Research on Escape Pathfinding Algorithm in Virtual Simulation of Fire

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Abstract. Research the authenticity of the virtual simulation of the fire and the problems of the pathfinding to escape. In a real fire, the phenomenon of explosion caused the nearby combustible materials fire with randomness. In order to meet the objective fire situation, the concept of probability of the trigger ignition was proposed to simulate the randomness of fire caused by nearby explosions. Because of the random factors caused by the explosion phenomenon in fire, taking into account the safety and efficiency of the pathfinding to escape, the navigation grid routing algorithm is further improved, a safety escaping algorithm is proposed, which divides the safe area and the dangerous area according to the probability of the trigger ignition and let the characters find the route to escape in the safety area according to the navigation algorithm. Finally, the simulation experiment is carried out. The simulation results show that the fire simulation scenes can be more realistic by combining the probability of the trigger of fire, and the safe escape pathfinding algorithm can provide a safety escaping route for the character.

1. Introduction
According to the latest statistics of the Ministry of Public Security Fire Bureau, in 2016 alone, a total of 312,000 fires were reported in the country, of which 1,065 were injured and 1,582 were killed in the whole China, with direct property loss of 3.72 billion yuan. Thus, fire brings great disaster and loss to the society. When the fire occurred, because of smoke, fire and other factors, most people were injured or even died due to a lack of fire escape experience. Therefore, it is of great practical significance to strengthen public fire escape education. Although the effect of fire drill is good, it is difficult to popularize because of its complexity [1]. The establishment of the virtual drilling system capability for fire escape can provide learners with intuitive learning methods and improve the experience of self-help in fire [2]. The issues of personnel escaping are always an important research topic in fire virtual escape simulation. At present, the research of fire escape is mainly divided into the research of escape path algorithm and the research of personnel escaping behavior [3]. There are two main researches on path algorithm in the following. One is the direct improvement to the traditional pathfinding algorithm, and the other is the research on path-finding algorithm applied in specific fields [4]. In this paper, the path-finding algorithm of the role in the virtual simulation of fire escape was studied, and put forward safe escape path-finding algorithm, so that the role in the fire scene can avoid obstacles in real-time and find a more secure shortest route to quick escape in fire hazard areas, and in UE4 [5-7] (Unreal Engine 4) In this paper, a simulation experiment on the safe escape pathfinding algorithm is carried out. UE4 engine has the advantages of fast rendering speed and realistic physical properties. It not only can develop large-scale games, but also is suitable for simulation system development [8]. In addition UE4 provides many useful tools for simulation system [9].
2. Introduction of Pathfinding Algorithm

2.1. Common Pathfinding Algorithm

A* algorithm (Heuristic search pathfinding algorithm) is essentially a best first search algorithm with constraint conditions, which is used to find a shortest path from a specified point to another in a two-dimensional grid [10]. The formula for A* algorithm is:

\[ f(n) = g(n) + h(n) \]  \hspace{1cm} (1)

The \( f(n) \) represents the cost estimate from the initial state through state \( n \) to the target state, and the \( g(n) \) represents the actual cost from the initial state to the state \( n \), and the \( h(n) \) represents the estimated cost of the best path from state \( n \) to the target state [11].

The waypoint algorithm is based on the A* algorithm [12], the waypoint is used as the pathfinding node of A* algorithm. To apply the waypoint algorithm to the problems of pathfinding, first of all, we need to divide the map into several regional grids, and then generate the corresponding map data, mainly mark the waypoint information, and then put the map data, starting point and target location into A* algorithm to calculate, and finally get a path composed of road points, as shown in figure 1, the yellow marker from A to B.

![Figure 1. Path generated by the waypoint algorithm](image1)

In fact, the navigation grid pathfinding algorithm is also based on A* algorithm [13] and the navigation grid pathfinding can make real-time dynamic adjustment according to the changes of various collisions and restrictions in the scene. Use the navigation grid generation tool to generate the

![Figure 2. Path generated by the navigation grid algorithm](image2)
navigation grid in the scene before the emulation system runs, the navigation grid must be a convex polygon, which can be used as a path search area in the scene, and then rely on light ray method or the corner point method after the system running to generate path points, and then calculate the optimal path based on the A* algorithm, complete the pathfinding process, and reach the target, as shown in figure 2, the orange marker from A to B.

The light ray method is in the navigation grid, known to the current point p and the direction vector n, to judge whether the light ray vector r (take vector n) intersects with the navigation grid, and where is the pass in and out point, then judge whether it can pass in, whether it can pass out, if not, through the navigation mesh is terminated. Finally, for all the navigation grids passing through, the edges and points are numbered and stored, to complete light ray detection.

The corner point method is the best turning point to find the shortest path in the pathfinding process. First, find the two endpoints on the edge of the navigation grid where the current point is located, connect to the current point to get two segments, and then find the next navigation grid through the edge of the two endpoints, determine whether each endpoint in the current two line segments in the angle and then update the algorithm according to the method of two line segments, and so iterative, when the two endpoints of the next navigation grid are on one side of a line, the endpoint of the non-current point of the segment is the best corner point.

The navigation grid algorithm is applied to the A* algorithm, the example of a triangle as a navigation grid is simply illustrated, as shown in figure 3, where the line with the arrowhead represents the path and the direction of the path finding, and the side of the triangle that begins to pass is called the pierce into edge, and the other side of the triangle that passes through is the pierce out edge. Applied to the formula (1), the \( g(n) \) is the length of the segment that is connected by the midpoint of the pierce into edge and the middle point of the pierce out edge, and the value of \( h(n) \) is the distance from the center point of the triangle to the target point, as shown in figure 3.

![Figure 3. Schematic of navigation grid pathfinding algorithm](image-url)

2.2. Analysis of Pathfinding Algorithm

In the real time virtual simulation system, the waypoint algorithm cannot change the route in real-time, nor can it alter the route according to the characters' characteristics, such as encountering the fire spot which is generated in the escape process of the fire escape simulation. Therefore, there are still many defects in the application of the algorithm of road point based on A*.

From Figure 1 and Figure 2, the results can be found. Compared with the waypoint algorithm, the navigation grid algorithm uses polygon region as the road node in A* algorithm, greatly reducing the
number of nodes, improving the efficiency of the algorithm, and solves the problem of "Z"-shaped route in the traditional waypoint algorithm.

But the traditional navigation grid algorithm cannot be directly used in the simulation of the fire for pathfinding to escape, because it only considers looking for the shortest path to the specified location, without considering the influence of escape personnel security caused by the fire explosion phenomenon and the point of ignition, which cannot meet the security requirement of personnel escape pathfinding in the fire scene, so this paper in view of the fire escape simulation application, the safety escape pathfinding algorithm is proposed.

3. Safety Escape Pathfinding Algorithm

3.1. Probability of the Trigger Ignition

In reality, after the fire, sparks from the explodes can cause fires in other parts of the vicinity, as in an explosion of randomness of the speed of sparks, so near sparks' trigger combustible fire also has a certain randomness and have a great relationship with the distance between the combustible storage and the detonation point. In order to make the fire escape simulation more in line with the objective conditions, it makes the escape route more secure. In this paper, a concept of the probability of the trigger ignition is proposed in the fire escape simulation.

In fire simulation scenario, when the explosive point triggers an explosion, each combustible in the scene is randomly given a (0, 1) of the probability value of the uniform distribution, and then the distance between the combustible storage \( f_i \) and the explosive point is calculated by \( L_i \), according to proportion scenario set the unit of distance for \( D \), \( W_L \), \( W_{PR} \) is distance weights and random probability weights respectively, then the probability of the trigger ignition \( P_i \) of the fuel \( f_i \) is:

\[
P_i = \left[ \frac{1}{L_i} \times W_L + PR_i \times W_{PR} \right]
\]

(2)

The farther away the combustible storage \( f_i \) is from the explosive point, the larger the \( L_i \) value will be, the larger the value of \( \frac{L_i}{D} \) will be, and the smaller the value of \( \frac{1}{L_i} \) will be, the smaller the value of the corresponding \( P_i \) will be in the same case of \( PR_i \).

According to the value of \( P_i \), it can be used to determine whether the combustible fire can be triggered, so that the fire scene simulation will be more real and in line with the actual situation; According to the value of \( P_i \), the path around the combustible is safe or dangerous, so that the character can avoid the danger zone and choose the shortest route to escape in the safe area.

3.2. Description of the Safety Escape Pathfinding Algorithm

First of all, create a fire escape simulation environment, and set the role. As escape personnel, the evacuation personnel follow the algorithm to find a way to escape after the fire, and the safe escape pathfinding algorithm is introduced below. The information of combustible material \( f_i \) is indicated by the value of \( flag(f_i) \), \( flag(f_i) = 0 \) indicates \( f_i \) is the dangerous point prone to fire, \( flag(f_i) = 1 \) indicates \( f_i \) is the ignition point, \( flag(f_i) = 2 \) indicates \( f_i \) is the safe point with little possibility of fire, and dis(a, b) indicates the distance between a and b.
Algorithm Safe escape pathfinding
1: \textbf{input}: Combustibles set $F = \{f_1, f_2, \ldots, f_i\}$, explosion point location $E$, $W_L=0.6$, $W_{PR}=0.4$, $n=64$, the unit of distance $D=2470$
2: \textbf{for} $1 \leftarrow i, n$ \textbf{do}
3: \hspace{10pt} $P(f_i) \leftarrow PR_i$
4: \hspace{10pt} $L_i \leftarrow \text{dis}(f_i, E)$
5: \hspace{10pt} $P_i \leftarrow \frac{\sum D \cdot W_L \cdot P(f_i) \cdot W_{PR}}{L_i}$
6: \hspace{10pt} \textbf{if} $P_i \geq 0.65$ and $P_i < 0.80$ \textbf{then}
7: \hspace{20pt} $\text{flag}(f_i) = 0$
8: \hspace{10pt} \textbf{else if} $P_i \geq 0.80$ \textbf{then}
9: \hspace{20pt} $\text{flag}(f_i) = 1$
10: \hspace{10pt} \textbf{else}
11: \hspace{20pt} $\text{flag}(f_i) = 2$
12: \hspace{10pt} \textbf{end if}
13: \hspace{10pt} \textbf{end if}
14: \hspace{10pt} \textbf{end for}
15: \textbf{output}: $\text{flag}(f_i)$

4. Simulation Experiment

4.1. Simulation Environment
This paper chooses to simulate the safe escape pathfinding algorithm on the UE4 engine. There are two important links in the virtual simulation system of fire escape, the realization of the fire scene and the search of the role safe escape route.

![Figure 4. Simulation experiment scene of fire escape](image)

The realization of the flame based on UE4 particle system, the realization of the role safe escape based on the safe escape pathfinding algorithm in this paper, the roles can avoid obstacles in safe areas to choose the shortest safe route to escape. In the simulation experiment, the fire point, the Explosion point, fire danger point, safe area, danger area and escape route of the escape personnel are recorded. The simulation scene is shown in Figure 4 above.

4.2. Design of Simulation Experiment
In this paper, the fire simulation model takes the 8*8 matrix as the fire occurrence area, and set number 21st to the point of explosion, other location as the fuel. The starting point of escape personnel
and the safe point B finally reaching is set in the matrix on both sides. According to the proportion of simulation model, set up the unit distance D for 2470, as shown in figure 5.

![Diagram](image)

**Figure 5.** The simulation model of safety escape pathfinding

The results of three simulation experiments in the simulation experiment are listed below, as shown in fig.6. The thicker lines represent the escape paths of the traditional navigation path algorithm, and the finer lines represent the escape paths of the safe escape route algorithm. If the triangle is the ignition point with a trigger ignition probability of P value greater than 0.8, the combustible material will trigger the fire. The diamond is the ignition danger point of the trigger ignition probability value P between 0.65 and 0.8, the 12 side shape is the set explosive point, the shadow area is the fire danger area, the blank area is the safe area, and only one black line indicates two pathfinding algorithms to get the path of the overlap.
The shaded region in the experimental results diagram indicates the dangerous spot of the flammable and the dangerous area around the ignition points. As shown in fig. 6 (a), the information of combustible materials in hazardous areas is shown in table 1. If the escape route passes through the shadow part, it is deemed that the evacuation process of the personnel is dangerous, and the escape route can avoid the shadow part as a safety escape route. From the simulation results can be intuitive to see in the figure, the points of ignition and prone to fire points will change as each experiment with random probability changes, the danger zone will change too. When the starting point and the safe point of the role are determined, the escape path obtained by using the traditional navigation grid
algorithm only considers the shortest path to avoid the obstacle search, regardless of the safety of the escape route, and the path obtained by using the safe escape algorithm is the shortest path to avoid the obstacle search in the safe area to avoid the fire danger area. The safe escape pathfinding algorithm is safe and effective.

Table 1. Figure 6(a) combustible materials' information in hazardous areas

| Figure | The labels of combustible materials | The probability of the trigger of fire | Set combustible materials information |
|--------|-----------------------------------|--------------------------------------|---------------------------------------|
| 13     | 0.816                             | Ignition point                         |
| 22     | 0.867                             | Ignition point                         |
| (a)    | 28                                | 0.763                                 | Dangerous point prone to fire         |
| 19     | 0.741                             | Dangerous point prone to fire          |
| 30     | 0.735                             | Dangerous point prone to fire          |

5. Conclusion
Aiming at the situation of the virtual simulation scene of fire escape, this paper makes further improvement based on the navigation grid algorithm, and puts forward the safe escape pathfinding algorithm. The safe escape pathfinding algorithm considering the randomness of combustible fire and the influence of ignition effect about the safety of personnel escape, and the traditional navigation path finding algorithm and safe escape pathfinding algorithm in the application of the fire escape were simulated. The simulation results show that the concept of trigger ignition probability improves the authenticity of fire escape simulation, and the safe escape pathfinding algorithm can avoid the dangerous area in fire scene accurately, which realizes the safety real-time pathfinding in the fire simulation scene.

Virtual simulation has important practical value and development prospect in real life. If the system is improved and combined with the current web App technology, it can realize the real fire scene after the rapid virtual simulation for the field personnel mobile phone simulation results, so that the disaster victims can observe the details of fire, such as the location information of fire danger zone etc., and quickly provide security escape routes for the affected personnel, etc., which can greatly improve the probability of fire safety escape, reducing the loss caused by fire on people's life and property.

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