Research on Bat Algorithm Evacuation Model Based on Entropy Correction

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Abstract. Safe evacuation is directly related to the safety of people's life and property, which is a very significant research topic. Based on the Bat Algorithm (BA) based crowd evacuation model, this paper comprehensively considers the influence of chaos degree on evacuation, introduces evacuation entropy for position correction, and constructs a BA evacuation model based on entropy correction. With the increase of the number of evacuees, the BA-based crowd evacuation model appears the phenomenon of queuing and congestion, which is alleviated by the model in this paper to some extent. Finally, the superiority of this model is verified by the comparison experiment with or without the entropy correction. The simulation results show that this model guides the crowd to avoid the chaotic area while advancing and effectively improve the evacuation efficiency.

1. Introduction
Crowding and stampede accident often lead to heavy casualties of property and people. On December 31, 2014, the Shanghai Bund suffered a stampede due to the gathering of tourists, causing 36 deaths and 49 victims. Therefore, the research on crowd evacuation has attracted the attention of many researchers at home and abroad. At present, evacuation models are mainly divided into microscopic model, mesoscopic model and macroscopic model [1]. Microscopic model has become the mainstream model of evacuation model because of its good description of evacuation individuals. The biological heuristic model is a kind of microscopic model, it relies on the similarity between biological population dynamics and crowd evacuation dynamics. Therefore, using swarm intelligence algorithm to build crowd evacuation model can better simulate crowd evacuation behavior. For example, Zong et al. [2] proposed a mixed traffic flow evacuation method based on multi-ant colony to solve the optimal path congestion problem of single ant colony. Yang et al. [3] combined cellular automata with PSO algorithm to simulate the evacuation behavior of students in teaching buildings. Hajjem et al. [4] proposed an evacuation guidance system based on ACO, which can provide more efficient and flexible evacuation schemes.

In literature [5], we introduced a new intelligent algorithm, Bat Algorithm, to construct a crowd evacuation model based on bat algorithm. Compared with the widely used PSO evacuation model, it improved the evacuation efficiency. However, in a large number of simulation experiments, it was found that with the increase of the number of evacuees, the crowd moved toward the same direction and gathered, resulting in queuing and even crowding, which greatly reduced the evacuation efficiency. In order to solve this problem, this paper introduces evacuation entropy into crowd evacuation model based on bat algorithm for position correction. Evacuation entropy was proposed by Xinquan Wei in 2015 to quantitatively describe the degree of chaos and order of crowd movement, and a mesoscopic crowd evacuation model based on entropy was constructed [6]. Zhao et al. [7] introduced evacuation
entropy into the PSO crowd evacuation framework for position correction, which improved the ordering and efficiency of evacuation. Therefore, by introducing the evacuation entropy correction sub-model, this paper constructs a bat algorithm crowd evacuation model based on entropy correction, which can guide the crowd to avoid crowding and chaos while advancing, reduce the evacuation time, and effectively improve the evacuation efficiency of the crowd.

2. Bat Algorithm evacuation model based on entropy correction

In this paper, crowd position and velocity were updated based on bat algorithm and modified based on evacuation entropy, collision was avoided by cost function, and a complete BA crowd evacuation model based on entropy correction was constructed. The flow framework is shown in figure 1.

![Figure 1. The flow framework of Bat Algorithm evacuation model based on entropy correction](image)

2.1 Position and velocity update based on BA

When an emergency occurs, the crowd in the scene begins an emergency evacuation, where the position and velocity of the crowd are used as the initial position and velocity of the evacuation model. After that, the position and velocity are updated based on bat algorithm, which is an optimization algorithm simulating that bats use echolocation to prey. The crowd is abstracted as bats, the exit position is abstracted as prey, the echolocation of bats is simulated by lights, broadcasts or other forms, and the position update model based on bat algorithm is constructed. It is mainly divided into the following three steps. For details, please refer to [5][8].

Step 1  update position and velocity

The velocity of evacuees is divided into two parts: speed direction \( D_i = [D_{ix}, D_{iy}]^T \) and speed \( S_i \). Update can be controlled by adjusting frequency and pursuing the global optimal individual. The formula is as follows.

\[
\begin{align*}
    f_i &= f_{\text{min}} + (f_{\text{max}} - f_{\text{min}}) \beta, \\
    D_i^{t+1} &= D_i^t + (x^* - x_i^t) f_i, \\
    x_i^{t+1} &= x_i^t + S_i^{t+1} \times D_i^{t+1},
\end{align*}
\]

where, \( f_i \) is the pulse frequency of evacuee \( i \). \( f_{\text{max}} \), \( f_{\text{min}} \) as the maximum and minimum frequency is constant. \( \beta \) denotes random function with the value between [0,1]. \( x_i \) is the position of evacuee \( i \). \( x^* \) is the position of the evacuee with the best fitness in the whole space. \( x^* - x_i^t \) is the unit vector that means the direction in which the individual \( i \) points to the globally optimal individual. The value range of \( S_i \) is [0,\( S_{\text{max}} \)], which is affected by the position of obstacles. Fitness reflects the good or bad position of evacuees in evacuation space, which is affected by the position of exits and obstacles.

Step 2  local search

The local search step is added to simulate the behavior that bats conduct extensive search in the early stage of prey, so that evacuees have a higher probability to perceive the position of the exit. If
the evacuee is far away from the exit and does not know the position of exit, a random local search will occur near the evacuee after getting the updated position of the evacuee. If the position after local search is better than the updated position, the search position is accepted as the updated position, that is, \( x_{i}^{t+1} = s \cdot x_{i}^{t+1} \). The local search formula is as follows.

\[
\begin{align*}
    s \cdot D_{i}^{t+1} &= D_{i}^{t} + \epsilon A^{t}, \\
    s \cdot x_{i}^{t+1} &= x_{i}^{t} + s_{i}^{t+1} \times s \cdot D_{i}^{t+1},
\end{align*}
\]

where, \( s \cdot D_{i} \) is the search direction of evacuee \( i \). \( \epsilon \) is a random function with the value between \([-1,1]\). \( A^{t} \) is the average loudness of all evacuees at time \( t \).

**Step 3** update pulse emission rate and loudness

When the bats sense prey, they will increase the rate of pulse emission and decrease the loudness, gradually shifting from search widely to moving toward the target. In order to imitate this phenomenon, we update the pulse frequency and loudness after position update, so as to promote the evacuation individual to move forward firmly and quickly towards the exit.

### 2.2 Position and velocity correction based on entropy

Position correction refers to correcting the previously obtained predicted updated position considering the influence of the degree of chaos on evacuation. Evacuation entropy evaluates the degree of chaos of evacuation by calculating the consistency of velocity direction and speed of crowd. Evacuation entropy is used to guide the crowd to the direction with low degree of chaos (i.e., low evacuation entropy). On the one hand, it can reduce the problem of low evacuation efficiency caused by crowd gathering, and on the other hand, it is also in line with the psychology of the crowd to move toward a stable region. Based on the reference [7], some changes are made in this paper to better serve the evacuation model. The main steps of position correction in this model are as follows.

**Step 1** judge whether to correct

Whether to conduct evacuation entropy correction depends on evacuation entropy threshold. Judge whether the evacuation entropy values of the 8 adjacent regions of the evacuee are all less than the evacuation entropy threshold. If there is a region larger than the threshold, the correction will be done, otherwise, no correction will be made. When the entropy values around the evacuation individual are low, the surrounding evacuation environment is relatively stable, so it is not necessary to guide the individual to move towards the relatively stable region.

**Step 2** determine correction direction

If the evacuation entropy correction is performed, the region with the lowest evacuation entropy value in the field of view is selected as the correction direction. 5 adjacent regions in the field of vision are determined according to the individual velocity direction, and the region with the lowest evacuation entropy is selected as the correction direction. If there are two or more regions with the lowest entropy, the region with the smallest angle between velocity directions is selected as the correction direction.

**Step 3** determine correction probability

After the correction direction is determined, the correction probability is determined according to whether the exit is seen, and then the correction direction is selected with correction probability to perform position correction. If the individual cannot see the exit, there will be a higher probability to select a stable region for evacuation, and the correction probability is set to 0.6. If the individual sees the exit, it will tend to move towards the exit, and the correction probability is set to 0.05.

As shown in figure 2, the black arrow is the expected update direction, the blue dotted arrow is the corrected direction, and 1-5 are the five adjacent areas in the field of vision. Figure 2(a) indicates that the region with the lowest entropy in the field of view is selected as the correction direction. Figure 2(b) indicates that when there are multiple regions with the lowest entropy, the region with the smallest angle between velocity directions is selected as the correction direction. Figure 2(c) indicates that when the entropy values in the adjacent regions are all less than the threshold, no correction will be made.
2.3 Obstacle avoidance mechanism

After getting the next position of the evacuation individual, it is necessary to judge whether the new position can be reached, that is, whether there are static obstacles and other evacuation individuals in the new position. If there are obstacles in the new position, obstacle avoidance is required. In this paper, the cost function value is used to determine the acceptable probability of next position. When the acceptable probability is 0, that is, the new position is unacceptable, obstacle avoidance measures will be adopted [8].

The flow chart of Bat Algorithm evacuation model based on entropy correction is as follows.

![Flow chart of Bat Algorithm evacuation model based on entropy correction](image)
The obstacle avoidance measure adopts the method of search around. Specifically, if the new position is unaccepted, another direction, add a random angle between -10°~10° to next step direction, would be consider. If this direction is still unaccepted, another direction, add a random angle between -20°~20° to next step direction, would be consider. By analogy until the next position is accepted.

3. Simulation and analysis
In this paper, a comparison experiment with or without evacuation entropy correction was performed using Matlab. Comparing this model with the bat algorithm evacuation model without evacuation entropy correction, we can see the positive impact of the evacuation entropy correction on evacuation.

3.1 Evacuation environment and parameter
The evacuation scene of this experiment is a single exit rectangular area of 60m×40m. The gray part of the surrounding area is the wall, and the red rectangle in the lower left corner is the exit. The number of evacuees is set to 100 and evacuation individuals are represented by circular particles. Some rectangular obstacles are randomly placed in the scene.

The values of parameters are shown in table 1. $S_{\text{max}}$ is the maximum speed of the evacuee, $R$ is the size of particles. $f_{\text{min}}$, $f_{\text{max}}$, $\alpha$, $\gamma$, $r_i^0$ are the parameters in Bat Algorithm. $\text{entropy\_threshold}$ is the evacuation entropy threshold. $\text{block\_size}$ is the grid size that is discrete for calculating the evacuation entropy value. The values of other parameters are the same as literature [5].

3.2 Analysis of simulation result
In order to reduce the impact of randomness of the initial position, we set the initial position of the two models to be the same, and average 200 groups of experiments. The simulation results were shown in table 2. As can be seen from the simulation results, compared with the evacuation model based on bat algorithm, the average evacuation time of this model is reduced by 28.24%, and the longest evacuation time is reduced by 29.70%.

A representative set of experimental data was selected to compare and analyze the influence of the introduction of evacuation entropy correction on evacuation path, evacuation efficiency and the degree of chaos in the evacuation process.

![Evacuation model without entropy correction](image1.png)  ![Evacuation model with entropy correction](image2.png)

**Figure 4.** Evacuation path

Figure 4 is a comparison of evacuation paths between two models, in which the solid blue line is the evacuation path of particles. In the early stage of evacuation, the distribution of particles is...
relatively scattered, the entropy value of each region is not high, and the influence of entropy correction on evacuation path is not obvious. In the later stage of evacuation, especially in the part near the exit, the entropy value increases gradually as the crowd gathers, and the effect of entropy correction becomes obvious. Compared with figure 4 (b), the route of figure 4 (a) is more concentrated and evacuation is more orderly. It seems that the result of figure 4 (a) is better. But in fact, most particles swarm into the space between two square obstacles in the lower left corner, causing congestion and seriously reducing evacuation efficiency. After the introduction of entropy correction, particles no longer focus on one road, but advance toward the exit in several roads, making greater use of space and improving evacuation efficiency.

As shown in figure 5, during the entire evacuation process, the number of evacuation individuals who haven’t left in the model with entropy correction is smaller than that without entropy correction. This indicates that in the same time, this model successfully evacuates more particles, with higher evacuation efficiency and better evacuation effect.

It can be seen from figure 6 that in the initial stage of evacuation, the entropy values of the two models are not much different. As the evacuation progresses, the entropy difference between the two models gradually increases. It shows that in the initial stage of evacuation, the particle distribution is more dispersed, the value of each region does not reach the evacuation entropy threshold, most particles does not make entropy correction, so the degree of confusion between the two models is not much different. With the progress of evacuation, the crowd gradually concentrates and the entropy correction begins to work. The total entropy value of the model with entropy correction begins to be smaller than the model without entropy correction. In the later stage of evacuation of the model without entropy correction, because the crowd gather around the exit and cannot be dispersed, it is difficult to reduce the degree of chaos, and a short platform period appears. In general, after the introduction of the evacuation entropy correction, crowd evacuation is more dispersed, which avoids crowd congestion to a certain extent and prevents the occurrence of more serious stampede.

4. Conclusion
The current evacuation model rarely quantitatively considers the impact of chaos on population evacuation. In this paper, on the basis of evacuation model based on bat algorithm, evacuation entropy, which represents the degree of chaos, is introduced to correct position. This model alleviates the queuing congestion problem of the original model to some extent, reducing the average evacuation time by 28.24% and the longest evacuation time by 29.70%, effectively improving the evacuation efficiency. In the future, we can start from the reality, study the influence of obstacles, guides and guiding signs in the environment as well as the panic and kin behavior caused by individual psychological on evacuation, so as to make the evacuation model more consistent with the reality.
Acknowledgment
This work was supported by the National Natural Science Foundation of China (No. 71573190).

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