IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received August 15, 2019, accepted September 16, 2019, date of publication September 25, 2019, date of current version October 8, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2943603

Modeling Group Structures With Emotion in Crowd Evacuation

YAN MAO[1], XINMIAO FAN[2,3], ZIXUAN FAN[2,3], AND WU HE[2,3]
[1]School of Business, Sichuan Normal University, Chengdu 610000, China
[2]College of Movie and Media, Sichuan Normal University, Chengdu 610000, China
[3]Visual Computing and Virtual Reality Key Laboratory of Sichuan Province, Sichuan Normal University, Chengdu 610000, China

Corresponding author: Wu He (wuhe83@163.com)

This work was supported in part by the National Natural Science Foundation of China under Grant 81560372, in part by the Scientific Research Fund of Sichuan Provincial Education Department under Grant 16ZB0069, in part by the Key Science Project of Sichuan Province of China under Grant 17ZA0392, and in part by the Visual Computing and Virtual Reality Key Laboratory of Sichuan Province under Grant KJ201413.

ABSTRACT Simulation on crowd evacuation has attracted plenty of attention in the past few years. Emotion plays a significant role in human decision making processes and on the behaviors during the evacuation. Moreover, grouping is a common phenomenon in crowds, and there are a lot of roles included in a group. In this paper, we present a unified framework to model the structure aspect of the groups with emotion for a crowd suffering fires and explosions in public areas. The proposed evacuation framework consists of two components: (1) an emotion model for various roles in the case of an emergency. Emotional changing is a complex process where different roles are influenced by different factors. (2) Both intra-group structure and inter-group relationship are considered to simulate the herd phenomenon in emergency. The structure and behaviors of a group are related to the emotions of different roles. A follower can decide whether to leave the group or not according to the emotion of the group leader and the one of his own, thus the members of the group may always dynamically change. Simulation results show that the developed framework can practically model the emotion changing and different group structures of evacuation crowds.

INDEX TERMS Simulation, crowd evacuation, emotion, group structure.

I. INTRODUCTION

Modeling and simulating evacuation crowd have been an active research topic in recent years. Many applications can benefit from modeling crowd evacuation, such as safety engineering, computer game, site planning, and emergency plan. In some large and crowded places, people are prone to chaos and congestion when an emergency occurs, resulting in huge economic losses, and even casualties. If we can simulate the evacuation of large crowds in complex buildings, it will realize a guiding significance for the emergency plan in an emergency. Researchers have developed many approaches to simulate evacuation behaviors in emergent situations [1], [2], [3]. Some of the existing crowd behavior models were based on homogeneous individuals [4], [5], while some others employed the heterogeneous individual as the research object to simulate evacuation processes [6], [7].

The associate editor coordinating the review of this manuscript and approving it for publication was Bora Onat.

Grouping is a common phenomenon in crowds in the real world, e.g., pedestrians will form a group with other individuals due to social relationship, the same goal, and so on. Santos *et al.* [8] thought that groups have four features including the context of the group operate, the aggregation of group members, group density, and relationships. Reference [9] presented a knowledge-based framework to model crowd motions in an unfamiliar environment. Different group structures can affect the efficiency and the realistic of evacuation crowds. For instance, a leader-follower structure is closer to the reality than a clustered structure, because people have a herd mentality in emergency situations.

From psychological findings [10], emotion constrains perception and reasoning so that evacuees with different emotions make different behavior decisions in the same environment. More and more studies have shown that it causes a huge difference between simulation results and real evacuation results, if the impact of emotion has not been considered during the simulation.

In this study, we propose a unified modeling and simulation framework for crowd evacuation that integrates emotion into the group structure. Each a group is constructed by a Leader-Follower model including a leader and some followers. The intra-group structure and inter-group relationship maintain the movement of a crowd. On the other hand, the emotions of individuals are affected by many factors, such as their roles, accident, and time. Each phenomenon (emotion, emotional change, intra-group structure, and inter-group relationship, etc.) has been implemented in our simulation framework.

Experiments are performed by using this framework to investigate the impact of emotion on evacuations. Particularly, the influence of leader's emotion on follower's emotion and behavior, and the size and movement of group will be investigated. Observing simulation results, we find that pedestrians escaping as multiple groups beads on Leader-Follower model with emotion exhibits a significant influence on the evacuation process.

The major contributions of this paper are listed as:

1) We propose a novel crowd behavior simulation method, which combines Leader-Follower model with emotional model, to simulate how people in panic follow their leader and escape.
2) We establish a novel emotion model to describe the different emotional contagion mechanisms of leaders and followers through both intra-group structure and inter-group relationship.
3) We present an improved social force model, which not only considers the forces among the individuals within a group, but also takes the ones among the groups into account.

The remainder of this paper is organized as follows: In Section 2, we review the evacuation simulation based on individual characteristics and the methods combining emotion and behavior models. Because this paper divides individuals into groups, the modeling of group is also reviewed. Section 3 presents a unified framework that models the intra-group structure and inter-group relationship of the pedestrian crowds under the influence of emotion. Section 4 provides some experiment results to demonstrate the effectiveness of integrating the emotion into a group structure for crowd evacuation. We summarize this paper and discuss future work in Section 5.

II. RELATED WORK

Simulations on crowds have gained tremendous attentions in recent years. There exist some models that are widely used to describe pedestrian behavior, for example, rule-based flocking systems [11], social forces model [12], lattice gas model [13], [14], cellular automaton model [15], and floor field model [16]. Physical property is an important factor that can not be ignored in crowd simulation. In order to describe the chaotic emergent behaviors at high densities, Golas et al. [17] used a continuous method in which interpersonal forces is represented as stress fields caused by discomfort and friction of the underlying simulated pedestrians. Luo et al. [18] proposed a framework to model proactive steering behaviors for agent-based crowd simulation, and the framework is extensible to incorporate different proactive steering behaviors for complex crowd scenarios.

Emergency evacuation is an important application area of crowd behavior simulation, in which the heterogeneity of agents, such as personality and emotion, is important to achieve a more realistic process of crowd movement [19]. Exploiting the well-known Eysenck 3-Factor personality model, Guy et al. [20] presented a modeling technique to generate heterogeneous crowd behaviors by adjusting the simulation parameters, which is mapped to the personality model. By adopting the OCEAN (i.e. openness, conscientiousness, extroversion, agreeableness, neuroticism) personality model and the OCC emotion model, Mao et al. [21] proposed an emotion based agent modeling framework to simulate crowd behaviors in public emergency. Liu et al. [22] proposed a personality-based emotional contagion model and simulated the crowd evacuation behaviors in a fire scenario, and they found that appropriate emotional contagion can speed up the evacuation of the crowd. Nguyen et al. [23] proposed a mathematical formalization of its two main components: emotion and its dynamic change to simulate multi-agent evacuation. Aydt et al. [24] offered an emotion engine based modern appraisal theory, which is able to model various emotional crowd characteristics. In [25], a simulation with psychological parameters was proposed, in which agents are endowed with three characteristics: personality based on the OCEAN model, mood based on the OCC model and emotion based on Pleasure-Arousal-Dominance model.

Integrating emotion and dynamic group behavior model, Mao et al. [26] discussed the impacts of emotion on their moving speed, the desired goal and path planning. In [27], a belief–desire–intention based extended decision field theory was proposed, which can simulate the human decision-making process driven by emotion under a dynamic environment. Luo et al. [28] gave emotional attributes to agents to estabtish a generic behavior modeling and simulation framework for crowd simulation, while focusing on imitating real human's decision-making process. Cai et al. [29] constructed a hierarchical model for virtual miner, which incorporates a finite state machine based behavior module and an emotion model combining OCEAN and OCC models. Results from [29] shown that the virtual miner' emotions exhibit an impact on their behavior choice. Lyu et al. [30] presented an emotion network by using theories of social network and interagroup emotions, and calculated motion variables through emotion commands.

In addition, hierarchical models, which can organize the individuals into large crowds, groups and individuals, have been developed [31]. Most of existing works on evacuation modeling and simulation adopt flow-based and individual-based approaches. Few work focuses on the aspect of grouping and group structures. Adopting scalar field method, Fang et al. [32] proposed a leader follower model, which

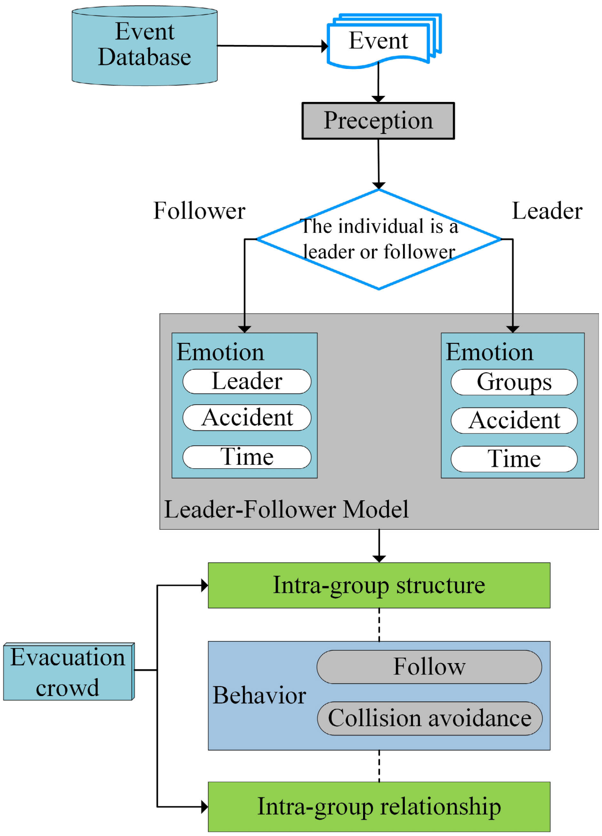


FIGURE 1. The framework of evacuation of this paper.

has the capability to simulate some social collective behaviors such as queuing and collective mobility and suffered difficulty handling counter-flow conditions in dense crowding situations. Qiu and Hu [33] proposed a novel well-defined framework to model the structure aspect of different groups, and an agent-based simulation system was designed to model the crowd behaviors with group structures. In [34], an improved social force model was proposed, in which group members are attracted by the leader to ensure that every individual follows its leader. Qin et al. [12] established a two-layer relationship mechanism, and added the aggregate force and collective collision avoidance force into the original social force to reproduce the self-organization phenomenon of the bi-direction pedestrian flow. In [35], agents are divided into groups based on their relative proximitys, and their desired velocity is calculated by social force model. However, most of these works did not consider the emotions of groups, which have an important impact on the evacuation of a crowd. We incorporate an emotion model into the evacuation framework, in which each group is built by using a Leader-Follower model, to simulate the dynamic changing of group structure.

III. SIMULATION DESCRIPTION

The main goal of this paper is to design a unified simulation framework to systematically model the different aspects of the group structure with emotion in evacuation crowd, as shown in Fig. 1. During the evacuation, individuals naturally follow the nearby individuals to form a group. Thus, an evacuation crowd consists of many groups, and each group is composed of different individuals with two roles, leader and follower. We consider emotion as a particular mental state which shows an important impact on the behaviors of the group individuals. Emotion is short-term and elicited from multiple factors, e.g., events, other individuals and objects. In the following sections, we will describe the emotion changing in groups via a Leader-Follower model and group structure of the crowd.

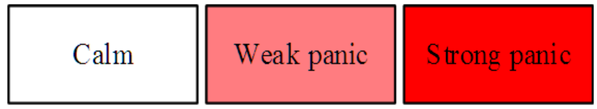


FIGURE 2. Particular colors represent the corresponding emotions.

A. THE EMOTION OF THE LEADER-FOLLOWER MODEL

A crowd contains a set of groups, each of which is based on a Leader-Follower model. In other words, a group contains a group leader and some group followers. The emotions and behaviors of the followers are influenced by the leader in the same group. However, the leader is influenced by someone follower in other groups. Similar to [36], the panic intensity of an individual is modeled as a floating point number depending on other individuals, accident and time in the emergency situation. Thus, $E_{panic}(t)$ represents the panic intensity felt by individual i at time t and $E_{panic}(t) \in [0, 1]$. We divide the emotion of an individual into three stages: $E_{panic}(t) \in [0, 0.3]$, individual i is calm; $E_{panic}(t) \in (0.3, 0.6]$, individual i feels weak panic; $E_{panic}(t) \in (0.6, 1]$, individual i feels strong panic. Each individual uses different colors (white, pink, and red) to graphically stand for his current emotion level, as shown in Fig. 2.

1) THE EMOTION CHANGE OF FOLLOWERS

During the evacuation, the emotions of the followers vary in real time. At each time step, t, we calculate the follower i's emotion of these three elements separately and clamp their sum between 0 and 1 as

$$E_{panic_i}(t) = \min(1, E_{panic_i}(t-1) + E_{leader\to i}(t) + E_{fire\to i}(t) + E_{time\to i}(t)) \quad (1)$$

where $E_{panic_i}(t-1)$ is the panic intensity of the follower i at the previous moment, $E_{leader\to i}(t)$ represents the intensity of the emotion spread by the leader towards follower i, $E_{fire\to i}(t)$ defines the intensity of the emotion spread by the accident, $E_{time\to i}(t)$ is the value of the emotional decay.

a: PANIC INTENSITY CHANGE BY THE LEADER

In a group, the leader serves as an important role in the emotions of the followers during the process of evacuation. The panic intensity of a follower decreases if the group leader does not feel panic; on the contrary, panic intensity will increase. In addition, we should consider that the leader expresses his emotion to the group followers in a different way, thus let λ_{leader} be the emotional expression power of the leader. The value of the expression power is a random variable and $\lambda_{leader} \in [0, 1]$. The intensity of emotion spread by the leader towards follower i can be expressed as

$$e_{leader\to i}(t) = \lambda_{leader} \cdot d_{leader} \cdot E_{panic_l}(t) \tag{2}$$

where $E_{panic_l}(t)$ means the panic intensity of the leader at time step, t, d_{leader} is a physical factor describing the distance between follower i and its leader. According to [37], it can be given by

$$d_{leader} = 1 - \frac{dis_{leader,i}}{Dis_{group}} \tag{3}$$

where $dis_{leader,i}$ is the physical distance between the leader and follower i, Dis_{group} is the maximum distance between the leader. So, the larger d_{leader} is, the more severely the follower i is influenced by the leader.

According to [38], the acceptable emotion of the followers not only depends on the emotion expression of the leader, but also relays on the neuroticism, a personality traits of the follower own [39]. The greater the value of neuroticism is, the easier emotion changes

$$E_{leader\to i}(t) = \delta_i e_{leader\to i}(t) \tag{4}$$

where δ_i means the neuroticism of follower i, and $\delta_i \in [0, 1]$. The value of δ_i is randomly initialized for each follower at the beginning of the evacuation simulation. For example, follower i accepts only 50% of the emotion intensity which spread by the leader, when $\delta_i = 0.5$.

b: PANIC INTENSITY INCREASE BY ACCIDENT

A sudden incident may occur in the scene, such as fires in the building. Moreover, individuals may change their positions in real-time during the evacuation, as they can dynamically perceive emergency events. When a follower perceives an accident, such as fires, his emotion intensity will increase. The intensity of the emotional increasing is related to the damage intensity of the fire and the distance between the fire and follower i

$$e_{fire\to i}(t) = \begin{cases} d_{fire} Int_{fire}(t), & dis_{fire,i} \le Dis_{fire}, \\ 0, & dis_{fire,i} > Dis_{fire}, \end{cases} \tag{5}$$

where $Int_{fire}(t)$ means the intensity of the fire at moment t. The intensity can dynamically change with the rising and fall of the fire in order to simulate more realistic evacuation process. $Int_{fire}(t) = 1$ indicates that the fire is exuberant, and $Int_{fire}(t) = 0$ means the fire has gone out. d_{fire} is a physical factor describing the distance between agent i and the fire. Similar to Eq. (2), it can be described as

$$d_{fire} = 1 - \frac{dis_{fire,i}}{Dis_{fire}} \tag{6}$$

where $dis_{fire,i}$ is the distance between the fire and follower i, Dis_{fire} is the maximum influence distance of the fire that individuals are not affected.

At the same time, an individual can perceive multiple fires within his perceive range. All of the fires perceived can affect follower i. Similarly, the acceptance of the emotion intensity depends on the neuroticism of follower i. The influence of the fire on follower i emotion can be given as

$$E_{fire\to i}(t) = \delta_i \sum_{f} e_{fire\to i}(t-1) \tag{7}$$

c: PANIC INTENSITY DECAY WITH THE TIME

The change of emotion is a complex process which depends on multiple factors. Emotions of the individuals increase due to stimuli and other individuals. However, the panic of an individual is not always active, which decays and disappears over time. Similar to [40], at each time step t, the value of an emotion intensity decreases as

$$E_{time\to i}(t) = -\beta_i E_{panic_i}(t) \tag{8}$$

where β_i is a decay coefficient, which determines the speed of emotional decay, which β_i ranges in (0,1), and the larger β_i is, the faster emotional decline will occur.

2) THE EMOTION CHANGE OF LEADERS

In the real world, crowd has a herd phenomenon in an emergency, following the front pedestrian to move. However, not all leaders are trained to control their emotions strictly and fully understand the environment. For instance, leaders can always keep calm and do not feel panic if they are firemen. If leaders are the employees in the mall, they may not feel panic too much because they have a comprehensive understanding of the environment. Leaders will also tend to panic and worry if they are just the shoppers without any related trainings in the mall.

Leaders can manage their emotions more effectively and minimize the impact of the external stimuli on themselves if they have been trained. But the emotional changing of the leaders is still a complex process, including the effects of other groups, fires, and time. So we define the emotion intensity of a leader as

$$E_{panic_l}(t) = \min(E_{panic_l}(t-1) + E_{group\to leader}(t) + E_{fire\to leader}(t) + E_{time\to leader}(t), 1) \tag{9}$$

where $E_{panic_l}(t-1)$ is the panic intensity of the leader at time step, $t-1$, $E_{group\to leader}(t)$ represents the intensity of emotion spread by a group towards the leader, $E_{fire\to i}(t)$ defines the intensity of the emotion spread by the accident, $E_{time\to i}(t)$ is the decay function of the emotion over time is equal to Eqs. (8).

a: PANIC INTENSITY CHANGE BY OTHER GROUPS

As mentioned before, only the group leader's emotion is influenced by the individuals in other groups. The mechanism of the group's effect on the leadership is similar to that of the leader's effect on followers, which is expressed as

$$e_{group\to leader}(t) = \lambda_{group} \cdot d_{group} \cdot E_{panic_{group}}(t) \tag{10}$$

where λ_{group} means the emotional expression power of the group and $\lambda_{group} \in [0, 1]$. $E_{panic_{group}}(t)$ means the emotion intensity of the group at the previous time moment, d_{group} is a physical factor describing the distance between the leader and the group, which is defined by the maximum perception distance Dis_{leader} and the Eulerian distance between the group and the leader $dis_{group,leader}$ as

$$d_{group} = 1 - \frac{dis_{group,leader}}{Dis_{leader}} \tag{11}$$

The group emotion is the average value of emotions of all the individuals in the group as follows

$$E_{panic_{group}}(t) = \frac{\sum_{i=1}^{Num_{group}} E_{panic_i}(t)}{Num_{group}} \tag{12}$$

where Num_{group} is the total number of the individuals in the same group, and $E_{panic_i}(t)$ indicates the emotion intensity of individual i.

The acceptance of the leader relys on training level, besides of the neuroticism, which can be describe as

$$E_{group\rightarrow leader}(t) = (1 - Train_l) \cdot \delta_{leader} \cdot e_{group\rightarrow leader}(t) \tag{13}$$

where $Train_l$ indicates the training level of the leader and the value of $Train_l$ varies in [0,1]. A larger $Train_l$ represents the leader's emotion is less affected by other groups. Actually, each individual in the group is assigned with a variable training level, but it will be considered only when the individual becomes a leader. The variable training level is initialized for each individual in a random manner at the beginning of the simulation. The leader may perceive multiple groups within the perceived range at the same time, and different groups have different effects on the leaders. This paper only consider the maximum influence of other groups on the leader. Moreover, δ_{leader} means the neuroticism of the leader.

b: PANIC INTENSITY INCREASE BY ACCIDENT

Similarly, a leader is also affected by fires during the evacuation. We present a function to calculate the part of panic generated by fires as follows

$$E_{fire\rightarrow leader}(t) = (1 - Train_l) \cdot \delta_{leader} \cdot \sum_{f} e_{fire\rightarrow leader}(t) \tag{14}$$

where $e_{fire\rightarrow leader}$ can be calculated by using Eqs. (5) and (6). Differing from the followers, the emotion changing of the leader is related to the training level. The leader with a high training level can minimize the panic caused by the fire.

B. GROUP STRUCTURES

In our work, a crowd consists of some other different groups formed by many individuals. At one time, each individual only belongs to one group. However, the grouping will not be fixed, because individuals are able to dynamically choose groups. Note that the number of the individuals in each group is greater than or equal to 1. Similar to [33], the group structure of a crowd is composed of two aspects: *intra-group structure* and *inter-group relationship*. Within a group, the intra-group structure is maintained by the leader-to-follower influencing relationships in Leader-Follower model. Meanwhile, the group-to-group relationships form the inter-group relationship.

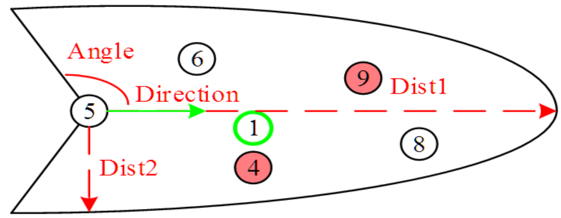


FIGURE 3. The perception range of an individual (The leader is labeled a green circle).

1) INTRA-GROUP STRUCTURE

As we simulate crowd motion by using the social force model [41], then emotion will change the velocity of an individual by the forces in social force model. In a group, each individual is set with a unique *ID*. we assume that the individual with the smallest *ID* is the leader in a group at the beginning of simulation. Similar to [35], the current moving direction of an individual is marked as Direction, and the perception range of the individual ($ID = 5$) is an elliptical area, as shown in Fig. 3. The individual ($ID = 1$) who is marked in green is the leader of the group. Angle defines the individuals perceptual field of view, and the distance of the visibility is specified by *Dist1* which defines the maximum front distance for visibility and *Dist2* which defines the maximum side distance for the visibility. In our work, *Dist1*, *Dist2*, and *Angle* are set to 25**Radius*, 6**Radius*, and 120 degrees, respectively. Moreover, the body radius of each individual is specified by *Radius*.

We consider that the behaviors of each individual (the leader and the followers) are composed of two aspects: Following and Collision avoidance.

Following: Herd behavior among a crowd is a common phenomenon in an emergency. As a group follower, its moving direction is mainly instructed by the leader. Secondly, the follower also follows the average moving direction of other followers in the same group. As a group leader, he may move towards the moving direction of some individuals in other groups. This behavior allows individuals in the same group to approximately move toward to the exits in the same direction. However, the leader will lose the leadership if his emotion is too panicky, and some followers will not continue to follow the leader and join other groups.

Collision avoidance: In the process of the movement, an individual may collides with other individuals in real time, which may cause push and stampede accidents. Therefore, the collision avoidance behavior of the individuals can keep safe distances among individuals, and improve the evacuation efficiency.

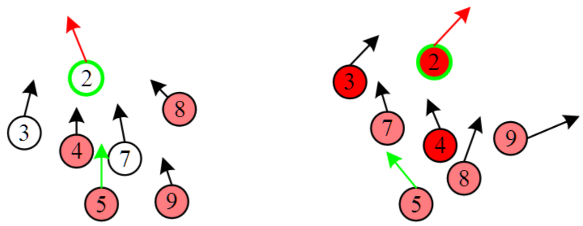


FIGURE 4. The emotion of the leader has an effect on the direction of the movement direction of followers.

a: FOLLOWING OF GROUP FOLLOWERS

Follower i will not only considers the moving direction of the leader, but also consider the moving direction of the neighbors in the same group and within the perception range, and the individual direction in last moment, as follows

$$\overrightarrow{v}_{foll_i}(t)=\gamma[E_{panic_i}\overrightarrow{v}_{foll_i}(t-1)+(1-E_{panic_i})\langle\overrightarrow{v}_{foll_j}(t-1)\rangle_i + (1-E_{panic_l})\overrightarrow{v}_{leader}] \quad (15)$$

We assume that three influence factors are weighted with parameter $E_{panic_{leader}}$ and E_{panic_i}. $\gamma(Z) = Z/\|Z\|$ means normalization of a vector Z. The emotion intensity E_{panic_i} of follower i influences the follower's preferred the individual direction $v_{foll_i}(t-1)$ or the average direction of other followers $\langle v_{foll_j}(t-1)\rangle_i$. We think calm individuals will keep the entirety of the group. Followers deviate from the group and choose individualistic behavior if E_{panic_i} is high, and follow other individuals calmly to maintain intra-group structure, if E_{panic_i} is low. On the other hand, the emotion intensity E_{panic_i} reflects the leader's degree of the leadership, followers follow the moving direction of the leader while E_{panic_i} is low; otherwise, the followers will not follow the leader, as shown in Fig. 4.

b: COLLISION AVOIDANCE OF INDIVIDUALS

Collision behavior may occur at any time in the process of real-time movement of the individuals (the leader and the followers). These behavior not only exists between the follower and the follower, but also exists between the follower and the leader in a group. In a simulation scenario, the obstacles may be static objects, walls, and other dynamic followers. The acceleration of the collision avoidance of individual i can be described as

$$m_i d\overrightarrow{v}_{avd_i}/dt = \sum_W \overrightarrow{f}_{iW} + \sum_j (\neq i)\overrightarrow{f}_{ij} \quad (16)$$

where $d\overrightarrow{v}_{avd_i}/dt$ represents the acceleration of the collision avoidance generated by individual i, due to walls and other individuals in time t, m_i is the mass of individual i, $\overrightarrow{f}_{iW}$ means the interaction force between individual i and wall W, $\overrightarrow{f}_{ij}$ is the interaction force between individuals i and j. These two interaction forces make the individuals keep the distances to other individual j and wall W.

We incorporate the speed of an individual with emotion intensity, and the desired speed $v_i(t)$ of the individual i in social force model are improved as

$$v_i(t) = \gamma_i(1-E_{panic_i}(t))v_i(t-1) + E_{panic_i}(t)v_i^{max} \quad (17)$$

$$\gamma_i = \begin{cases} 1, & \textit{if individual } i \textit{ is a follower} \\ 1.5, & \textit{if individual } i \textit{ is a leader} \end{cases} \quad (18)$$

where $E_{panic_i}(t)$ indicates the emotion intensity of individual i at time t, v_i^{max} is the maximum speed of individual i. The speed of a leader is higher than that of a follower. The greater the emotion value is, the greater the maximum speed v_i^{max} will be. In the experiments, we set v_i^{max} for individual i with calm as 1m/s, v_i^{max} for individual i with weak panic as 1.3m/s, and v_i^{max} of individual i with strong panic as 1.6m/s.

2) INTER-GROUP RELATIONSHIP

Each group has a unique *GroupID*. During an emergency evacuation process, a group is likely to follow other groups nearby due to the lack of an objective evaluation of the emergency situation [42]. In our work, groups maintain the inter-group relationships primarily through the behaviors of the leaders.

a: FOLLOWING OF GROUP LEADER

The group leader is influenced by the individuals in other groups and follows the individual that has the greatest similarity. The similarity $Similarity_j$ between leader *leader* and individual j in other groups is affected by two aspects: distance and emotion, as follows

$$Similarity_j = \frac{1-E_{panic_j}}{Distance(leader, j)} \quad (19)$$

$$MSId = Max(Similarity_1, \ldots, Similarity_n) \quad (20)$$

$$Follow = \begin{cases} \textit{leader with MSId}, & \textit{if MSId exists} \\ \emptyset, & \textit{otherwise} \end{cases} \quad (21)$$

The shorter the Euclidian distance $Distance(leader, j)$ from *leader* to individual j is, and the lower of emotion intensity E_{panic_j} of individual j is, and further more likely the *leader* will follow individual j. However, if there is no such a follower in other groups in the perception range, the *leader* will not follow any other individuals.

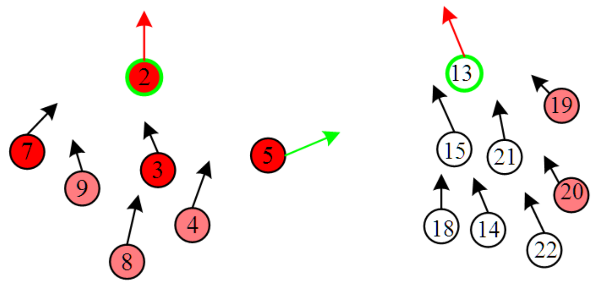
b: DYNAMIC GROUPING OF CROWD

The members of the group who can dynamically select groups are not fixed. When the emotion intensity E_{panic_l} of the group leader is greater than the threshold κ_i (the emotion intensity that follower i can accept), follower i will leave the original group. Then, follower i will join other groups with the most similarity and follow the leader of the new group, as shown in Fig. 5. The process of dynamic grouping is presented as

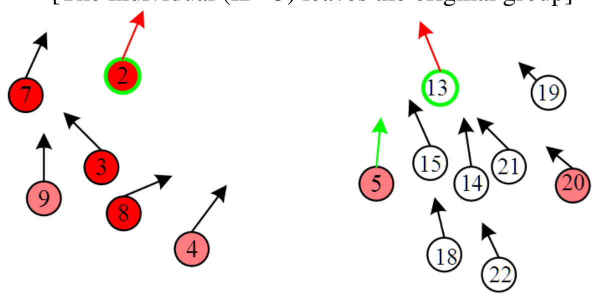
$$Similarity_{leader} = \frac{1-E_{panic_l}}{Distance(i, leader)} \quad (22)$$

$$MSId = Max(Similarity_1, \ldots, Similarity_n) \quad (23)$$

$$Select = \begin{cases} \textit{group with MSId}, & \textit{if MSId exists and } E_{panic_l} > \kappa_i \\ 0, & \textit{otherwise} \end{cases} \quad (24)$$



[The individual (ID=5) leaves the original group]



[The individual (ID=5) joins a new group]

FIGURE 5. **The process of dynamic grouping of individuals.**

IV. EXPERIMENT

We run a diverse set of crowd simulation in various situations, and all experiments are realized by using C++ in the Visual Studio 2013 and Unity 3D 6.0. We implemented on a PC with Windows 10, Inter Core i7 3.6 GB processor, an AMD Radeon R5 graphics card, and 8 GB RAM.

Two principal characteristics of pedestrian movements (the flow and the individual) are considered in this section. The evacuation crowd realized by using divided into a series of groups. The inter-group relationship implemented by adopting flow-based approach, and the intra-group structure is individual-based approach. The experiments mainly include four parts: 1) We simulated evacuations with or without emotional contagion to analyze the importance of our emotional mechanism. 2) We analyzed the effect of the leader on emotional contagion and evacuation time. 3) We simulated evacuations considering leaders with different training levels. 4) We validate the effectiveness of our simulation results by comparing with [25] and [35]. In addition, when the emotions of individuals are affected by the accidents, we choose different colors to represent different emotional intensity. White stands for calm ($E_{panic}(t) \in [0, 0.3]$), red for extreme panic ($E_{panic}(t) \in (0.6, 1]$), and pink is between these two states ($E_{panic}(t) \in (0.3, 0.6]$). Furthermore, leaders are marked in green.

A. COMPARE THE EVACUATION RESULT OF CROWD WITH OR WITHOUT EMOTION

We compare the evacuation results of the crowd with or without considering emotion in the shopping mall with 200 individuals. The simulation scenario is with a size of size 35m × 30m. There are five small rooms in this scenario and we mark A, B, C, D, E, respectively. In addition, at the beginning of the simulation, there is only one group in each room. Simulation results without emotion are shown in Fig. 6. Since the influence of emotion has not been considered in the evacuation model, each group has a fixed membership. Fig. 7 shows the evacuation crowd simulation with emotional contagion. At the start of the simulation, some panic followers are wandering briefly, so as to show that some pedestrians are at a loss when an emergency occurs in the real world. Soon, the individuals evacuate to the exits together in groups. From Fig. 7, we can see that individuals show different emotions in groups, and the emotions of individuals are constantly changing. For example, a follower can vary from calm to panic, because of closing the fire, and he can also change from panic to calm due to the positive infection of the leader. Moreover, the results of the crowd simulations with emotional contagion show that the members of the groups with emotion will change. For example, some members in Group D leave from Group D and join Group E. This is the main reason for the differences between Fig. 6(b) and 7(b).

On the other hand, compared with the groups with emotion, the speed of the groups without emotion is slower, as shown in Fig. 6(b), and the individuals remaining in the shopping mall are more than the ones shown in Fig. 7(b). In addition, the followers with strong panic, are in front of the followers with other emotions in most of the groups, as depicted in Fig. 7(b). This is because emotions can affect the individual's speed, which can be explained by Eqs. (11). The experiment shows that our model can simulate real-world emergency situation more realistically, as individuals are set with different levels of emotion during the crowd evacuation.

To further prove the effect of emotion on individual's speed, we compared the evacuation time between the groups with emotional contagion and those without emotions. In this experiment, the pedestrian size varies from 100 to 800. The comparison results are presented in Fig. 8. This gap of evacuation times will gradually increase, as the size of the crowd increases. However, when the number of individuals exceeds 500, the gap narrows. Because the large number of individuals leads to congestions.

B. THE INFLUENCE OF LEAER ON GROUP EMOTIONAL CONTAGION

The simulation includes 200 individuals who are distributed in an indoor environment with a size 20 m × 20 m. A simulation scenario with seven exits is shown in Fig. 9. In a real scenario, there are many reasons for the formation of group structure. In the initialization stage of the experiment, the individual with relatively a close distance form a group and the individual with the smallest ID is selected as the leader of the group. In this experiment, the training value of all leaders are set as 0.9. In other words, the emotions of the leaders will not easily change during the evacuation.

In the early stage of the evacuation, most of the individuals are in a state of strong panic (color: red). With the passage of time and being gradually away from the fire source, the emotions of the followers are infected by the

(a) t=5 s (b) t=10 s

FIGURE 6. The evacuation crowd without considering the impact of emotion. (a) t = 5 s. (b) t = 10 s.

(a) t=5 s (b) t=10 s

FIGURE 7. The evacuation crowd under the impact of emotion. (a) t = 5 s. (b) t = 10 s.

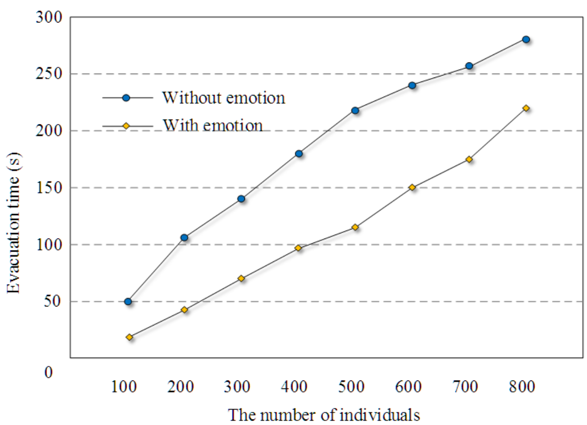


FIGURE 8. The comparison of evacuation time of crowd with or without considering emotions.

calm emotion of the leader in the same group. Emotional values gradually decrease and tend to be calm (color: white). Meanwhile, the followers move along with the leaders to the appropriate exit without any collisions, and they do not leave the group or join another group, because the all leaders always keep calm.

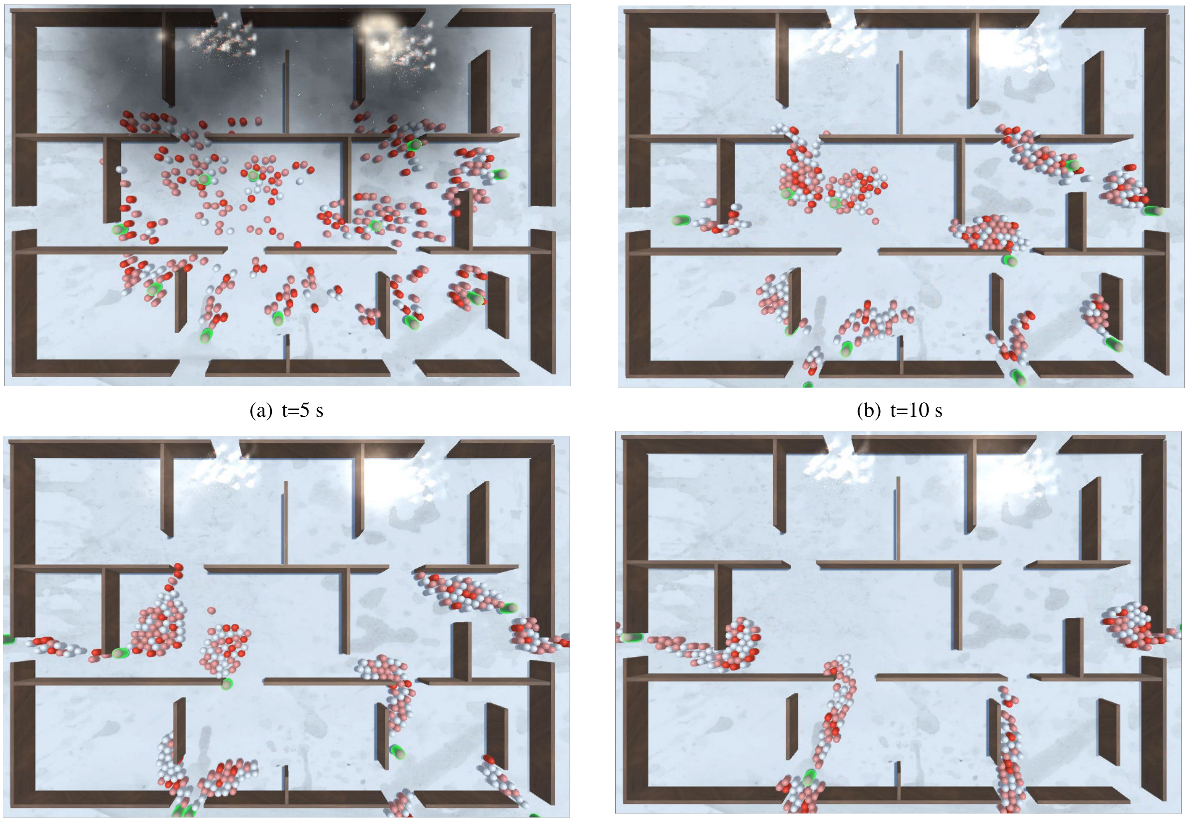
Referring to the inter-group relationship, the leaders of the groups follow each other, when the groups with the same targets (exits). In the groups with inconsistent targets, the interaction among the leaders is small. Leaders choose safe targets with close distances and far away from fire.

When we conduct the simulation with 5 leaders, the average evacuation time for the individuals is 68s. When the number of the leaders increases to 15, the average evacuation time for the individuals is 47s, as shown in Fig. 10. In both of the simulations, 200 individuals are distributed. The results reveal that we can reduce the evacuation times for the individuals by increasing the number of the leaders in the field.

C. THE IMPACT OF LEADERS' EMOTION ON CROWD EVACUATION

This experiment explores the relationship between the emotion of the leader and the emotion of a group. The virtual environment is constructed according to office buildings, in which there are two floors with multiple office rooms and a large hall. There are two safety doors in the office building to the outside environment. 250 individuals are considered in the whole scene, where there are 50 individuals in the hall, and the rest are in the office rooms. At the beginning of simulation, 50 individuals are randomly distributed in the hall with a size 22m × 20m. When an explosion happens, the individuals will continuously flood into the hall from the office and run to the doors to evacuate.

The main factor that influences the emotional change of leaders is their training ability. In Fig. 11, we set the training values of leaders as 0.1, and the training values of the leader are set to 0.8 in Fig. 12. Most of the leaders are in a strong panic state, and the followers are also in a state of extreme negative in Fig. 11(a). In Fig. 12(a), when the training level



(a) t=5 s (b) t=10 s

(c) t=15 s (d) t=20 s

FIGURE 9. The demonstration of crowd evacuation under different emotional states in rooms. (a) t = 5 s. (b) t = 10 s. (c) t = 15 s. (d) t = 20 s.

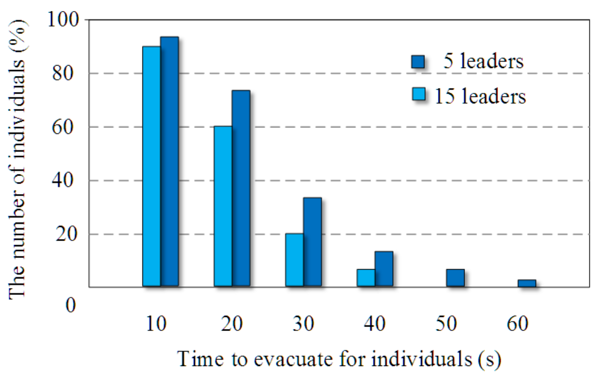


FIGURE 10. The average evacuation time of crowd with different number of leaders.

TABLE 1. The average emotion of leaders with different training levels.

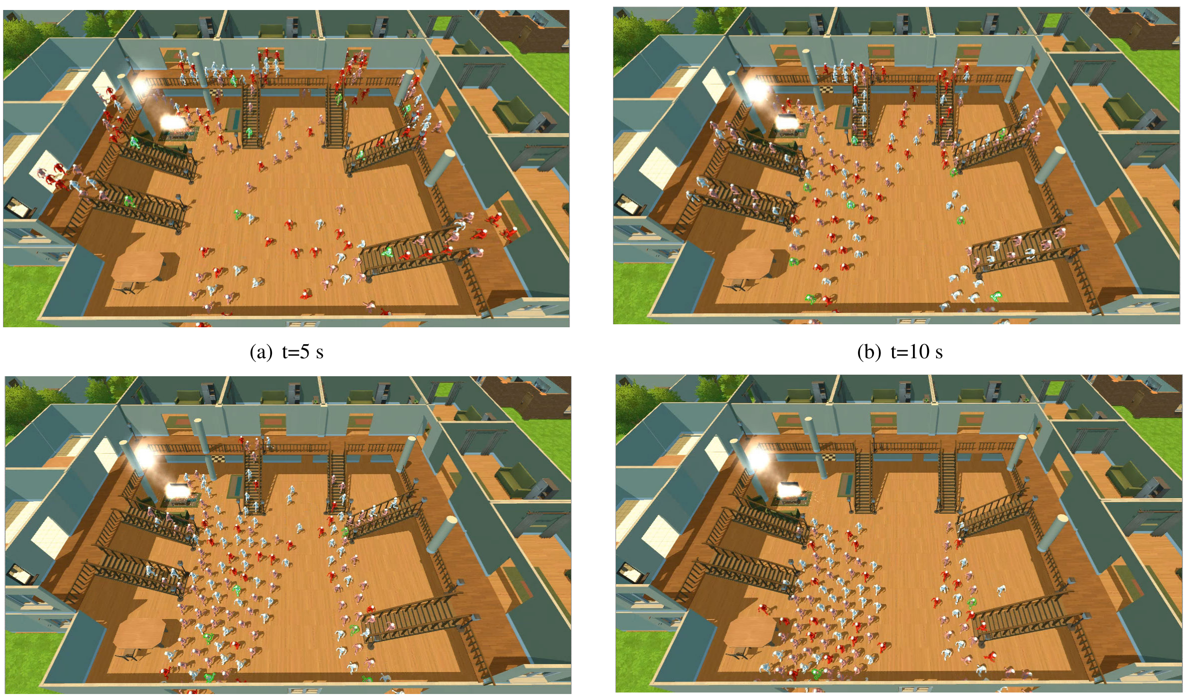
Evacuation time (s)	10	30	50	70	90
Level=0.1	0.68	0.72	0.64	0.62	0.50
Level=0.2	0.55	0.56	0.54	0.51	0.43
Level=0.3	0.52	0.49	0.50	0.46	0.37
Level=0.4	0.45	0.36	0.04	0.37	0.32
Level=0.5	0.34	0.32	0.28	0.24	0.20
Level=0.6	0.25	0.19	0.17	0.16	0.10
Level=0.7	0.24	0.18	0.15	0.17	0.11
Level=0.8	0.16	0.15	0.12	0.11	0.08
Level=0.9	0.13	0.11	0.07	0.06	0.01

is high, the leader will not be easily affected by the surrounding environment, and can maintain a state of low emotional value (calm, or weak panic). The intra-group relationship of the individuals is weak, and the relative positions of the individuals are dispersed. Individuals will leave their groups many times and follow new leaders, when the leaders are in strong panic state (for example, the red circle in Fig. 11(a)). On the contrary, as shown in Fig. 12, the individuals close to each other can form a series of groups for evacuation, and follow the leaders of their groups when the emotional values of the leaders are low. Almostly, no followers will reselect their leaders in the whole evacuation process. As shown in Fig. 11(d), there are about 110 followers who are evacuating, and 26 of them return to calm, accounting for 23.6%. From Fig. 12(d), we can see that about 100 followers are running away, and 37 of them return to calm, accounting for 37%. This shows that the leader's high level of training can help followers stay calm and evacuate faster.

Experiments are carried out by using the proposed simulation framework to examine the influence of leaders' emotion on the evacuation procedures. The simulation scenario represents an office building, which is as same as previous experiments. There are 500 individuals in the virtual scene.

(a) t=5 s (b) t=10 s (c) t=15 s (d) t=20 s

FIGURE 11. The demonstration of crowd evacuation when the training level is 0.1 at different time. (a) t = 5 s. (b) t = 10 s. (c) t = 15 s. (d) t = 20 s.



(a) t=5 s (b) t=10 s (c) t=15 s (d) t=20 s

FIGURE 12. The demonstration of crowd evacuation when the training level is 0.8 at different time. (a) t = 5 s. (b) t = 10 s. (c) t = 15 s. (d) t = 20 s.

We set different training levels for the leaders (Level = 0.1, Level = 0.2, Level = 0.3, . . ., Level = 0.9), and observed the emotional changes of the leaders and groups as evacuation time increased. Table 1 shows a comparison made amongst the average emotion intensity of the leaders with different levels of training, and Table 2 shows the average emotion of

TABLE 2. The average emotion of crowd with different training levels.

Evacuation time (s)	10	30	50	70	90
Level=0.1	0.76	0.86	0.76	0.70	0.60
Level=0.2	0.72	0.68	0.71	0.65	0.53
Level=0.3	0.70	0.75	0.63	0.62	0.43
Level=0.4	0.69	0.70	0.58	0.53	0.35
Level=0.5	0.61	0.56	0.51	0.35	0.24
Level=0.6	0.61	0.52	0.44	0.31	0.16
Level=0.7	0.58	0.51	0.38	0.29	0.14
Level=0.8	0.60	0.49	0.34	0.25	0.10
Level=0.9	0.56	0.43	0.26	0.13	0.05

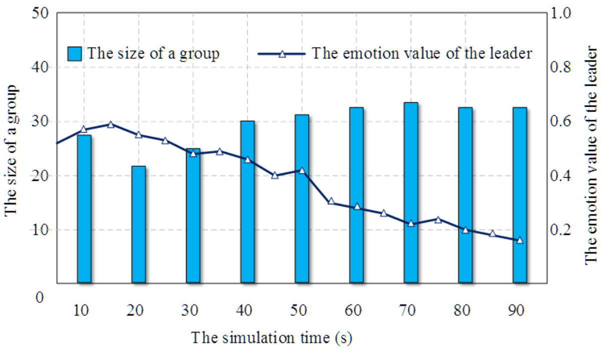


FIGURE 13. The emotion of the leader affects the size of a group.

the group led by the leaders at different levels of training. From Table 1, we can see that the higher the training level of the leaders is, the lower the emotional intensity of the leaders is. Meanwhile, as time goes by, the emotions of the leaders will gradually decrease. Table 2 shows that the crowd is prone to strong panic if the training level of the leader is low. Besides, the higher the training level of the leader is, the faster the team will recover its calmness.

This experiment explores the relationship between the size of a group and the emotions of the leaders. Fig. 13 shows the overall experiment results, where Y-axis records the size of a group and the emotional value of the leader, and X-axis indicates the simulation time. We can see that, when a leader is too panic, his followers will leave him and choose another leader, thus the size of the group gradually decreases. On the contrary, the size of the group moderately increases if the emotional value of the leader is low.

D. COMPARISON OF DIFFERENT EVACUATION MODELS

The method of Luh et al. [35] divides the crowd into a series of groups, but does not consider the impact of emotion. Durupinar et al. [25] introduce emotion contagion model into crowd. Table 1 shows the quantitative comparisons of the frames per second (FPS) and total evacuation time (TET) among the three methods in presence of crowds with different sizes. Although the FPS of our approach is slightly slower than the method [35], wehave considered the important effects of the emotion which can greatly improve the reality of evacuation simulation. Moreover, the TET of our approach is shorter than that of the two other methods.

TABLE 3. Comparison of different evacuation models.

Number	FPS (frame/s)			TET (s)		
	200	1000	2000	200	1000	2000
Our method	66.23	50.97	38.51	58	236	524
Method [29]	75.42	55.84	40.35	65	267	586
Method [30]	62.49	46.35	32.18	62	258	562

V. CONCLUSION

The main contribution of this paper is that we propose a simulation framework for crowd evacuation, which integrates emotion into group structure by using Leader-Follower model. Specially, making use of Leader-Follower model, an emotional change model is proposed for evacuation crowd. Moreover, we explore the intra-group structure and inter-group relationship to maintain the movement of a crowd. The group structure will not be fixed, because the followers can dynamically choose group according to the emotion of the leaders and themselves.

In the future, we will set up a new crowd model with more psychological elements to enable our simulation model to simulate evacuation behaviors more accurately. On the other hand, we will employ general-purpose computing on graphics processing units to improve the efficiency of the simulation, thus it can sustain massively modeling and simulation of evacuation crowd. Moreover, we will also focus on learning individual trajectories from real scenes to reproduce crowd behavior.

REFERENCES

[1] M. Manley, Y. S. Kim, K. Christensen, and A. Chen, "Airport emergency evacuation planning: An agent-based simulation study of dirty bomb scenarios," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 46, no. 10, pp. 1390–1403, Oct. 2016.

[2] M. Zhou, H. Dong, D. Wen, X. Yao, and X. Sun, "Modeling of crowd evacuation with assailants via a fuzzy logic approach," *IEEE Trans. Intell. Transp. Syst.*, vol. 17, no. 9, pp. 2395–2407, Sep. 2016.

[3] D. Chen, L. Wang, A. Zomaya, M. Dou, J. Chen, Z. Deng, and S. Hariri, "Parallel simulation of complex evacuation scenarios with adaptive agent models," *IEEE Trans. Parallel Distrib. Syst.*, vol. 26, no. 3, pp. 847–857, Mar. 2014.

[4] S. Patil, J. van den Berg, S. Curtis, M. C. Lin, and D. Manocha, "Directing crowd simulations using navigation fields," *IEEE Trans. Vis. Comput. Graph.*, vol. 17, no. 2, pp. 244–254, Feb. 2011.

[5] Q. Gu and Z. Deng, "Generating freestyle group formations in agent-based crowd simulations," *IEEE Comput. Graph. Appl.*, vol. 33, no. 1, pp. 20–31, Jan./Feb. 2011.

[6] F. Durupinar, N. Pelechano, J. Allbeck, U. Gudukbay, and N. I. Badler, "How the ocean personality model affects the perception of crowds," *IEEE Comput. Graph. Appl.*, vol. 31, no. 3, pp. 22–31, May/Jun. 2011.

[7] S. J. Guy, S. Kim, M. Lin, and D. Manocha, "Simulating heterogeneous crowd behaviorsusing personality trait theory," in *Proc. ACM SIGGRAPH/Eurograph. Symp. Comput. Animation*, Aug. 2011, pp. 43–52.

[8] G. Santos and B. Aguirre, "A critical review of emergency evacuation simulation models," in *Proc. NISTWorkshop Building Occupant Movement During Fire Emergencies*, 2004, pp. 1–54.

[9] G. Zhang, D. Lu, L. Lv, H. Yu, and H. Liu, "Knowledge-based crowd motion for the unfamiliar environment," *IEEE Access*, vol. 6, pp. 72581–72593, 2018.

[10] A. Ayesh, "Perception and emotion based reasoning: A connectionist approach," *Informatica*, vol. 27, no. 2, pp. 119–126, Jun. 2003.

[11] B. J. Wellman and J. B. Hoagg, "A flocking algorithm with individual agent destinations and without a centralized leader," *Syst. Control Lett.*, vol. 102, pp. 57–67, Apr. 2017.

[12] X. Qin, H. Liu, H. Zhang, and B. Liu, "A collective motion model based on two-layer relationship mechanism for bi-direction pedestrian flow simulation," *Simul. Model. Pract. Theory*, vol. 84, pp. 268–285, May 2018.

[13] Y. Z. Tao and L. Y. Dong, "A floor field real-coded lattice gas model for crowd evacuation," *Europhys. Lett.*, vol. 119, no. 1, 2017, Art. no. 10003.

[14] H.-Y. Shang, H.-J. Huang, and Y.-M. Zhang, "An extended mobile lattice gas model allowing pedestrian step size variable," *Phys. A, Stat. Mech. Appl.*, vol. 424, pp. 283–293, Apr. 2015.

[15] J. Ji, L. Lu, Z. Jin, S. Wei, and N. Lu, "A cellular automata model for high-density crowd evacuation using triangle grids," *Phys. A, Stat. Mech. Appl.*, vol. 509, pp. 1034–1045, Nov. 2018.

[16] C. Chen, Y. Tong, C. Shi, and W. Qin, "An extended model for describing pedestrian evacuation under the threat of artificial attack," *Phys. Lett. A*, vol. 382, no. 35, pp. 2445–2454, Sep. 2018.

[17] A. Golas, R. Narain, and M. C. Lin, "Continuum modeling of crowd turbulence," *Phys. Rev. E, Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.*, vol. 90, no. 4, Oct. 2014, Art. no. 042816.

[18] L. Luo, C. Chai, J. Ma, S. Zhou, and W. Cai, "ProactiveCrowd: Modelling proactive steering behaviours for agent-based crowd simulation," *Comput. Graph. Forum*, vol. 37, no. 1, pp. 375–388, Feb. 2018.

[19] M. Xu, X. Xie, P. Lv, J. Niu, H. Wang, C. Li, R. Zhu, Z. Zheng, and B. Zhou, "Crowd behavior simulation with emotional contagion in unexpected multihazard situations," *IEEE Trans. Syst., Man, Cybern. Syst.*, to be published.

[20] S. J. Guy, S. Kim, M. C. Lin, and D. Manocha, "Simulating heterogeneous crowd behaviors using personality trait theory," in *Proc. ACM SIGGRAPH/Eurograph. Symp. Comput. Animation*, Aug. 2011, pp. 43–52.

[21] Y. Mao, Z. Li, Y. Li, and W. He, "Emotion-based diversity crowd behavior simulation in public emergency," *Vis. Comput.*, pp. 1–15, Jun. 2018. doi: 10.1007/s00371-018-1568-9.

[22] T. Liu, Z. Liu, Y. Chai, J. Wang, X. Lin, and P. Huang, "Simulating evacuation crowd with emotion and personality," *Artif. Life Robot.*, vol. 24, no. 1, pp. 59–67, Mar. 2019.

[23] V. T. Nguyen, D. Longin, T. V. Ho, and B. Gaudou, "Integration of emotion in evacuation simulation," in *Proc. Int. Conf. Inf. Syst. Crisis Response Manage. Medit. Countries*. Cham, Switzerland: Springer, Oct. 2014, pp. 192–205.

[24] H. Aydt, M. Lees, L. Luo, W. Cai, M. Y. H. Low, and S. K. Kadirvelen, "A computational model of emotions for agent-based crowds in serious games," in *Proc. IEEE/WIC/ACM Int. Conf. Web Intell. Intell. Agent Technol.*, vol. 2, Aug. 2011, pp. 72–80.

[25] F. Durupinar, U. Güdükbay, A. Aman, and N. I. Badler, "Psychological parameters for crowd simulation: From audiences to mobs," *IEEE Trans. Vis. Comput. Graphics*, vol. 22, no. 9, pp. 2145–2159, Sep. 2016.

[26] Y. Mao, X. Du, Y. J. Li, and W. He, "An emotion based simulation framework for complex evacuation scenarios," *Graph. Models*, vol. 102, pp. 1–9, Mar. 2019.

[27] G. P. Cimellaro, S. Mahin, and M. Domaneschi, "Integrating a human behavior model within an agent-based approach for blasting evacuation," *Comput.-Aided Civil Infrastruct. Eng.*, vol. 34, no. 1, pp. 3–20, Jan. 2019.

[28] L. Luo, S. Zhou, W. Cai, M. Y. H. Low, F. Tian, Y. Wang, X. Xiao, and D. Chen, "Agent-based human behavior modeling for crowd simulation," *Comput. Animation Virtual Worlds*, vol. 19, nos. 3–4, pp. 271–281, 2008.

[29] L, Liu B, Yu J, J. M. Zhang, "Human behaviors modeling in multi-agent virtual environment," *Multimedia Tools Appl.*, vol. 76, no. 4, pp. 5851–5871, Feb. 2017.

[30] L. Lyu and J. Zhang, "Toward modeling emotional crowds," *IEEE Access*, vol. 76, pp. 55893–55906, 2018.

[31] P. Tang and G. Shen, "Decision-making model to generate novel emergency response plans for improving coordination during large-scale emergencies," *Knowl.-Based Syst.*, vol. 90, pp. 111–128, Dec. 2015.

[32] J. Fang, S. El-Tawil, and B. Aguirre, "Leader–follower model for agent based simulation of social collective behavior during egress," *Saf. Sci.*, vol. 83, pp. 40–47, Mar. 2016.

[33] F. Qiu and X. Hu, "Modeling group structures in pedestrian crowd simulation," *Simul. Model. Pract. Theory*, vol. 18, pp. 190–205, Feb. 2010.

[34] Y. Li, H. Liu, G.-P. Liu, L. Li, M. Philip, and B. Hu, "A grouping method based on grid density and relationship for crowd evacuation simulation," *Phys. A, Stat. Mech. Appl.*, vol. 473, pp. 319–336, May 2017.

[35] P. B. Luh, C. T. Wilkie, S.-C. Chang, K. Marsh, and N. Olderman, "Modeling and optimization of building emergency evacuation considering blocking effects on crowd movement," *IEEE Trans. Autom. Sci. Eng.*, vol. 9, no. 4, pp. 687–700, Oct. 2012.

[36] S. Folkman, *Stress: Appraisal and Coping*. 2013, pp. 1913–1915.

[37] Z. Liu, T. Liu, M. Ma, H.-H. Hsu, Z. Ni, and Y. Chai, "A perception-based emotion contagion model in crowd emergent evacuation simulation," *Comput. Animation Virtual Worlds*, vol. 29, nos. 3–4, p. e1817, May Jun./Aug. 2018.

[38] Y. Mao, S. Yang, Z. Li, and Y. Li, "Personality trait and group emotion contagion based crowd simulation for emergency evacuation," *Multimedia Tools Appl.*, pp. 1–28, May 2018.

[39] P. H. Lodhi, S. Deo, V. M. Belhekar, "The five-factor model of personality," Tech. Rep. doi: 10.1007/978-1-4615-0763-5_11.

[40] X. Du, W. He, Y. Mao, and Y. Rao, "Crowd evacuation simulation based on emotion contagion," *Int. J. Simul. Process Model.*, vol. 13, no. 1, 43-56, 2018.

[41] D. Helbing and P. Molnar, "Social force model for pedestrian dynamics," *Phys. Rev. E, Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.*, vol. 51, no. 5, pp. 4282–4286, 1995.

[42] N. Pelechano and N. I. Badler, "Modeling crowd and trained leader behavior during building evacuation," *IEEE Comput. Graph. Appl.*, vol. 26, no. 6, pp. 80–86, Nov./Dec. 2006.

YAN MAO received the B.S. degree from the Education Science College, Sichuan Normal University, Chengdu, China, in 2007, the M.S. degree from the Psychology College, Southwest University, Chongqing, China, in 2010, and the Ph.D. degree from the School of Economics and Management, Southwest Jiaotong University, Chengdu, in 2018. She is currently a Lecturer with the School of Business, Sichuan Normal University. Her research interests include emotion, emotion decision, and virtual reality.

XINMIAO FAN is currently pursuing the B.S. degree with the College of Movie and Media, Sichuan Normal University. She is also a Junior Researcher with the Visual Computing and Virtual Reality Key Laboratory of Sichuan Province, Sichuan Normal University. She has also gained experience in this area working on research projects. Her research interests include crowd animation and traffic simulation.

ZIXUAN FAN is currently pursuing the B.S. degree with the College of Movie and Media, Sichuan Normal University. She is also a Junior Researcher with the Visual Computing and Virtual Reality Key Laboratory of Sichuan Province, Sichuan Normal University. She has also gained experience in this area working on research projects. Her research interests include crowd animation and emotion simulation.

WU HE received the B.S. degree in computer science and technology from the North University of China, Taiyuan, China, in 2004, and the M.S. and Ph.D. degrees in computer application technology from Southwest Jiaotong University, Chengdu, China, in 2008 and 2017, respectively. He is currently an Associate Professor with the College of Movie and Media, Sichuan Normal University. His research interests include computer graphics, virtual reality technology, crowd animation, and traffic simulation.