Optimal Design of Obstacles in Emergency Evacuation Using an Arch Formation Based Fitness Function

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Abstract. Congestion in pedestrian crowds is a critical issue for evacuation management and it is possible to alleviate crowd congestion by appropriately placing obstacles in the evacuation scene. To alleviate the crowd congestion by suitably placing obstacles, it is important to extract the characteristics of the evacuation process to improve the evacuation efficiency. In this paper, an arch formation based obstacle optimization approach is firstly employed to get the suitable characteristics of obstacles in a evacuation scene. Concretely, the arch formation in a dense crowd is used to guide the crowd congestion alleviation. The radial pressure, which can represent the strength of arch formation, is used to build a new fitness function for the PSO. The proposed approach can guide the design of pedestrian facilities to achieve a better management of evacuation. In this paper, the effectiveness, and quality of the proposed approach are validated through analysis and simulations.

Keywords: Evacuation simulation · Particle swarm optimization
Crowd congestion · Arch formation

1 Introduction

For the few decades, dynamic characteristics of pedestrians in panic evacuation has attracted many attentions because the increase of congestion situations and mass events in reality. The incessant developments in evacuation research will bring significant benefits in public traffic management, architecture design and risk avoidance. Therefore, it is necessary to improve the research of emergency evacuation to achieve a better management and control on evacuation for safety and comfort reasons.

Although the emergency evacuation is a critical issue for crowd safety management, the relative rarity of crowd accidents creates several issues related to these researches. Since occurrence of crowded situation is still mostly unpredictable, data considering those accidents are very scarce. For this reason, simulation modeling and

Y. Sun et al. (Eds.): ChineseCSCW 2018, CCIS 917, pp. 129–145, 2019.
https://doi.org/10.1007/978-981-13-3044-5_10

experiments are the primary approaches for modeling crowd evacuation behavioral during emergency evacuation.

In this paper, we focus on improving the evacuation effect by changing the design of pedestrian facilities, which is achieved by set obstacles in the evacuation scene. With the development of the evacuation researches, many scholars have found that obstacles near the exit can influence the outflow and the crowd congestion. So it is important to set the obstacles correctly to achieve a better management of evacuation.

Although a lot of researches have already been developed on how to improve the evacuation by obstacles, there are still limitations for application because it is difficult to obtain the optimal characteristics of obstacles. For example, configurations of obstacles are complicated, and it is hard to distinguish effects of different characteristics. Therefore, the optimization of obstacles in evacuation is a topic worthy of exploration.

This paper proposes an approach to optimize the obstacles in evacuation scene to alleviate the crowd congestion in a dense crowd. The main contributions in this paper are shown as follows:

1. It proposed that the arch formation in a dense crowd can alleviate the crowd congestion. The arch formation, which is a result of self-organized motion of evacuation crowd, has potentials to influence the crowd congestion, and it can be adjusted by the obstacles. Therefore, it is possible to optimize the configurations of obstacles according to the arch formation to improve the evacuation.
2. We put forward that the radial pressure of the arch formation in a dense crowd is a suitable index to assess the adjustment effect of obstacles. The radial pressure is a characteristic of the arch formation and is changes with the crowd congestion. By using the radial pressure as an index, it is possible to study the relationship between the arch formation and the configuration of obstacles and assess the state of arch formation, which is important for crowd congestion alleviation.
3. Based on the calculating of radial pressure, a fitness function for Particle Swarm Optimization (PSO) algorithm is proposed to improve the optimization of obstacles. This new fitness function can improve the efficiency of obstacle optimization to achieve the congestion alleviation.

The rest of this paper is organized as follows. Section 2 introduces related literature on the social force model, obstacle configuration optimization, arch formation and PSO algorithm. Section 3 describes the arch formation based congestion alleviation approach and the radial pressure based fitness function. Simulation setups, results, and an in-depth discussion are provided in Sect. 4. The concludes is given in Sect. 5.

2 Related Works

2.1 Social Force Model (SFM)

Emergency evacuation is a complex process because crowd behavior usually seems to be irregular, chaotic, and unpredictable [1]. There are many factors that will restrict and influence the dynamic adjustments of evacuation. Therefore, modelling interactions among a crowd and the states of pedestrian individuals is important for management of evacuation. Simulation modeling is the main method for understanding evacuations, and many evacuation models have been proposed by scholars, such as the social force model (SFM) [2, 3], cellular automata model [4–6], fuzzy logic-based model [7], and agent-based model [8]. Many typical self-organized phenomena and collective behaviors can be reproduced by these models [9].

The SFM proposes a way to illustrate the exclusive interactions among crowd pedestrians and the interactions between pedestrians and obstacles. In this model, every pedestrian has a desired velocity which illustrates his destination, and acceleration (deceleration) is decided by different forces. As a microscopic continuous evacuation model, the SFM can reproduce many self-organizing crowd motion, such as oscillatory effects at bottlenecks and lane formation in bidirectional flows.

The SFM is used to simulate many scenarios, such as crowds in densely situation and panic escape [10]. Given that the SFM is suitable to simulate the characteristics of evacuation pedestrians, it has attracted many attentions to be used to simulate more phenomena in crowds [11–13].

As a microscopic model, the SFM has great potential for providing high-quality motion details for crowd evacuation. For example, by using the SFM, Helbing et al. proposed a “crowd pressure” to quantitate and represent congestion in crowds. Their works have illustrated that the SFM can simulate crowds in very crowded dangerous situations [1]. In this paper, the SFM was used to conduct the evacuation simulation.

2.2 Research on Obstacles in Emergency Evacuation

In emergency situations, it is feasible to increase the evacuation efficiency by suitably placing obstacles near the exit. Helbing et al. found that the outflow can be increased by appropriately placing obstacles near the exit [14]. In their follow-up work, Helbing also found that obstacles may increase pedestrian flow by 30% compared to that without the obstacle [1]. Yanagisawa et al. found that the mean traveling time of pedestrians was reduced by 25% in an experiment when an obstacle was arranged for actual pedestrians [15]. However, obstacles with inappropriate configurations negatively affect the evacuation efficiency. Zhao et al. simulated an evacuation and found that placing obstacles symmetrically near the exit door may be harmful for evacuation [16].

The obstacle’s configuration should be properly adjusted to get an optimal improvement in crowd evacuation. Therefore, a significant amount of research has already been conducted to determine the proper configuration of the obstacles (i.e., position). Jiang et al. used a genetic algorithm to achieve a layout design of the obstacles [17]; however, they only considered pillar-like obstacles. Other differently shaped obstacles, such as thin, flat panels, can also enhance the evacuation efficiency. Frank et al. studied the pedestrian behavior on an escape situation obstructed by a panel and pillar near the door [18]. Zhao et al. employed a modified differential evolution (DE) to optimize the characteristics of differently shaped obstacles and thus achieved a minimum evacuation time for all pedestrians [16].

Obstacle placement has been proven to be a suitable approach to improve the evacuation effect. However, this topic is worthy of further exploration because the applications of obstacles are still limited.

2.3 Research of Arch Formation in Crowd Evacuation

An arch-shaped structure (or arching phenomena) at bottlenecks is a typical phenomenon in systems such as traffic, civil engineering, granular flow through a hopper and escape evacuation [19]. In some situations, evacuation crowds exhibit collective phenomena similar to those observed in granular experiments, for example, evacuation flows at bottlenecks [20]. In this paper, the arching effect in an evacuation crowd is called an arch formation. An arch formation is difficult to avoid when panic pedestrians gather at an exit, see Fig. 1. The arch formation is formed and broken repeatedly, and this phenomenon may decrease the outflow rate and increases congestion. Therefore, it is necessary to develop an approach to solve the arch formation problem as much as possible.

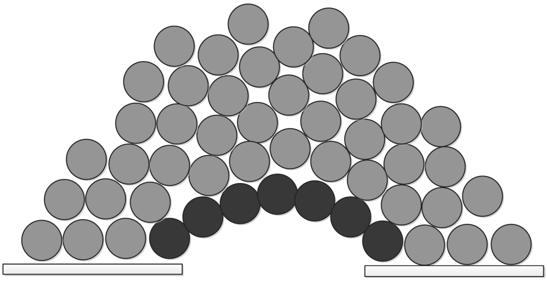


Fig. 1. The diagram of an arch formation in a dense crowd

Many studies have been conducted to study arch formation. Suzuno et al. discuss the arch formation in an evacuation process with the social force model [19]. They discussed the physical mechanism of obstacles in a evacuation system and showed that the obstacle affects arch formation in three ways. Twarogowska et al. analyzed two macroscopic crowd dynamic models and studied the pedestrians evacuation in a room with one exit [21]. They discussed the crowd motions such as clogging at bottlenecks and stop-and-go waves. In their simulations, the density profiles of the crowd showed a congestion situation with an arch formation.

In summary, the arch formation, which is a typical phenomenon in pedestrian evacuation systems, has direct or indirect relations with the flow rate and congestion of a crowd. This phenomenon may hinder an evacuation and increase crowd congestion. This limitation motivates the authors to develop a possible method that can solve the arch formation problem.

2.4 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO), which was firstly proposed to model the behaviors of bird, is a famous approach for optimization problems. As a population-based optimization approach, PSO has attracted many research attention, and a large number of modifications had been conducted to modify the basic algorithm, comprehensive surveys of which can be found in [22, 23]. Nowadays, it has been well recognized as an efficient approach for intelligent search and optimization.

PSO has attracted many attentions in engineering problem optimization because it has powerful search performance and algorithmic simplicity. PSO maintains many good solutions as the leaders to guide the optimization process, which is different from differential evolution and genetic algorithms. For these reasons, the PSO was also applied to optimize the configurations of obstacles in an evacuation scene. For example, Cristiani et al. introduced a new approach that guarantees both the opacity of the obstacles and impermeability, and the PSO was used to optimize the configurations of obstacles. The simulation result showed that the model can increase the evacuation efficiency by adding multiple optimally placed and shaped obstacles in the walking area [24].

In this paper, the PSO algorithm is used to guide the configuration optimization of obstacles in a evacuation scene.

3 Optimal Design of Obstacle for Emergency Evacuation

3.1 Arch Formation Based Congestion Alleviation for Emergency Evacuation

In this section, we focus on the relation between crowd congestion and arch formation. Previous studies have reported that the density at bottlenecks in a crowd has a characteristic that it will oscillatory changes in the flow direction [1, 10]. In fact, it is obvious that there are many self-organized motion in a dense crowd, among them oscillating flows, which is an inevitable phenomenon caused by crowd congestion [1, 25]. The arch formation, which is formed and broken repeatedly, is a kind of self-organized motion caused by the oscillatory changes. Therefore, arch formation is a common phenomenon in crowds and is hard to avoid because it is caused by crowd congestion.

The arch formation, which is formed and broken repeatedly, is a kind of self-organized motion caused by the oscillatory changes in an evacuating crowd. The arch formation, which is formed and broken repeatedly, will hinder the evacuation process when it is formed. Congestion will increase because pedestrians behind the arch are still pushing each other to get close to the exit, which is dangerous for the pedestrians. Therefore, the critical problem of an arch formation is that it hinders the evacuation process.

Given that the arch formation is a common phenomenon in crowds and is harmful to evacuation, solving the negative effect caused by arch formation in crowds is a critical issue for dense crowds.

Although the arch formation hinders the evacuation process and increases congestion, it can also endure external pressure from outside pedestrians, which is a positive effect for evacuation. Therefore, it is important to find an approach that makes use of advantageous effects and solves disadvantageous effects to solve the arch formation problem.

Figure 1 shows a situation where an arch formation has formed at an exit. In this situation, the arch formation has only a negative effect on the crowd because it is too close to the exit. Although the arch formation can still endure external pressure, it does not benefit the evacuation because there are no pedestrians inside the arch formation. Even worse, external pressure will increase the duration of the arch formation. However, there will be several positive effects if an arch formation is formed at an outer position, see Fig. 2. First, the arch formation at an outer position can protect pedestrians near the exit. If the arch formation endures external pressure, the pedestrians inside it will not suffer from overcrowding. Second, the arch formation at an outer position is wider and endures less pressure than the one in Fig. 2, and thus, it is unstable and collapses easily. This situation will benefit the evacuation because the shorter the duration of the arch formation, the more rapid the evacuation is and the less congestion that occurs.

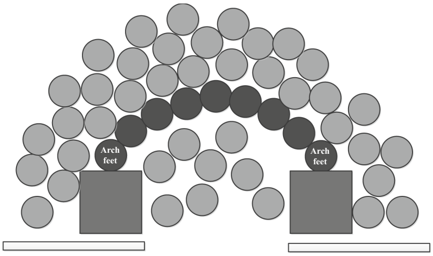


Fig. 2. An outer-arch (pedestrians with dark color) and arch feet.

The above idea inspires the authors to devise an approach to solve the arch formation problem in evacuation by changing the position of the arch formation. This approach, which uses self-organized motion to solve the congestion problem, is different from existing approaches.

3.2 Radial Pressure Based Fitness Function for PSO

In this paper, we use the radial pressure of the arch to evaluate the effect of arch formation and obstacles. The benefits include: In this paper, we focus on the optimization of obstacles in evacuation scene to achieve the crowd congestion alleviation, and the PSO is used to get the optimization configuration. As mentioned above, adjusting the arch formation by obstacles may be a suitable approach to alleviate the crowd congestion. Therefore, the concrete target of the proposed approach is to adjust the arch formation by the optimization of obstacles.

The radial pressure of the arch formation in a crowd is used to evaluate the effect of arch formation and obstacles and build a new fitness function for the PSO in this paper. According to the references [26, 27], the radial pressure of the arch formation is an index of the strength of an arch formation. This variable can evaluate the state of an arch formation, which is suitable to analyze the adjustment effect of obstacles. Thus, this radial pressure based fitness function has great potential to guide the optimization process of obstacles.

This paper proposes an approach to calculate approximately the radial pressure based on a reasonable arch axis. Although arch formation in crowds has various shapes, relevant research shows that it is possible to analyze arch formation by a static mode [20]. In this paper, the reasonable arch axis is used to analyze arch formation. This model is extensively used in research on the arching effect in civil engineering, and it provides a theoretical basis and design method for the application of the arching effect. In this work, the reasonable arch axis is considered as a static model of the arch formation during a crowd evacuation. This hypothesis allows us to ignore the concrete detail of the arch formation and focus on the relation between the obstacles and arch formation. The structure of the reasonable arch axis is shown in Fig. 3, and the formula for this model is as follows [28, 29]:

$$y = 4 \cdot r / \left(s^2 \left(s \cdot x - x^2\right)\right), \tag{1}$$

where S is the arch span, r is the rise of the arch, x is the abscissa of the arch axis and p is the pressure act on the arch formation.

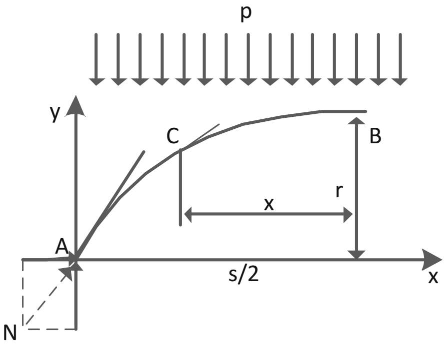


Fig. 3. Computation model of the reasonable arch axis

The horizontal thrust and vertical bearing force at a random point on the axis of arch are respectively:

$$N = p \cdot s^2 / (8h), \tag{2}$$

$$N_2 = p \cdot x, \tag{3}$$

The radial pressure at a random point on the arch axis is:

$$N_c = \left(p \cdot \sqrt{s^4 + 64 \cdot x^2 \cdot h^2}\right) / (8h), \tag{4}$$

The radial pressure at point A is the biggest and at point B is the least.

$$N_A = \left(p \cdot \sqrt{s^4 + 16 \cdot h^2}\right)/(8h), \tag{5}$$

$$N_B = \left(p \cdot S^2\right)/(8h), \tag{6}$$

In this paper, the congestion alleviation ability of obstacles increases with the decrease of the radial pressure. This is because the radial pressure represents the strength of arch formation, and the crowd congestion varies inversely with the strength of arch formation. However, there are still many limitations on the radial pressure because there will be no arch formation when the radial pressure is too small. Therefore, it is necessary to set several constraints to ensure the effect of the radial pressure. In this paper, we introduce a condition to limit the spacing of the obstacles.

$$s < s_{max} = 4 \cdot d \cdot cos\varphi/(p \cdot (1 - sin\varphi)), \tag{7}$$

where d is the length of the obstacle, φ is the internal friction angle and is usually be set to 15°–20°. Therefore, the final fitness function is:

$$F = \lambda_0 \cdot N_A + \lambda_1 \cdot N_B, S < S_{max}, \tag{8}$$

where N_A and N_B are the radial pressure of the arch formation in the crowd, λ_0 and λ_1 are weight coefficients and default is 1.

4 Simulation Design and Analysis of Results

In this paper, the PSO was used to optimize the configurations of obstacles to alleviate the crowd congestion. First, we will demonstrate the evacuation simulation that we designed to test the effect of obstacles. Second, the simulation result and the analysis are given.

4.1 Simulation Design

The original evacuation scene is a room with one exit, see Fig. 4. In this paper, we use the diameter of the particle as the length units. The room is 150 d long and 100 d wide. The length of the door is 6 diameters. Pedestrian initialization position is random distributes uniformly in the evacuation scene.

The social force model is used to conduct the evacuation simulation. The central position of the door is used to represent the direction of driving force. We put forward a new method which is similar to the density to quantify the effect of obstacles. According to the characteristics of the social force mode, there is an overlap between two pedestrians when they compress each other, as shown in Fig. 5(a). The radial

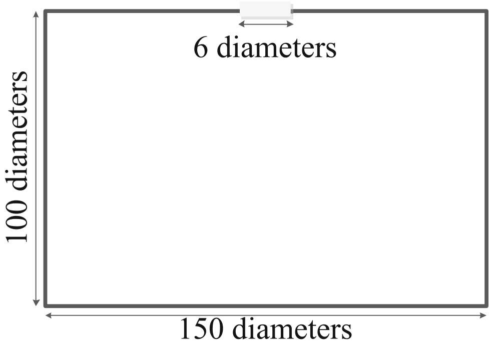


Fig. 4. The original evacuation scene.

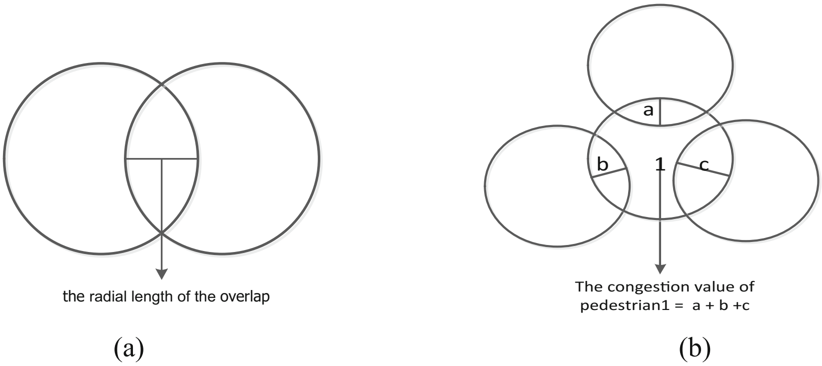


Fig. 5. (a) Congestion value between two pedestrians; (b) Congestion value of a pedestrian.

length of the overlap is used to represent the congestion value. The whole congestion value of a pedestrian is the sum of the overlaps, see Fig. 5(b). The congestion value of the crowd is the average of the congestion value of all the pedestrians.

First, the hypothesis that the arch formation in a dense crowd can be used to alleviate the congestion was tested by a simulation. We used the average congestion value of crowd as the index to illustrate the comparison result. There are 500 pedestrians in the evacuation scene. The obstacle we used to control the arch formation is a square with a width of 4 diameters. A 3-diameter distance is designated between the obstacle and the front wall to allow many pedestrians inside the outer-arch. The obstacles are placed symmetrical with spacing of 8 diameters. In this section, the scene without obstacles is the original scene and the scene with obstacle is the modified scene. We ran each specific condition several times and use the average as the final result. Second, the hypothesis that the radial pressure can be used to build a fitness function to guide the optimization of obstacles was also tested.

The formulation of the PSO iteration is as follows:

$$V_i^{k+1} = V_i^k + C_1^k \cdot N_1 \cdot \left(P_i^k - X_i^k\right) + C_2^k \cdot N_2 \cdot \left(P^k - X^k\right), \tag{9}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1}. \tag{10}$$

where k is the iteration number, X_i is the position of the ith particle of the swarm, P_i is the best point ever met by the *i*th particle in the previous iterations (corresponding to the personal best value of the objective function), P^k is the global best point ever experienced by the whole swarm, V_i is the velocity of the *i*th particle, C_1 and C_2 are two weight coefficients which influence the balance between the global and local search phase, ω is the inertia effect, χ is a speed limiter. In this paper, the values are set as follows: $C_1 = 2$, $C_2 = 1.494$, $\chi = 1.0$, $\omega = 0.729$.

The arch formation in a dense crowd is used to guide the design of the obstacle. Therefore, we focus on the variables that can influence the arch formation. In this paper, the approach that adjusting the arch formation by the obstacles is inspired by the usage of anti-slide piles in civil engineering. Anti-slide piles are a common tool to adjust the soil arching effect in civil engineering. The principle of the anti-slide pile is that it changes the position of the arch feet [27–29]. The spacing between the anti-slide piles, the size of the piles and the spacing between the piles and the exit are key configurations that influence the adjustment effect of the anti-slide piles. Therefore, we changed the corresponding variables of obstacles to adjust the effect of obstacles, which is similar with the usage of anti-slide piles. It is consist of the distance between the obstacle and the front wall and the distance between the symmetrical obstacles, see Fig. 6. The original scene is the same as the scene in the previous simulation, and the number of pedestrians is 300.

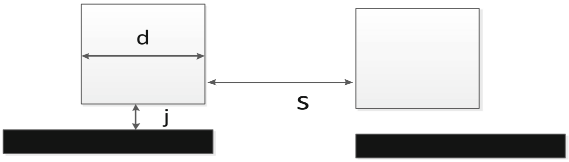


Fig. 6. The optimization variables of obstacles in our method.

The state vector is as follows:

$$x = [s|j|d]. \tag{11}$$

In this paper, the radial pressure is used to build a fitness function to guide the optimization of obstacles in evacuation scene to alleviate the crowd congestion. To demonstrate the effect of the new fitness function, a comparison test which used the average congestion value as the fitness function is given.

We use the evacuation process that pedestrians evacuate the scene as the objective function. To simplify the calculation process, a simplified method for the optimization was proposed in this paper. See Fig. 7, the red line is the congestion value in evacuation without obstacles, and the green line and blue line are congestion values in evacuation with different obstacles. It is obvious that different congestion values have a similar downtrend, which means that the congestion in a period of evacuation process can represent the congestion of the whole evacuation. Therefore, the congestion value during the 100th frame to the 120th frame is used to represent the congestion value of the whole evacuation process.

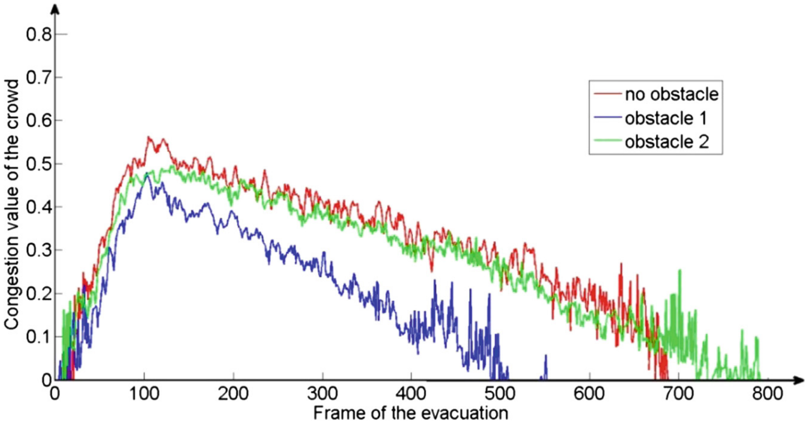
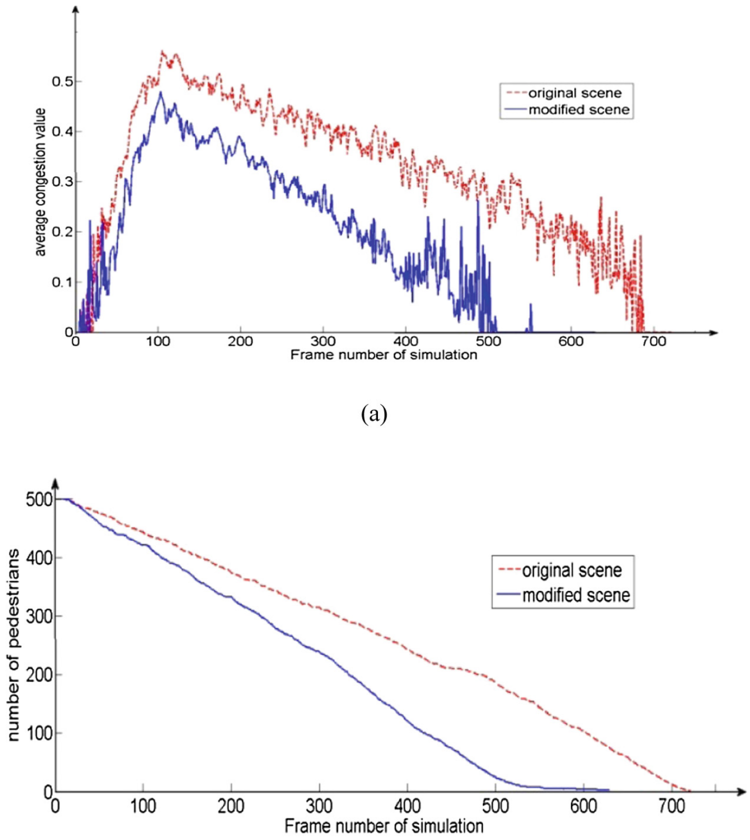


Fig. 7. The horizontal axis indicates frame numbers of the running simulation, the vertical axis indicates the average congestion value. The red line is the congestion value in evacuation without obstacles, the green line and blue line are congestion values in evacuation with different obstacles. (Color figure online)

We used the number of iterations and objective congestion value as termination conditions for the PSO. In this paper, the number of iterations we used is 10 and the objective congestion value is 0.1

4.2 Simulation Results Analysis

Here, results of simulation and analysis are given to demonstrate the effect of our approach. In Fig. 8(a), the average congestion value in different scenes are given. Obviously, the average congestion value in the modified scene is lower than it in the original scene. This result illustrates that the obstacles set according to the arch formation can truly alleviate the congestion. In Fig. 8(b), the evacuation efficiency in different scenes are presented. The frame number is corresponding with the time and number of pedestrians is used to represent the evacuation efficiency. In Fig. 8(b), the pedestrians number in the modified scene is declining more quickly than that in the original scene. It is obvious that arch formation controlled by the obstacles can increase the evacuation efficiency. Therefore, the arch formation in a dense crowd can be used to alleviate the congestion and improve the evacuation efficiency.



(a)

(b)

Fig. 8. (a) Comparison of average congestion values in different scenes. This result is the average of all congestion values of pedestrians. The horizontal axis represents frame numbers of the running simulation, and the vertical axis indicates the average congestion value. The red dash line is the average congestion value in the original scene, and the blue solid line is the average congestion value in the modified scene. (b) Comparison of evacuation efficiency in different scenes. Horizontal axis is the number of frame, and the vertical axis is the number of pedestrians in the scene. The red dash line is the number of pedestrians in the original scene, and the blue solid line is number of pedestrian in the modified scene. (Color figure online)

Figure 9 is a distribution diagram, which is drawn by our previous testing data, of the congestion value. It is used to illustrate the relations between control variables and the fitness value. The variation of congestion value of crowd is indicated by the change of color. The congestion value changes obviously when the spacing between obstacles and spacing between obstacles and the wall change and changes little with the size of obstacle. This phenomenon shows that the size of obstacles has less influence on congestion alleviation than the spacing. The distribution diagram of the congestion value can provide prior information to guide the optimization process.

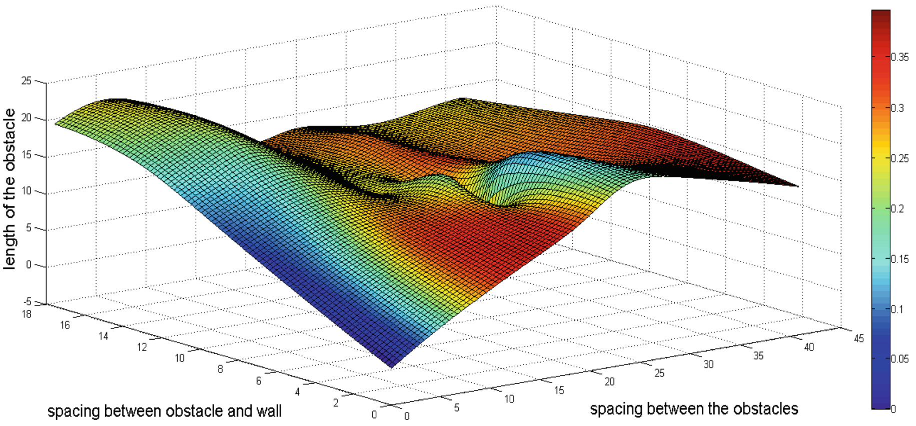
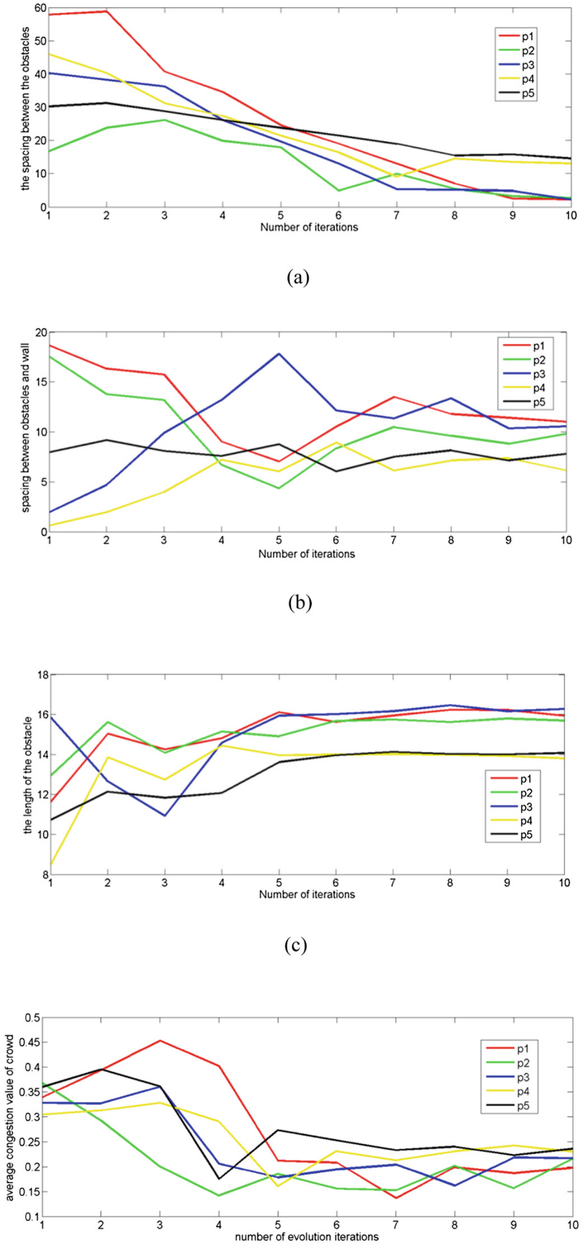


Fig. 9. Distribution diagram of the congestion value. The x axis is spacing between obstacle and the wall, the y axis is spacing between obstacles and the z axis is the size of obstacle. The different colors in the diagram indicate different congestion values. As shown in the color-bar, red color demonstrates high congestion value; blue color demonstrates low congestion value. (Color figure online)

The optimization result that guided by the fitness function which is based on the congestion value is shown in the Fig. 10. Figure 10(a) to (d) are evolution process of the spacing between obstacles, the spacing between the obstacle and the wall, the size of the obstacle and the congestion value of the crowd. The lines from p1 to p5 are different particle swarms that with different state vectors. Figure 10 shows that the optimization results of state vector are divided into two groups. The reason is that the congestion alleviation can be achieved by different approaches. Obstacles with suitable configurations may alleviate the crowd congestion without adjusting the arch formation. Although the obstacle, which would not adjust the arch formation, can also alleviate the congestion, it increases the probablity that the optimization result is trap in local optimum. Therefore, the fitness function based on the congestion value has limitation in guiding the optimization of obstacles.

The optimization result that guided by the new fitness function which is based on the radial pressure is given in the Fig. 11. Figure 11(a) to (d) are evolution process of the spacing between obstacles, the spacing between the obstacle and the wall, the size of the obstacle and the congestion value of the crowd. The lines from p1 to p5 are different particle swarms that with different state vectors. The Fig. 11 shows that the optimization results of state vector are uniformly converges to a stable value, and average congestion value is lower than that in Fig. 10. This is because the optimization guided by the new fitness function can find the suitable configuration of obstacle to adjust the arch formation, and the congestion alleviation is achieved by the arch formation. Therefore, the fitness function based on the radial pressure is suitable to guide the optimization of obstacles to adjust arch formation for crowd congestion alleviation.



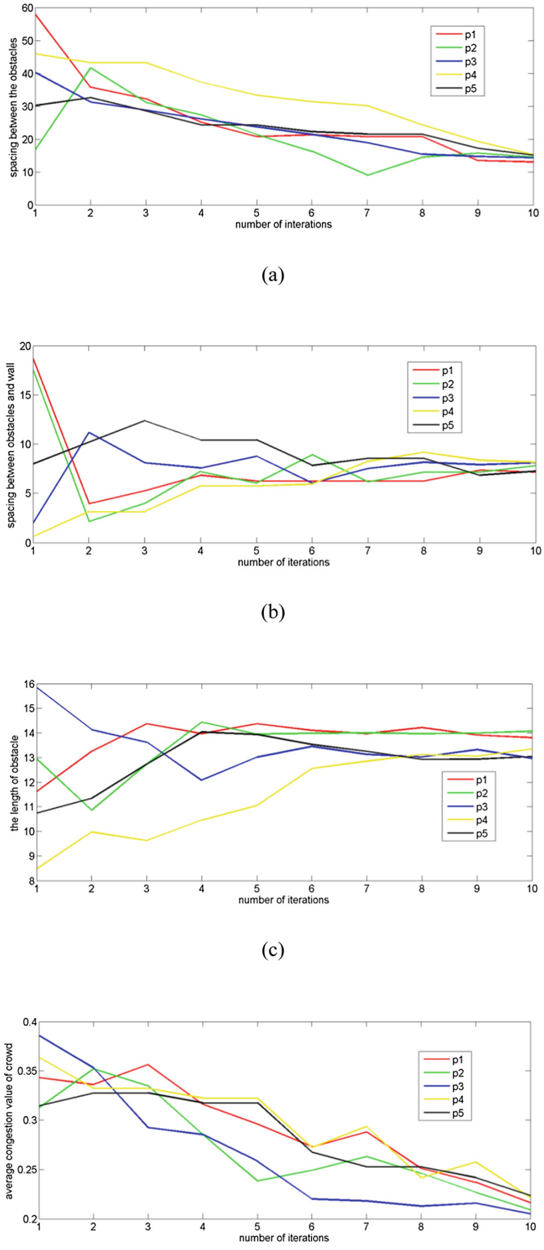
(a)

(b)

(c)

(d)

Fig. 10. These pictures show the variation of configurations of obstacles calculated by the direct fitness function. (a) the y axis is the spacing between obstacles, (b) the y axis is the spacing between the obstacles and the wall, (c) the y axis is the size of the obstacle (d) the y axis is the crowd congestion. The x axis is the number of evolution. Different colors representing different particle populations. (Color figure online)



(a)

(b)

(c)

(d)

Fig. 11. These pictures show the variation of configurations of obstacles calculated by the indirect fitness function. (a) the y axis is the spacing between obstacles, (b) the y axis is the spacing between the obstacles and the wall, (c) the y axis is the size of the obstacle (d) the y axis is the congestion value of the crowd. The x axis is the number of evolution. Different colors representing different particle populations. (Color figure online)

5 Conclusion

In this paper, we pay attention to the crowd congestion by the adjustment of arch formation in a dense crowd. The configurations of obstacles are optimized by the PSO to achieve a better adjustment of arch formation, and a radial pressure based fitness function is proposed to guide the optimization. The simulation results are as follows:

1. The arch formation in a dense crowd can be adjusted by the obstacles in evacuation scene to alleviate the crowd congestion. Therefore, the arch formation can be used to
2. The arch formation can be used to guide the optimization of obstacles. Concretely, the radial pressure, which is an index of the strength of arch formation, can be used to build a new fitness function for the PSO, and it can improve the convergence speed of the optimization process.

In summary, the proposed approach is suitable to optimize the configurations of obstacles to achieve an alleviation of crowd congestion. However, there are unresolved issues for this approach too. Although the arch formation can modify the optimization of obstacles, the adjustment is too simple for the evacuation. Since obstacles are tools for us to adjust the arch formation, the configuration of the obstacle needs further research. Our simulation environment is just a simple scene. There is a necessary for better methods to achieve the modeling and simulation of complex environments.

Acknowledgments. This research is supported by the National Natural Science Foundation of China (61472232, 61572299, 61373149 and 61402270).

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