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An Evacuation Simulation Modelon Passenger Ships based on Multi-grid Cellular Automata Method

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Abstract: A new evacuation model has been proposed for the passenger ships with multi-exit and multi-channel. The multi-grid cellular automat method is used to model the spatial characteristics and passenger behavior in a more detail and natural way. And a local random optimal navigation strategy is designed for pedestrians'updating rules which consider the balance of directionality and randomness of pedestrians in the evacuation process. At last, a simulation examination in aship with 240 passengers is presented to illustrate the validity of proposed model.

Keywords: Ship evacuation; Multi-grid model; Local random optimal navigation

1. Introduction

In this years, Research on the evacuation behavior of crowds in crowded spaces such as various buildings, public places, and various large-scale modes of transport has been a hot topic for researchers in the field of fire safety. Researchers use crowd evacuation simulation to reproduce or predict various phenomena and characteristics in the evacuation process, and provide suggestions for improving security of spatial layout and reasonableevacuation guidance [1-16].

The evacuation model can be divided into two categories: macroscopic and microscopic. The former regards evacuation personnel as a kind of fluid, and studies evacuation activities based on fluid mechanics theory, while the latter simulates evacuation activities based on individuals and simulates the behavior for each person toreproduce the evacuation process. Compared to the macroscopic model, the microscopic model can more flexibly describe the interaction between people and people in the evacuation process and the relationship between people and the environment, and then more closely approach the actual situation. So it is widely used in the research of various types of evacuation problems. Microscopic evacuation model mainly includes social force model[1], cellular automata[2], lattice gas model[3], multi-grid model[4] etc. Among them, social force model is a classic continuous model, and other models are all discrete models. Continuous model can describe the process of evacuation in a more meticulous way, but which will become hard for computing when the as the scale of problem grow [5].So in large-scale crowd evacuation and complex environmental space, the computationally efficient discrete models are commonly used.And under certain mobile strategies, many simulation performances of the evacuation process for discrete and continuous models have a high degree of similarity [6].

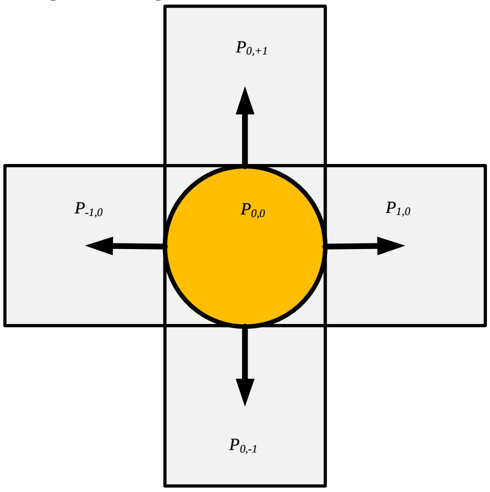
Passenger ship is an important application scenario of the evacuation model. Ships often have more complex obstacles within their distribution, and personnel movements are affected by factors like wind and waves[7]. Compared with other public space, the problem of evacuation on ships has its particularity and complexity. Balakhontceva M et al.[8,9] studied the evacuation behavior of passengers in extreme situations, such as hull damage, storms, swaying hulls, etc. based on social forces and agent models. Ha S et al. [10,11] used a cellular automaton model that considered passengers' behavior to simulate the evacuation of ro-ro ships. Zhang DZ[12] studied the effects of wind waves on the speed of evacuation personnel and studied the characteristics of passenger evacuation time under the influence of different storm levels. Chen M et al [13,14] used a multi-grid automaton model to simulate the crowd evacuation process in the hull's multi-compartment space and used a fine grid to more meticulously portray the evacuation trajectory of humans in the hull.And in this work, a new evacuation model was proposed for passenger ship with complex spatial features, and local random optimal navigation will be applied to model the action of passengers on ship.

The remainder of this paper is organized as follows. Section 2 introduces the main features of the single-gird model and multi-grid model for evacuation. And in Section 3, the reachable area of pedestrian was defined and a new moving strategy based on local random optimal navigation was constructed for multi-grid evacuation model. Section 4 illustrates the simulation of the evacuation process on a passenger ship with complex spatial structure.At last, section 5 summarizes the main work of this article and presents several future research recommendations.

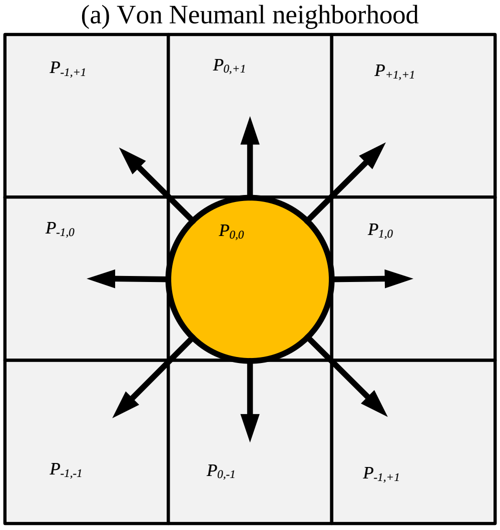
2. Preliminaries

2.1. Single-gridmodel(SGM)

In the discrete evacuation models, the CA(cellular automata)[2] and the lattice gas model[3] usually divide the evacuation scene into a 0.4m × 0.4m grid, and use a grid to occupy the space occupied by pedestrians. We call these type of model as single-grid model for evacuation in this paper.Andin the pedestrian movement process of the single-grid model, it can be expressed by moving the grid occupied by the pedestrian to the grid around it.The following Figure 1 shows the moving area graphics of pedestrians, which are call as Von Neumanl neighborhood of a gird for four directions and Moore neighborhood of a gird for eight directions.



(a) Von Neumanl neighborhood



(b) Moore neighborhood

Figure 1. Moving directions

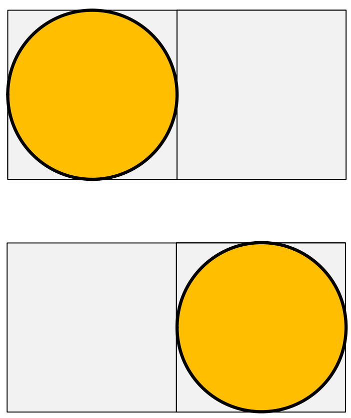
In the lattice gas model , pedestrians will walk according to a non-backward random walk process[3],and every step to arbitrary direction except backward will be taken by an certain transfer probability and the position of all people is updated with a specific sequence. And in the CA model , pedestrian movement is determined by transfer probability using the following formula[2]

$$P_{ij} = N \cdot \exp\left(K_D D_{ij} + K_S S_{ij}\right)\left(1-n_{ij}\right)x_{ij} \qquad (1)$$

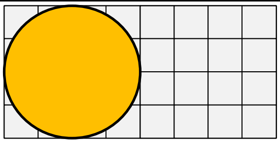
with normalization factor Ntomake sure $\sum P_{ij} = 1$, obstacle indicator $x_{ij} = 0$ for forbidden grid(i,j) like wall and $x_{ij} = 1$ for an available grid(i,j) , and occupation indicator $n_{ij} = 1$ if the grid(i,j) is occupied by some pedestrian and $n_{ij} = 0$ for the grid(i,j) occupied by no pedestrian. And the Dij and Sij are the dynamic field value(change dynamically with the crowd moves) and static field value(determined by the distance to the exit) of the grid(i,j), and KS and KDrepresent the coefficient of the static field and the dynamic field respectively.

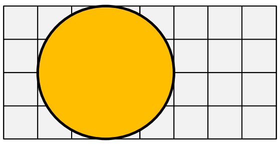
2.2. Multi-grid model(MGM)

An obvious drawback of the single gird model is that the grid is too large and a pedestrian will occupies one entire grid.Andat each step, the pedestrian can only walk around a grid or stop at origin position.In the simulation of large-scale crowds, the single-grid model is difficult to reflect the subtle movement of pedestrians, making all personnel side by side and walking around.Therefore, Song WG et al.[4] proposed a more accurate multi-grid model, and divided the evacuation scenes with 0.1m×0.1m small grids. Each pedestrian occupies 4×4 small grids. In a multi-grid model, a distance of at least 0.1 m can be displayed in a more detailed way. The following Figure 2 shows the behavior of a pedestrian moving to the right once in a single-grid model and a multi-grid model.



(a) single-grid model

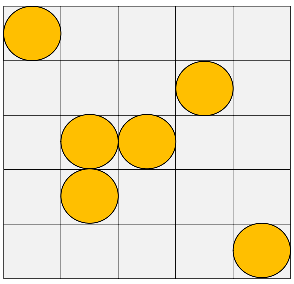




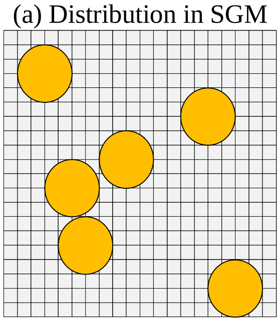
(b)multi-grid model

Figure 2. Moving behavior of two models

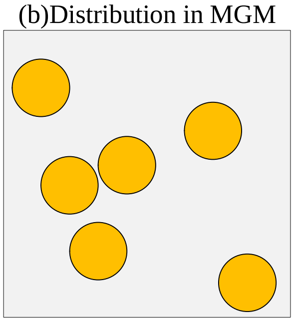
In the traditional single-grid model, each pedestrian occupies a grid, so that the pedestrian distribution in a space is evenly distributed like the Pic (a) in the Fig. 3. But in real life, the pedestrian distributionis staggered andpeople will not stand side by side or side by side, like the Pic (c) in the Figure 3. So the layout of multi-grid model in the distribution of pedestrians, like the Pic (b) in the Fig. 3, is much closer to actual distribution.



(a) Distribution in SGM



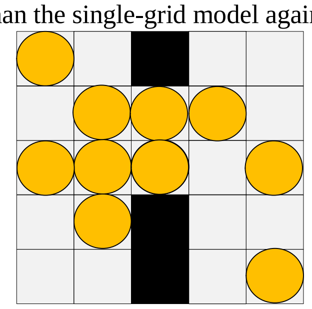
(b)Distribution in MGM



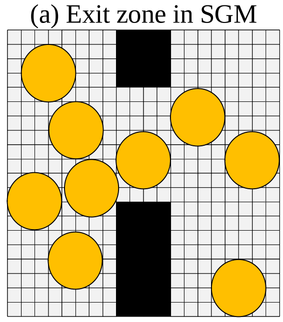
(c) Actual distribution

Figure 3. Pedestrian distribution

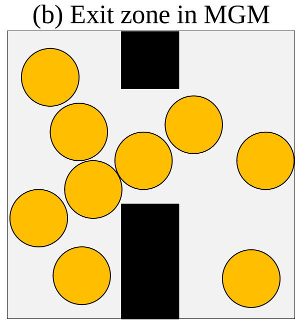
In actual situation like the Pic (c) of Fig. 4, if the exit can only allow two people to pass, when one person is stuck in the middle of the doorway, other pedestrians cannot pass. As can be seen in Pic (a) of Fig.4, in the single-gird model, because each person occupies a grid, and can only move one grid, so anyway, the exit can allow two pedestrians to pass, which is inconsistent with the reality. The Pic (b) of Figure 4 shows how the multi-gird model simulates the distribution of pedestrians near the exit, it can be seen that the multi-gird model fit the actual distribution well than the single-grid model again.



(a) Exit zone in SGM



(b) Exit zone in MGM



(c) Actual Exit zone

Figure 4. Pedestrian in exit zone

For many spatial features, the multi-grid model have more powerful ability to describe reality than single-gird model, and the multi-grid model can also use more finer gird to get as close as to the continuous situation[15],which will bring more complicated calculations and cost more computing time as the gird get finer.The updating rules of single-grid model can also be well transplanted to the multi-grid situation[4,13,14], and single-grid model can be seen as a special multi-grid modelin some level.

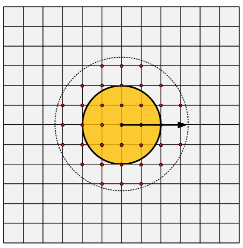
3. Model

In the cellular automata evacuation model, the static field is used to describe the attraction of the exit to pedestrians, and the probability of the pedestrian moving in all directions is described in conjunction with the dynamic field based on herd behavior ,while in the lattice gas model pedestrian actfollow the non-backward random walk rules. And the mobile strategyof the multi-grid model usually takes the setting from both two types of single-grid models.In this paper, we construct a new moving strategy which mainly inspired by the work about the local optimal navigation method[6,16].

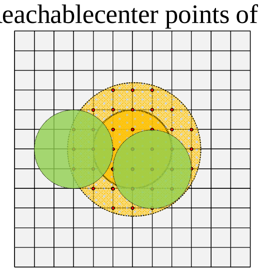
3.1. Reachable area for a pedestrian

In this article, the reachable area within a certain time for a pedestrian is defined as the all the grids which can be reached by the pedestrian from the center point of grid occupied by the current pedestrian to the center points of these girds. The length of the pedestrian's action radius is maximum distance he can reach with his maximum walking speed in the certain fixed time.

For example, suppose that the pedestrian's maximum walking speed is 3.4m/s, and the unit time interval for each update movement is 0.1 second, then the center points that a pedestrian can reach is the pedestrian center represented by all the red nodes in Pic (a)in the Figure 5, where the side of the grid is 0.1m. When the pedestrian moves, he can move to any center of the reachable centers shown in the Pic (a). And the green circle in the Pic (b) in Fig.5 indicates the two position that the pedestrian can occupy in the next moment. The green circle on the left of the Pic (b) indicates one furthest position the pedestrian can reach, and the green circle indicates one the nearestposition can reach without considering the taking stop action.



(a) Reachablecenter points of grids



(b) Two reachable grids for pedestrian to occupy

Figure 5. Reachable area for a pedestrian

And then, the area of all the grids may be occupied the pedestrian in the next moment are shown in the Figure 6.

Compared with the traditional model, using the reachable area for a pedestrian to predict the next position pedestrian located inget pedestrians more flexible choices in one updating period.

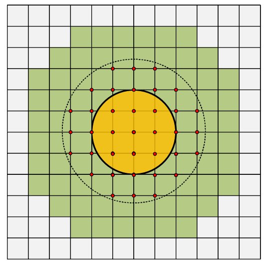
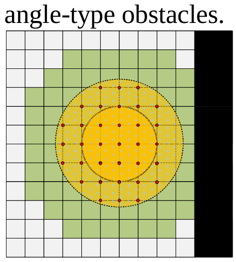
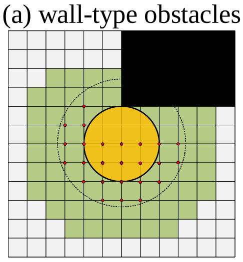


Figure 6. All grids of the reachable area

Obstacle is a very important spatial element in the evacuation model. They are represented as areas that cannot be reached by pedestrians in the entire evacuation process.The gridsof obstacles cannot be occupied by all pedestrians.For the situation that obstacles are in the vicinity of pedestrians, reachable areas of pedestrians are still can be defined as before. The center points that a pedestrian can reach well be less when there are some obstacle grid close to the pedestrian and then the grids of the reachable area will also be reduced because the obstacle grids occupy some grids of the all grids pedestrians can reach. The Pic (a) and Pic (b) of Figure 7 show two type of reachable areas of pedestrian when affected by the wall-type and angle-type obstacles.



(a) wall-type obstacles



(b) angle-type obstacles

Figure 7. All grids of the reachable area withobstacles nearby

3.2. Distance measure

We use Sij to represent the distance from the grid in i-th row and the j-th column of the evacuation zone, and distance of the obstacle grids will be set as infinite. For simple scenes, the distance between the grids and the destination exits can be calculated using Euclidean distance.And for the room with a lot of obstacles, Manhattan distance is chosen to make the calculations easy and fast[17].The following Fig. 8 below shows the Manhattan distance in the grids to show the distance from the destination to current grid.

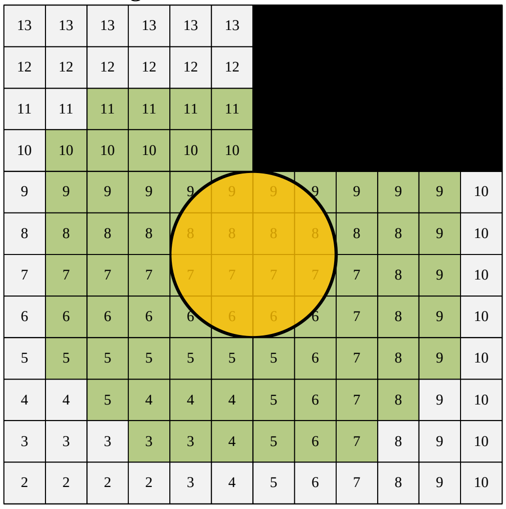


Figure 8. Manhattan distance of the grids near a pedestrian

In this paper, the distance of a pedestrian to the destination will be calculated as the average value of all distances of the grids currently occupied by the pedestrian. For a pedestrian k, his distance Dkto the destination can be expressed as

$$D_k = \frac{\sum_{(i,j)\in P_k} S_{ij}}{N} \qquad (2)$$

Where the Pkrepresent the set of all girds occupied by pedestrian k, and N is the number of occupied grids. And we can get the distance to the destination of the pedestrian in the Figure 8 is 7.5.

3.3. Local random optimal navigation

The moving strategy is the critical content of a pedestrian evacuation model, which dominates how a pedestriantake a reasonable action to get the next position from current position. In our model, we assume that all pedestrians have a clear understanding of the route to the exit, and each person will always hope to choose the shorter route than a longer route to the destination.For one single pedestrian, his reachable area tells all possible next positions in a fix time period, the main idea of local optimal navigation[6] will let him to choose the closest position to the destination. But we know many people will not take such action like this in practice. On one hand, pedestrians often cannot accurately know which landing point is closest to the destination. And on the other hand, people usually need to keep a comfortable psychological distance from outside world. So a pedestrian usually will not get to close to the obstaclesor other pedestrian. Based on these two facts, we build a local random optimal navigation to capture the movement of the pedestrians.

In our moving strategy, the reachable area of pedestrians will firstly be calculated according to their position and the obstacle grids near them. Then, every pedestrian will randomly select the next position in their reachable area. For pedestrian k, the probability of reaching his available landing point i is expressed as

$$P_{k,i} = N\exp\left(-K\left(D_k - D_{k,i}\right)\right)\left(1-n_i\right)x_i h_i \qquad (3)$$

Where Dkis the current distance from pedestrian k to the destination, and Dk,iand is distance from pedestrian k to the destination when landing on the available landing point i, and K is the coefficient for and distance difference, and with

$$\text{occupation indicator: } n_i = \begin{cases} 0, & \text{no grid in the area point } i \text{ refered to occupid by others} \\ 1, & \text{else} \end{cases}$$

$$\text{obstacle indicator: } x_i = \begin{cases} 1, & \text{no obstacle grid lie in the area point i refered to} \\ 0, & \text{else} \end{cases}.$$

$$\text{direction indicator: } h_i = \begin{cases} 1, & D_k - D_{k,i} > 0 \\ 0, & D_k - D_{k,i} \le 0 \end{cases}$$

Thenormalization factor Nis set make $\sum P_{k,i} = 1$. It should be noticed that the value setting of the direction indicator h_i make the pedestrian will not get to the position further away to destination than current position.In actual operation, in order to accelerate the calculation, we can just use the N possible landing points with the smallest distance to destination. For example, Figure 9 shows five possible landing points of a pedestrian.And if we take only one possible landing point, the pedestrian will walk guided by the local optimal navigation.

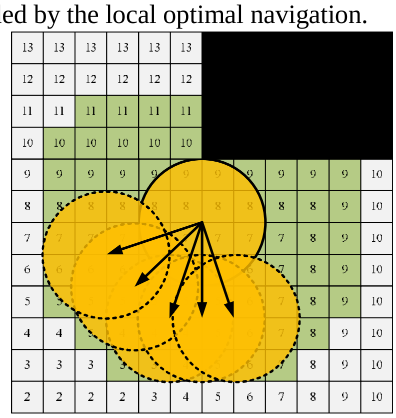


Figure 9. Possible landing position

It is easy to see that the position with smaller distance to destination will be chosen by a bigger probability. And the distance of one position is calculated as the average value of Sij of the girds it contained. So we can make the

Sij of the girds adjacent to the obstacles or pedestrian bigger than it should be to reduce the probability of the landing area contained it being choosing as next position.

4. Simulation

In this section, we will use a passenger ship loaded with 240 passengersexamine proposed method. The length of the boat is 40 meters and the width is 9.8 meters. The distribution of rooms and obstacles is shown in the following Figure 10.

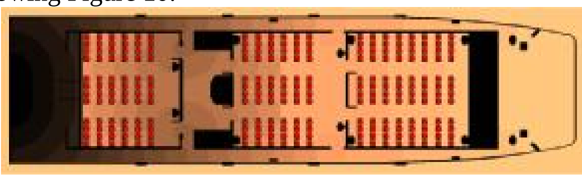


Figure 10. Passenger ship with 240 persons

Before thesimulationof evacuation, the space of ship will firstly be meshed by 1000×980 square grids with 0.1m side and very person on ship is set to occupy 4×4square grids on his seat. As shown in Fig.10, the passenger ship has three cabins, each with 72 persons,72 persons and 106 persons in the seats respectively.When an emergency occurs, all passengers need to be evacuated to the rear of the passenger ship waiting for rescue. And in the evacuation process, all passengers will act follow the rules: (1) choose the closest exit to leave the current cabin(four exits are markedinlittle green rectangle shown in Fig. 11);(2) after reaching the corridorofone side of the ship, keep movinguntil reaching safe zone (safe zoneis marked in a greenbig rectangle in the stern as shown in Figure 11).

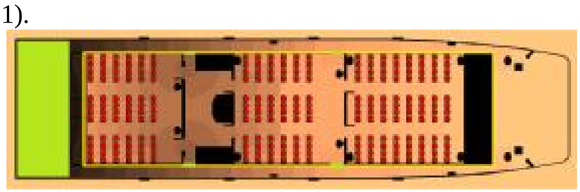
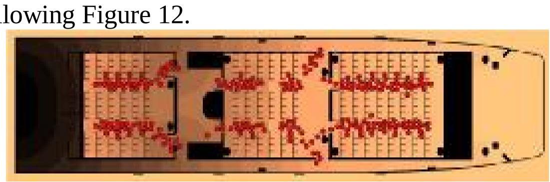
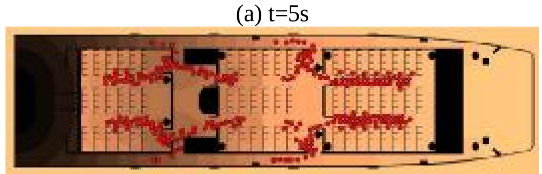


Figure 11. Exits and Safe zone

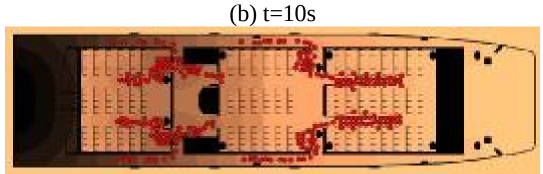
The static value Sijof grids will be calculated using its Manhattan distance to its destination depended on its position. The destination of the grids inside of yellow box are set be the closest exit to it, and the destination of the grids outside of yellow box are set be the safe zone in the stern. And the Sijof grids adjacent to the obstacles or pedestrian are added by 3 in the simulation. We use 1 second as the shortest update time, andthe snapshot of evacuation process at 5s,10s,…,30s as are shown in the following Figure 12.



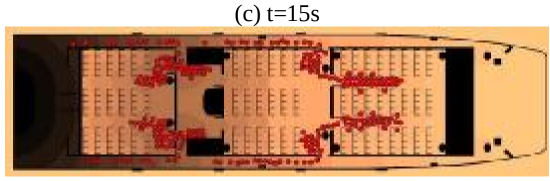
(a) t=5s



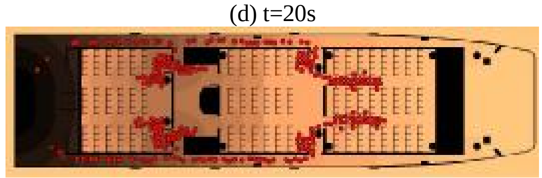
(b) t=10s



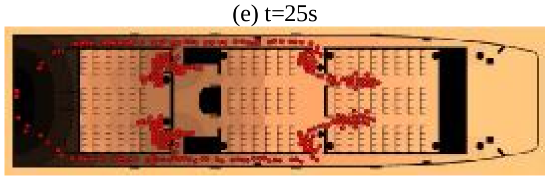
(c) t=15s



(d) t=20s



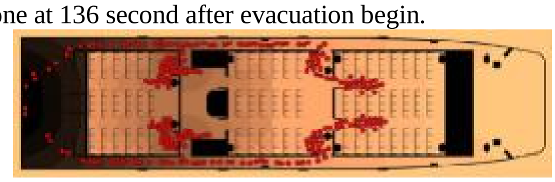
(e) t=25s



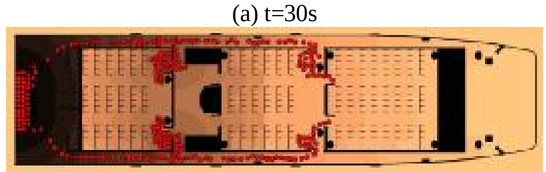
(f) t=30s

Figure 12. The snapshot of evacuation at t=5s,10s,⋯,30s

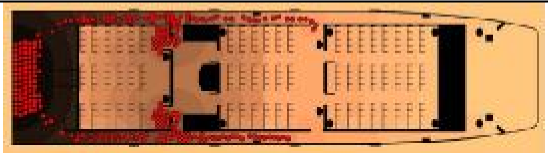
From the first thirty seconds of the evacuation process of the ship passengers shown in Fig.12, We can clearly see the congestion of passengers at the exit.And there are small gaps between passengers and between passengers and obstacles as in the actual situation.The distribution of passengers in the action trajectory is more natural than the traditional single-grid model.The snapshot of evacuation process at 30s,50s,…,130s as are shown in the following Figure 13, and all the passengers reached safe zone at 136 second after evacuation begin.



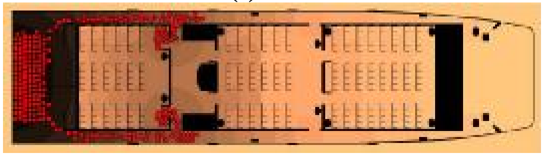
(a) t=30s



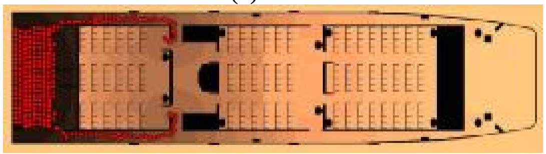
(b) t=50s



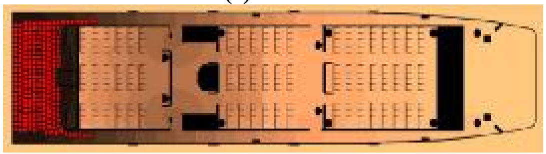
(c) t=70s



(d) t=90s



(e) t=110s



(f) t=130s

Figure 13. The snapshot of evacuation at t=30s,50s,⋯,130s

5. Conclusion

In this work, a new multi-gird evacuation model which can deal with evacuation problem in some place with complex spatial structure by very simple rules. And the simulation examination shows the evacuation process produced by proposed model appear to be very natural and in line with people's behavioral characteristics. And we also can see a lot of settings of the proposed model can be changed to furtherresearch to test the performance in more scenes. Besides, others rules and setting can be created or transplanted into this basic simple evacuation simulation scheme based on proposed model in the future study.

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