to get the group gap value c.

3. Constructing Visibility-Voronoi$^{(c)}$ Diagrams

After obtaining the gap value c of the group, the construction process of VV$^{(c)}$-diagram is composed of the following three steps:

Step 1: Inflating the Obstacle Area

Because the virtual human can be simplified into a circular intelligent body with a certain length of radius. In order to simplify the construction process of VV(c)-diagram, firstly, Minkowski method are used to expand the obstacle area to transform the motion planning of the circular agent into the planning of the point-agent. Therefore, the obstacle area $\mathcal{O}$ needs to be transformed as follows:

$$\mathcal{O}' = \mathcal{O} \oplus B\left(r_0\right) = \left\{q \in \mathcal{C} : q = q_1 + q_2 \mid q_1 \in \mathcal{O}, q_2 \in B\left(r_0\right)\right\} \tag{7}$$

where, $\mathcal{O}'$ represents the obstacle area after expansion. $B\left(r_0\right)$ represents the area occupied by the circular agent.

$$B(r_0)=\left\{(x',y')\,|\,(x-x')^2+(y-y')^2\le r_0^2\right\} \tag{8}$$

Obviously,

$$\mathcal{O}'=\bigcup_{i=1,\dots,m}\left(P_i\oplus \mathrm{B}(r_0)\right) \tag{9}$$

Since we want the gap value between the path of the group and the obstacle to be c, we further inflate the obstacle $\mathcal{O}'$. The expanded barrier area is denoted as $\mathcal{O}_c$.

$$\mathcal{O}_c=\mathcal{O}'\oplus B(c)=\bigcup_{i=1,\dots,m}\left(P_i\oplus \mathrm{B}(r_0+c)\right) \tag{10}$$

The obstacle area in the configuration space corresponding to $\mathcal{O}_c$ is denoted as $\mathcal{C}_{obs}^{c}$

Step 2: Calculating the Reduced Visibility Graph $\mathcal{G}_c$ of $\mathcal{C}_{obs}^{c}$

Reduced visibility graph, also known as the shortest road map, is a viewable graph that removes redundant edges. For convex polygon obstacles $\mathcal{C}_{obs}$, reflex vertices are used to indicate polygon vertices whose interior angles are greater than π. Therefore, all vertices of a convex polygon are reflex vertices. The side of $\mathcal{G}_c$ comes from two different sources:

Successive reflection vertex: If two reflecting vertices are the endpoints of one of the edges of $\mathcal{C}_{obs}^{c}$, the two reflecting vertices are called successive reflecting vertices, then an edge is constructed between the two vertices of $\mathcal{G}_c$.

The edge of double tangent: If the line between any two reflected vertices is a bitangent line, then in $\mathcal{G}$, a visible edge is constructed between the two reflected vertices, such a double-tangent edge is called valid visible edge.

So, the edge of the shortest route map doesn't Pierce the inside of $\mathcal{C}_{obs}$.

Step 3: Constructing the VV$^{(c)}$-Diagram

First calculate the intersection of $\mathcal{C}_{obs}^{c}$ and Voronoi diagram $\mathcal{V}$, i.e. $\mathcal{C}_{obs}^{c}\cap\mathcal{V}$. VV$^{(c)}$-diagram is the union of the shortest road map $\mathcal{G}_c$ and $\mathcal{C}_{obs}^{c}\cap\mathcal{V}$, that is:

$$\text{VV}^{(c)}\text{-diagram}=\mathcal{G}_c\cup\left(\mathcal{C}_{obs}^{c}\cap\mathcal{V}\right) \tag{11}$$

In the narrow region (the gap value of the path is less than c), the agent group cannot pass through the narrow region with the gap value of no less than c, but this narrow region may correspond to the shortest path to the target position. Thus, the advantage of VV(c)-diagram is as follows: The group moves according to the shortest road map in a wide area (minimum distance between obstacles $\ge 2c$), and in a narrow area (minimum distance between obstacles $< 2c$) according to Voronoi diagram, so as to take into account the path length and path gap.

4. Modifying Evaluation Function and Generating Group Trajectory

After the initial position and target position of a given group, we connect it with the constructed VV$^{(c)}$-diagram, and then use the search algorithm to calculate the shortest path according to the evaluation function. In order to consider the influence of path gap on the path of inquiry in the interrogation stage, when using VV$^{(c)}$-diagram for path query, we need to modify the evaluation function of Dijkstra algorithm, that is, modify the length of the VV$^{(c)}$-diagram edge through the gap information. The length of the modified VV$^{(c)}$-diagram is calculated according to the following formula:

$$ML(e_i) = L(e_i) \cdot \left(\frac{c}{\min(clearance(e_i))} \right)^{\kappa} \qquad (12)$$

Where, e_i is any edge in the VV$^{(c)}$-diagram, $ML(e_i)$ and $L(e_i)$ represent the length of the modified and unmodified edges, respectively. Equation (12) guarantees that the length of the edge with small clearance will be "punished", so that the length of the path and the clearance of the path can be taken into account again when the path is inquired.

Finally, by querying of VV$^{(c)}$-diagram, we get the moving trajectory of the group.

5. Experimental Results and Discussion

In our simulation, a polygon obstacle in space is used for simulation experiment. The Voronoi diagram of the obstacle area is shown in figure 1. The expansion treatment of the polygon obstacle area is shown in figure 2.

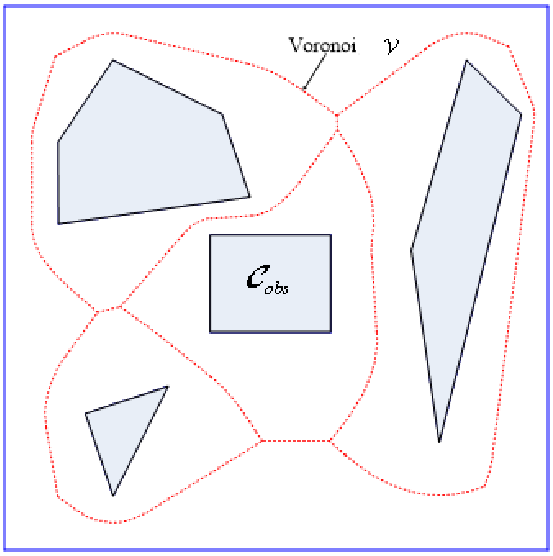


Figure 1. The voronoi diagram of the obstacle area

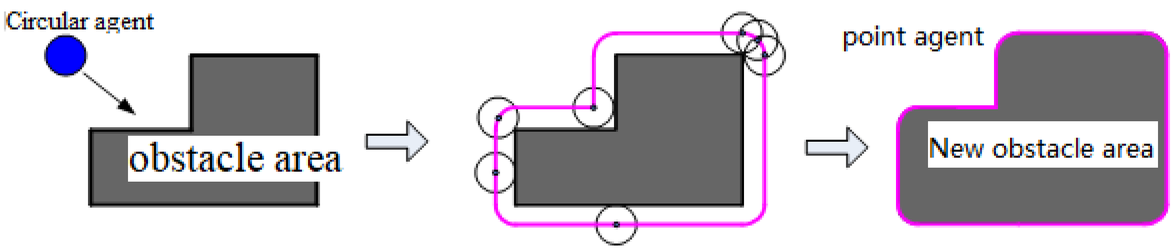


Figure 2. Inflated obstacle area

The obstacle area $\mathcal{C}_{obs}^{c}$ of $\mathcal{O}_c$ is shown in figure 3

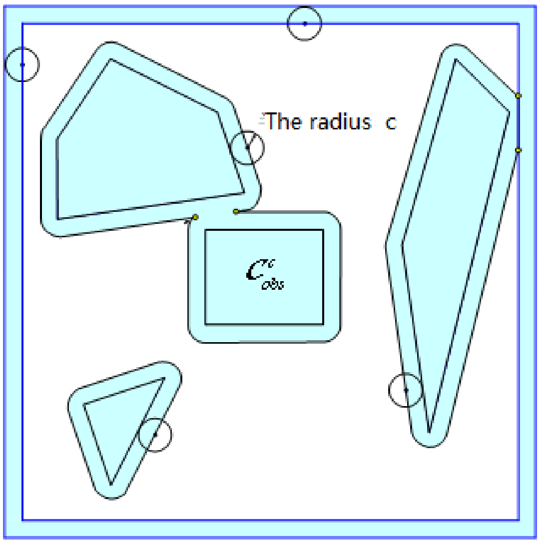


Figure 3. The barrier area $\mathcal{C}^c_{obs}$ after expansion

According to $\mathcal{C}_{obs}$, we can get VV$^{(c)}$-diagram of the obstacle area.

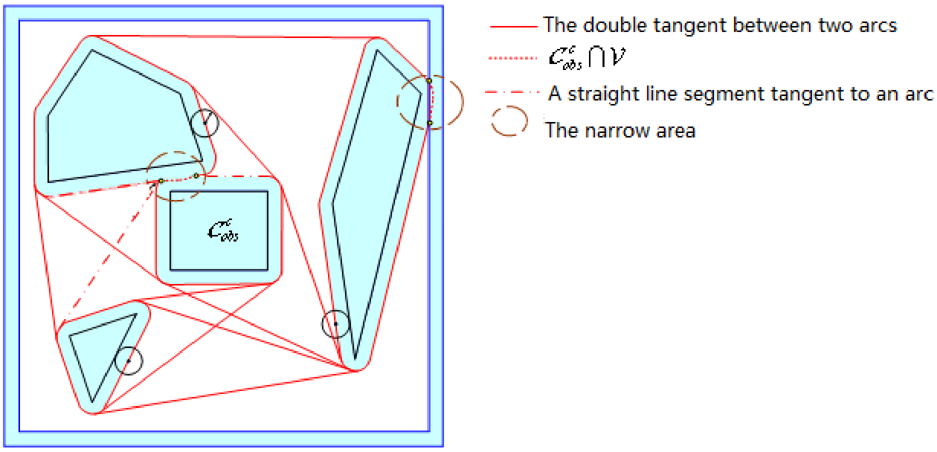
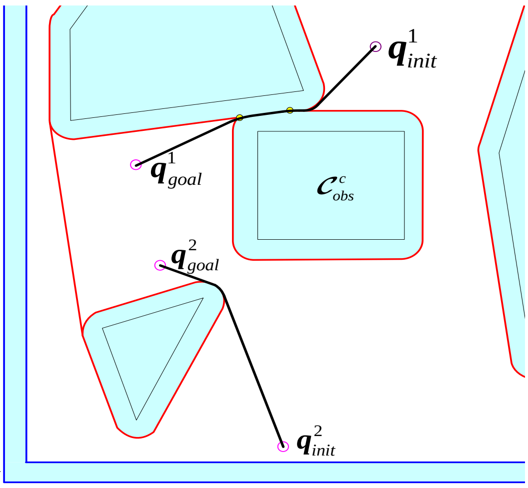


Figure 4. The VV$^{(c)}$-diagram of $\mathcal{C}_{obs}$

On the basis of VV$^{(c)}$-diagram, the smooth track of the group is obtained by the query algorithm which is illustrated in figure 5.



query

Figure 5. Smoothed trajectories of the group

6. Summary

In this paper, $VV^{(c)}$-diagram based group behavior is deeply studied, and a realistic group behavior generation method is proposed. Firstly, the support trajectories of groups are constructed on the basis of visual-voronoi graph. Compared with previous methods, the method based on $VV^{(c)}$-diagram graph in this paper can meet the four requirements of group trajectories, thus laying an important foundation for generating real group behaviors.

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8. References

[1] D. Thalmann, S. Raupp Musse. Crowd Simulation. Springer, London, 2007

[2] Duives D C, Daamen W, Hoogendoorn S P. State-of-the-art crowd motion simulation models[J]. Transportation Research Part C: Emerging Technologies, 2013.

[3] Bellomo N, Piccoli B, Tosin A. Modeling crowd dynamics from a complex system viewpoint[J]. Mathematical Models and Methods in Applied Sciences, 2012, 22.

[4] J. Johnson, K. Hauser. Optimal acceleration-bounded trajectory planning in dynamic environments along a specified path. IEEE International Conference on Robotics and Automation, 2012: 2035-2041

[5] Wilmarth S A, Amato N M, Stiller P F. MAPRM: A probabilistic roadmap planner with sampling on the medial axis of the free space[C]//Robotics and Automation, 1999. Proceedings. 1999 IEEE International Conference on. IEEE, 1999, 2: 1024-1031.6. Olfati-Saber, R.. Flocking for multi-agent dynamic systems: algorithms and theory, IEEE Trans. Automat. Contr., 2006, Vol.51(3):401-420

[6] Champagne J, Tang W. Real-time simulation of crowds using voronoi diagrams[J]. EG UK Theory and Practice of Computer Graphics, 2005: 195-201.

[7] Geraerts R, Kamphuis A, Karamouzas I, et al. Using the corridor map method for path planning for a large number of characters[M]//Motion in Games. Springer Berlin Heidelberg, 2008: 11-22.

[8] Geraerts R, Overmars M H. The corridor map method: Real-time high-quality path planning[C]//Robotics and Automation, 2007 IEEE International Conference on. IEEE, 2007: 1023-1028.

[9] Wein R, van den Berg J P, Halperin D. The visibility-Voronoi complex and its applications[J]. Computational Geometry: Theory and Applications, 2007, 36(1):66 – 87.

[10]Wein R, Van den Berg J, Halperin D. Planning high-quality paths and corridors amidst obstacles[J]. The International Journal of Robotics Research, 2008, 27(11-12): 1213-1231.