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An Emergency Evacuation Behavior Simulation Method Combines Personality Traits and Emotion Contagion

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ABSTRACT Simulation emergency evacuation is an important part in the field of safety engineering, affective computing plays a vital role in the popularization of artificial intelligence, computer simulation and human-computer interaction. Inspired by this field, this paper proposes a method for simulating group interactions during emergency evacuation. First, each individual is assigned with dynamic survival needs and psychological quality based on urgent event and the external influence. Second, the emotional interaction of the group is realized based on OCEAN (Openness, Conscientiousness, Extroversion, Agreeableness, Neuroticism) personality trait and the improved CA-SIRS (Cellular Automaton-Susceptible Infected Recovered Susceptible) model. Third, after the perception of the external environment changes, the accident experience and panic level are used as factors of emotion update. At last, the environmental familiarity and nearby flow factors are introduced to path planning process. Based on emotion contagion, this method explores individual's emotional changes in different scenarios and situations. Combined with personality traits and emotional contagion, the experimental results show that the proposed method can simulate dynamic emotional changes in emergency situations in both efficient and reasonable way and provide guidance for emergency evacuation.

INDEX TERMS Emergency evacuation, OCEAN personality traits, CA-SIRS model, emotion contagion.

I. INTRODUCTION

Affective computing is a growing field which involves multiple fields of science such as artificial intelligence and psychology. It has important application value in different domains. By simulating group behavior, researchers derived the general rules of group simulation and helped people to better understand and predict group behavior in reality. In addition, the use of affective computing helps us to analyze the psychological changes of people in real-world.

Modeling group behavior is mainly divided into micro and macro categories, the micro models include social force model [1], [2], particle system [3] and so on. Most of these models consider about the single type of group movement, ignoring the impact of psychological factors on group behavior. The macro models are widely used such as data-driven model [4] and potential field-based model [5], etc. They can speed up the convergence, but only study the overall crowd movement which lacks of detailed group movement.

The behavior simulation models usually focus on physiological interactions such as path planning [6]–[9] and collision avoidance [10]–[12], which pay less attention to the influence of psychological factors such as personality traits and emotion cognition. Besides, most of the interactions in real life are based on psychological factors and physical environment. And there is a two-way correlation between behavioral interaction and psychological factors. That is, psychological factors affect behavioral interactions, and psychological factors also change dynamically based on behavioral interactions.

Emotion contagion in group is similar to the spread of the disease. The epidemiological SIR (Susceptible Infected Recovered) model [13] is very suitable for simulating people in public emergency situations. Emotion contagion can

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describe the emotional changes of the crowd during evacuation in which individuals can transmit emotions to each other. Under the condition of emotion contagion, through further division, it can be divided into two processes: emotion contagion and emotion update. After the emotion reaching the threshold, the emotion will update to another state.

Affective computing is an emerging interdisciplinary research field bringing together researchers and practitioners from various fields, ranging from artificial intelligence, natural language processing, cognitive and social sciences [14]. Most of the existing researches on affective computing are based on EEG [15], [16] or facial expression [17]–[19]. The physiological response caused by the subject's emotional fluctuations is also an important concern of affective computing. Simultaneously, the method of affective computing through speech recognition has also received more attention [20]–[22].

This paper focus on how emotion of the group are transmitted during the emergency evacuation, and how the emotion and personality traits affect the group interactions. The OCEAN personality traits model [23] and intimacy relationship are introduced into crowd simulation to realize the interactive psychological behavior. Our emotion contagion model is further improved on the basis of CA-SIRS model [24]. The improved CA-SIRS model and the emotion update method based on accident experience and panic level were introduced into emergency evacuation to simulate psychological behavioral interactions. Considering the environmental familiarity and nearby flow factors, the crowd escape process can be simulated effectively.

According to the design of the experimental scene, users can design the personality and intimacy of the crowd to simulate different kinds of emergency scenarios. Through the visualization of crowd evacuation, this approach can be used for evacuation drill, building planning, etc. Also, it can assist in building planning, export distribution and design.

From the perspective of survival needs to psychological quality, this paper proposes an emotion contagion computing method which combines personality traits and emotion contagion. The main contributions of this paper are summarized as follows:

1. An improved CA-SIRS model was proposed by introducing the personality traits and the intimacy relationship.
2. The emotion change process was subdivided into emotion contagion and emotion update, and it can achieve more accurate of the emotion change process.
3. The accident experience and panic level are introduced into emotion update to simulate dynamic and realistic emergency evacuation.

The rest of this paper is organized as follows. Section 2 reviews the related work. Section 3 expounds the framework of this paper, briefly introduces the simulation process of emergency evacuation behavior based on personality traits and emotion contagion. Section 4 details the method of this paper, and explains the two-way correlation between psychological factors and behaviors. Section 5 combines the simulation experiments to verify the authenticity of the simulation method. Finally, section 6 draws conclusions and puts forward suggestions for future work.

II. RELATED WORK

With the development of computer simulation technology, researchers have conducted long-term exploration of emergency evacuation simulation. And they have put forward many important theories in different research fields.

Technology used for simulating crowd behavior plays an important role in computer graphics domain. With the gradual improvement of science and technology, behavioral simulation has attracted a lot of attention. Malinowski *et al.* [25] constructed an architecture of crowd-based simulation application based on parallel agents, which can simulate large-scale agents. Weiss *et al.* [26] proposed a novel crowd simulation method to explore the efficiency and stability of position-based dynamics. Luo *et al.* [27] provided an agent-based crowd simulation modeling for steering behavior. Yao *et al.* [28] present a reinforcement learning based data-driven crowd evacuation (RL-DCE) framework by extracting the dynamic features in the video.

The simulation of emergency evacuation is a hot spot in the field of public safety. Social force model [1] can be used to simulate the emergency evacuation dynamics of the crowd, but since this model is relatively simple, it can only simulate crowd evacuation in a simple building structure. As the scale of modern buildings grows larger and more complex, robust models are needed to simulate the large-scale crowd evacuation. The extended route choice model can simulate pedestrian route selection [29]. Liu *et al.* [30] designed a multi-population cultural algorithm framework and presented a crowd evacuation simulation approach based on navigation knowledge and two-layer control mechanism. Cassol *et al.* [31] assessed and optimized the crowd evacuation plan. Zhang *et al.* [32] proposed a framework for modeling crowd movements in unfamiliar environment. According to the characteristics of evacuation in high-density crowd, Ji *et al.* [33] proposed a new triangular gird cellular automata model. A fuzzy logic approach [34] was proposed to describe crowd evacuation behaviors taking the effect of assailants into account the effect of assailants.

Although these models have provided reasonable solutions in route selection, they do not consider the impact of emotional factors. Emotions can transmit from one individual to others based on their intimacy. Emotions can affect the implementation of the time-consuming evacuation during path planning. Considering the influence of emotional contagion can improve simulation realism.

In social psychology, one of the most famous personality traits models is the OCEAN model [23], also known as the "Five-Factor Model". PAD (Pleasure, Arousal, Dominance) model [35] divides emotions into three parts: pleasure, arousal and dominance. OCC (Ortony, Clore, Collins) model [36] indicates that emotions are positive or negative reactions.

Durupinar *et al.* [37] parametrized the common attributes of individuals to simulate collective behaviors from audience to mobs. Among them, the emotional features use two emotion models, PAD and OCC. Fu *et al.* [24] simulated the process of population emotional dynamics by modifying the epidemiological SIR model [13] into a cellular automaton. Mao *et al.* [38] considered the impact of third party authorities on agents during evacuation. Song *et al.* [39] studied the interaction between optimists and pessimists. Basak *et al.* [40] proposed a data-driven approach using existing emotion contagion and a crowd simulation framework. Manley *et al.* [41] presented an agent-based model (ABM) which explicitly considered the physical and psychological characteristics of individuals with disabilities. Mao *et al.* [42] investigated the modeling group structures with emotion in crowd evacuation. Liu *et al.* [43] studied the effect of emotional transmission on navigation information. Zhang *et al.* [44] studied the effect of positive emotions on emotional transmission. In order to realistically simulate the process of crowd communication, Hong *et al.* [45] comprehensively considered the impact of virtual cyberspace and physical cyberspace.

Bever *et al.* [46] explored how to use chatbots to enhance the social skills training of guards through voice and text input. Medeiros *et al.* [47] designed a chatbot that can reduce stress. Bosman *et al.* [48] summarized the virtual agents of professional social skills training in recent technologies. Formolo *et al.* [49] obtained interpersonal posture by extracting information from human voice signals.

Ren *et al.* [50] proposed a semi-automatic corpus-based sentiment calculation method by improving the quality of the automatically collected corpus and the accuracy of label annotations. The method also includes functions of automatic filtering and sentiment estimation. The multi-modal data set [51] was used in multiple calculation methods to facial videos and varioued bio-sensing modes to compare the performance of human emotion classification, and proposed a multi-modal emotion classification method in the field of emotion computing research. Mariooryad and Busso [52] used an asymmetric bilinear factorization model to decouple linguistic and emotional information. Kratzwald *et al.* [53] combineed deep learning and affective computing to propose a text-based emotion recognition method. Schuller [54] focused on the impact of affective computing on the ''joy or fear'' expression of autistic children.

Inspired by affective computing, this paper propose an emergency evacuation simulation based on personality traits and emotional contagion. Under the influence of emotional factors, we improve the path planning model to reduce the time-consuming task, and the efficiency of emergency evacuation is improved.

Combined with personality traits and emotion contagion, we study the group interaction from two aspects: psychology and behavioral. The OCC model [36] divides emotions into 22 types. The emotions we studied included calm, disappointment, fear, worry, horror and hope. The intimacy relationship is introduced to the emotion contagion, and the accident experience and the panic level are used as factors that affect emotion update. Combining emotional contagion and path planning, experimental results prove that the method can better express the dynamic emotional changes and simulate the escape behavior in emergency evacuation.

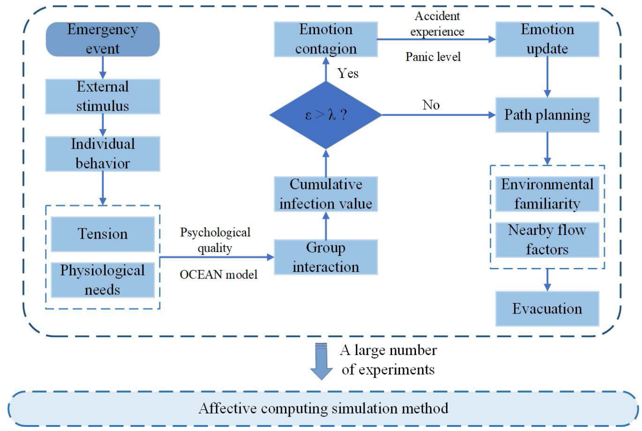


FIGURE 1. Simulation framework.

III. ALGORITHM OVERVIEW

This paper takes emotion as the research object and simulates the behavior of different personality traits and emotion contagion effect in emergency evacuation. The framework is shown in Fig.1. The specific steps using in this simulation are as follows:

1 **Individual initiation**: individuals in the groups are granted survival needs and psychological quality. The personality traits (based on the OCEAN model [23] and intimacy are randomly assigned, get the current different emotions and intimacy values. The higher the intimacy value is, the closer the individuals' relationships are.
2 **Emotion contagion**: the emotions of the surrounding individuals are acquired according to the perceptual ability based on the improved CA-SIRS model and individuals' intimacy. If the cumulative value ε of an emotion is greater than the infection threshold λ, the emotion will change to another state.
3 **Emotion recognize and update**: external stimuli with the perception range affects both physical and psychological qualities. Based on the accident experience and panic level to achieve emotion update.
4 **Path planning**: the environmental familiarity and nearby flow factors are computed to integrate with path planning.
5 **Affective computing**: emotion-based affective computing method is realized through psychological factors such as personality traits and emotion contagion. Through large number of random experiments, the method can quantify the relationship between

emotion factors and can simulate emotion recognition, understanding and expression.

IV. GROUP SIMULATION

A. PERSONALITY TRAITS

During simulation, individuals will become tense and have physiological needs when an emergency occurs. The stimuli includes dynamic and unstable. Individual psychological quality and personality traits will affect group interaction.

In this paper, individuals are assigned with different personality traits to simulate diverse group interactions in real life. According to the OCEAN model [23], the personality of individual is defined as shown in Eq.1.

$$\varphi = [\psi^O, \psi^C, \psi^E, \psi^A, \psi^N] \tag{1}$$

where, ψ^O is openness, ψ^C is conscientiousness, ψ^E is extroversion, ψ^A is agreeableness, ψ^N is neuroticism.

B. INTIMACY

In real-world scenarios, the intimacy relationship directly affects group behavior, and the relationship of high intimacy is tighter and the interaction is more frequent. The intimacy is a kind of dynamic factor, e.g. the strangers who never know each other gradually can become friends by communication, and friends are gradually unfamiliar with the lack of contact.

In this paper, the intimacy factor I_{ij} between individual i and j is defined as:

$$I_{ij} = u_{ij} \cdot (h_{ij} + q_{ij}) \tag{2}$$

where the sensitivity $h_{ij} = \varphi_i - \varphi_j$ between i and j is used to evaluate the uncertainty of whether peer individuals can interact with each other under the influence of complex external conditions. u_{ij} is the degree of connection between i and j which is decided by their social relationships (e.g., families, friends or colleagues), and the common features q_{ij} represents the cognitive rapport and approbation degree between this two individuals. If $I_{ij} = 0$, it means that i and j are strangers.

C. EMOTION CHANGE

In social life, the communication between people is mostly accompanied by emotional changes. People judge the subjective experience and the feelings of others through emotion. Constantly, these feelings can cause changes in facial expressions, gestures, and tone expressions. In the process of continuous development of computer science and technology, affective computing technologies have provided computers with higher intelligence to recognize, understand, express and adapt to human emotions.

Inspired by this field, we refine emotion change into emotion contagion, emotion recognition and emotion update. The details are as follows:

1) EMOTION CONTAGION

Researchers have found that the emotion contagion process is similar to the infection of disease. In [24], Fu *et al.* proposes the CA-SIRS model to simulate emotion contagion in dynamic populations. However, the CA-SIRS model is a single emotion model that does not consider the effects of different internal emotions. Inspired by [24], this paper improves the CA-SIRS model by applying two attributes of emotional change (emotional expression intensity and emotional reception intensity) to multiple emotions. These emotions can be transmitted and perceived by other individuals and spread freely among the crowd. The formula for calculating individual emotional changes is as follows:

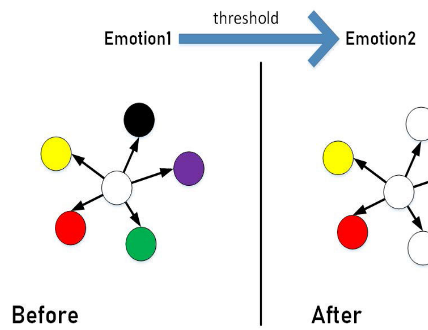


FIGURE 2. Emotion update.

$$\triangle E_i = [1 - \frac{1}{1 + exp(-D_{ij})}] \cdot P_i \cdot R_{ji} \cdot I_{ij} \tag{3}$$

where $\triangle E_i$ represents the i's emotional change value, P_i indicates the emotional expression intensity of i, R_{ji} indicates the emotional strength of i received from j, D_{ij} represents the distance between i and j. P_i, R_{ji}, I_{ij}, and D_{ij} are all greater than 0.

2) EMOTION RECOGNITION AND UPDATE

Emotion update is the process of changing the current emotional state after the individual's own emotional value reaches the emotional threshold under the condition of emotional infection. The process consists of three steps:

1 Individuals are affected by emotion contagion,
2 Emotion recognition is to calculate the amount of emotional change and the threshold,
3 Emotion update is to choose not to express the emotional state or change the emotional state after judging the size.

Each emotion has a threshold λ. If the intensity of a certain emotion reaches its threshold, the individual will recognition the emotion. The emotion update process is shown in Fig.2. The disc-shaped entities represent different individuals, and the color is their emotional states (individuals with the same emotional state have the same color). Each individual's emotion can transmit to others as shown in this figure. The central individual will generate emotional output to the surrounding individuals, which cause emotion update. The depth of the color indicates the degree of infection.

The emotional threshold λ represents the ability to update emotions. The threshold is calculated as follows:

$$\lambda = f(I, D) \tag{4}$$

where, λ is calculated based on the intimacy I, and distance D.

The emotion update can be represented as follows:

$$\varepsilon = \triangle E(\alpha\phi^{\delta} + \beta\phi^{\vartheta}) \tag{5}$$

where, $\alpha, \beta \in [0, 1]$ are the ability to understand the accident and the panic level. The panic level ϕ^{ϑ} is decided according to the personality and emergency, and individuals with more stable or calm personalities (with higher components of O, E and N) have lower panic level during evacuation. And with the accumulation of accident experience, ϕ^{δ} will increases. ε is achieved through $\triangle E$.

Emotion update means that an individual changes his current emotion by accepting the emotions of other individuals. When $\varepsilon < \lambda$, the emotion state does not change. When $\varepsilon > \lambda$, the emotion will be updated by adding the emotional changes defined in Eq. 3.

D. PATH PLANNING

In path planning, individuals with more stable and calm emotions can realize path selection faster. It can be seen that emotions have an impact on path planning. Individual emotions can influence the path selection time, and the calculation formula is as follows:

$$T = f(emotion,\ \varepsilon) \tag{6}$$

where, T is time-consuming for path selection, and *emotion* is the emotion state (calm, disappointment, fear, and so on). The more stable and calmer an individual is, the shorter the path. By improving stability and calm to achieve effective evacuation in a relative time and achieving more efficient simulation.

In emergency evacuation, whether the person can reach the safe area before the danger occurs is affected by the path planning. Under the premise of short consumption time, the environmental familiarity and the nearby flow factors are important in judging the safety of the path.

Environmental familiarity consists of spatial cognition and sense of direction. The formula is:

$$M = [\zeta,\ \sigma] \tag{7}$$

where, $M \in [0, 1]$ is the environmental familiarity, ζ is the spatial cognition, σ is the sense of direction, and [] is the vector weight. Spatial cognition is based on spatial architectural style and spatial memory, and the sense of direction is based on individual experience and direction feelings.

Spatial cognition includes spatial architectural style and spatial memory, and its calculation formula is:

$$\zeta = \mu\chi + \upsilon\eta \tag{8}$$

where, μ and υ are the difference coefficients between the current position and the individual living environment, and χ and η are the spatial architectural style and spatial memory, which are dynamically composed of the spatial environment. And when $\mu > 0,\ \upsilon > 0$, the current location is similar

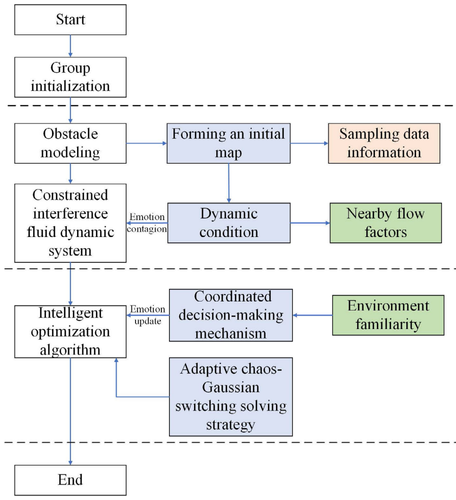


FIGURE 3. Path planning.

TABLE 1. Randomly generated personality trait ratios.

	O	C	E	A	N
3(b)	0.18	0.25	0.14	0.23	0.20
3(c)	0.12	0.21	0.26	0.08	0.33
3(d)	0.23	0.15	0.07	0.17	0.38

to the individual living environment, and the spatial architectural style and spatial memory have a positive impact on the individual; when $\mu < 0,\ \upsilon < 0$, it indicates that the current location is significantly different from the individual living environment, and the spatial architectural style and spatial memory have a negative impact on the individual.

The sense of direction is based on individual experience and the ability to explore directions, and its calculation formula is:

$$\sigma = \omega\tau \tag{9}$$

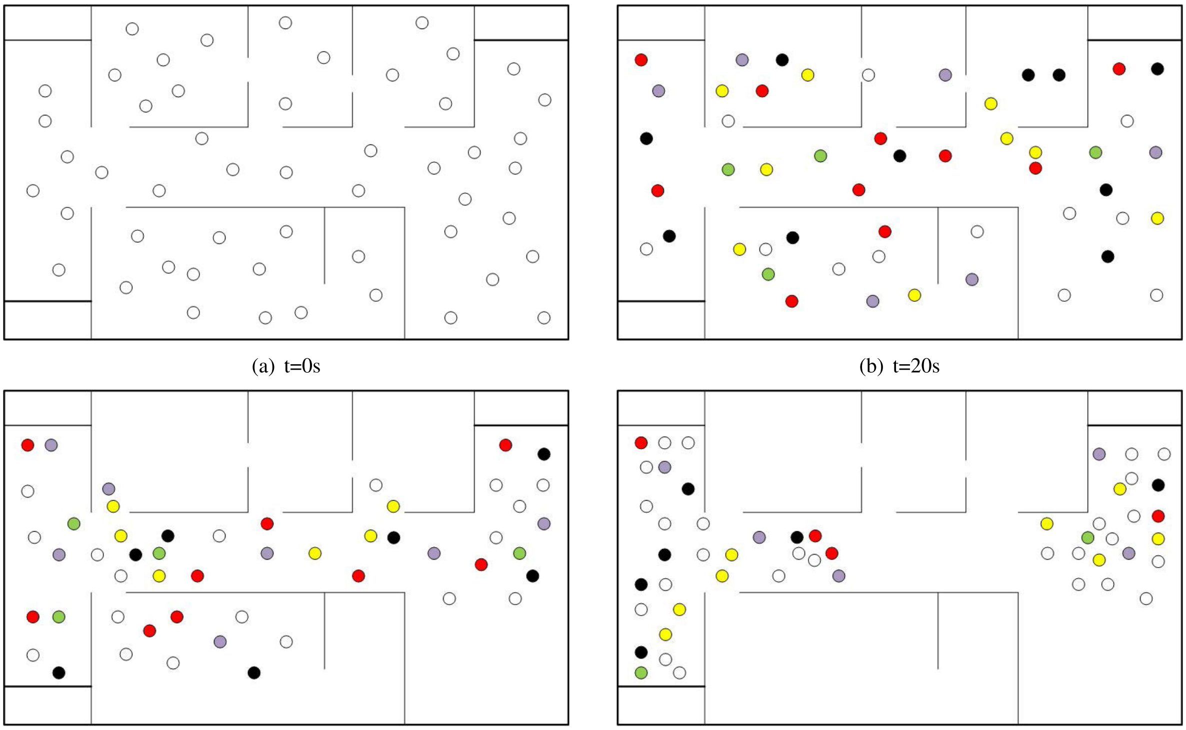
where, ω and τ are the individual experience and direction exploration ability, when $\omega, \tau = 0, \sigma = 0$.

The keys to affecting the nearby flow factors L include the width of the road C, the number of exits N, and the shortest distance d from the exit, which is defined as:

$$L = \frac{C \cdot N}{min(d)} \tag{10}$$

where, L is the nearby flow factor, C is the width of the road, N is the number of exits, and d is the distance from the exit.

In the proposed model, emotional factors are transmitted through group behavior interactions. Since our proposed model focus on how the different factors impact the evacuation, we do not specifically model these social relationships (e.g. social power), instead we model social relations and intimacy through simple mathematical models to describe the social relations. Personality traits and emotional thresholds influence the constrained interference fluid dynamic system, thereby realizing the effect of emotion on path planning. At the same time, through the update of emotions, the peer decision-making mechanism in path planning is improved to complete the related formation of groups moving towards the



(a) t=0s
(b) t=20s
(c) t=40s
(d) t=60s

FIGURE 4. The influence of personality traits on emotions.

evacuation points. On the basis of above mentioned method, this approach realize the impact of emotional factors on emergency evacuation, and complete the path planning of emergency evacuation.

In this paper, the path planning model of [7] is applied to group simulation, and the environmental familiarity and nearby flow factors are introduced to improve the rationality and reality of simulation. Fig.3 is a diagram of the path planning process in this paper. The group configuration should be predefined, and the obstacles are represented as polygons and the obstacle information is added to dynamic conditions of nearby human flow factors to the constrained interference fluid dynamic system. Based on the constrained dynamic system, the initial navigation map is generated. With the simulation goes on, the environment will change dynamically, different factors (e.g., personality, intimacy, environmental familiarity and flow factor) are introduced into crowd decision-making process to simulate emergency evacuation.

V. EXPERIMENT

In this paper, all the experiment results are collected on a personal computer with Intel i7-3770 3.4GHz CPU, NVIDIA GTX960 graphics card, and 8 GB of RAM.

A. THE INFLUENCE OF PERSONALITY TRAITS ON EMOTIONS

The experiment is a one-story teaching building with four classrooms and three exits. Individuals are labelled as different colors depending on the type of emotions. White is for calm, purple is for disappointment, black is for fear, yellow is for anxiety, red is for horror, and green is for hope. The initial situation is that the individual default emotion is calm, as shown in Fig.4(a). When an emergency occurs, individual emotions are influenced by personality traits, producing individuals with different emotions.

Fig.4(b), (c), and (d) show the changes in individuals with different personality traits after a certain period of time. The emotions mainly include calm, disappointment, fear, anxiety, horror, and hope. Table 1 shows the randomly generated personality traits O, C, E, A, and N ratios.

As can be seen from Fig.4, personality traits are the important factors influencing the generation of emotions. Emotions also change over time. In order to explore the performance of individuals with different personality traits in Eq.1. in emergency evacuation, the randomly generated groups of 10 groups with personality traits are simulated in classroom evacuation simulation, and Table 2 is the simulation results.

It can be seen from the experiment results that the personality traits affect the individual's different emotions in an emergency. And the individuals with calm and hope can complete the evacuation behavior in a short time. Disappointment, fear, anxiety and horror people need more time to complete evacuation.

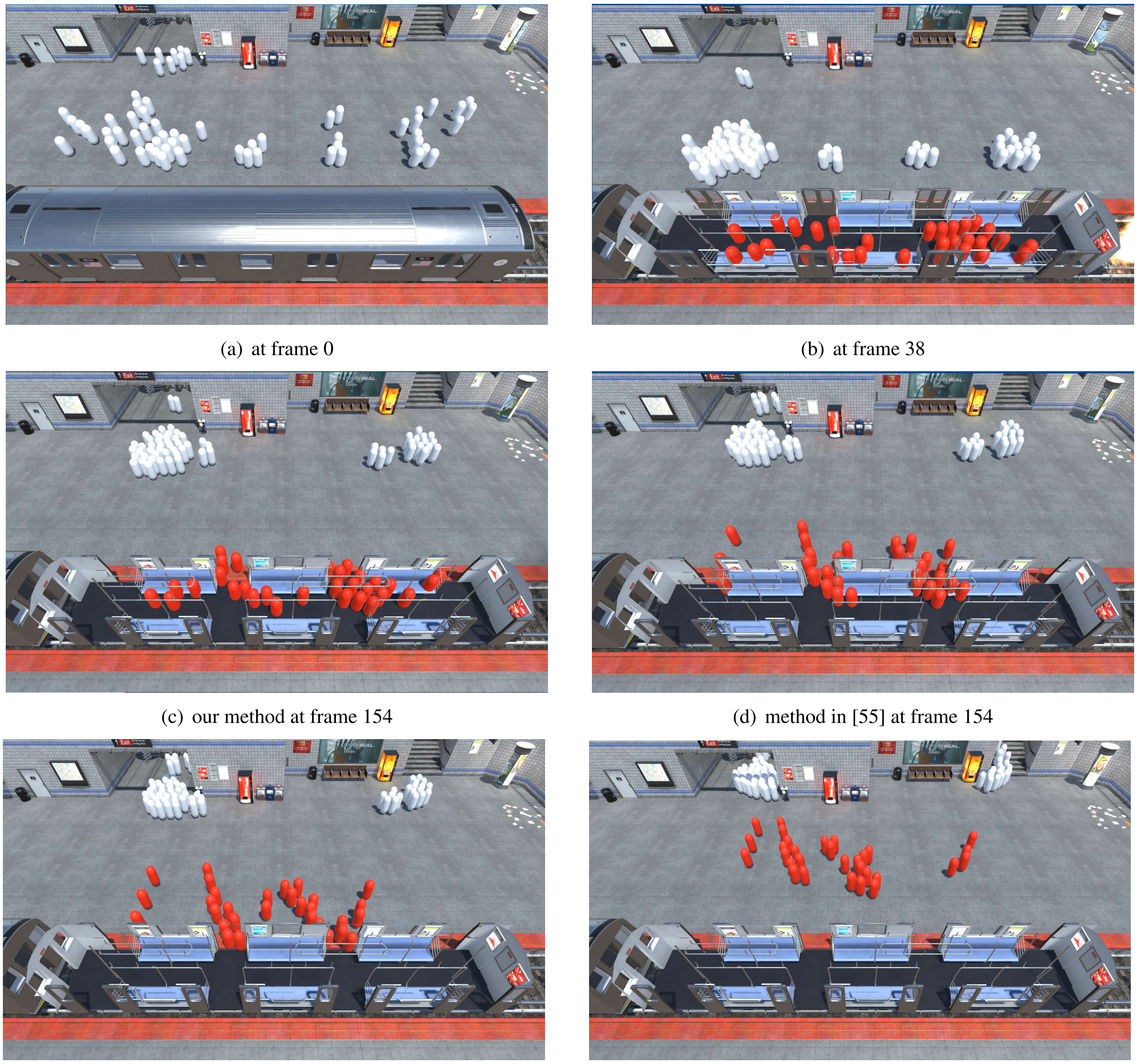
B. THE IMPACT OF EMOTION ON EMERGENCY EVACUATION

1) THE IMPACT OF EMOTION CONTAGION ON EMERGENCY EVACUATION

In order to verify the impact of emotion contagion on emergency evacuation, this article simulates an evacuation

TABLE 2. The influence of personality traits on emergency evacuation.

	O	C	E	A	N	Main emotion	Evacuation time
Group 1	0.09	0.21	0.11	0.27	0.32	clam, hope	18.72s
Group 2	0.15	0.34	0.27	0.08	0.16	clam, fear	23.54s
Group 3	0.39	0.08	0.37	0.07	0.09	disappointment, anxiety	26.33s
Group 4	0.07	0.10	0.42	0.08	0.33	fear, horror	29.86s
Group 5	0.21	0.40	0.03	0.31	0.05	hope, anxiety	21.49s
Group 6	0.26	0.11	0.25	0.13	0.25	disappointment, fear	25.51s
Group 7	0.09	0.14	0.26	0.10	0.41	anxiety, horror	28.33s
Group 8	0.13	0.29	0.14	0.20	0.24	clam, anxiety	23.39s
Group 9	0.16	0.38	0.17	0.22	0.07	hope, fear	21.77s
Group 10	0.07	0.17	0.26	0.08	0.42	disappointment, horror	27.61s



(a) at frame 0

(b) at frame 38

(c) our method at frame 154

(d) method in [55] at frame 154

(e) our method at frame 347

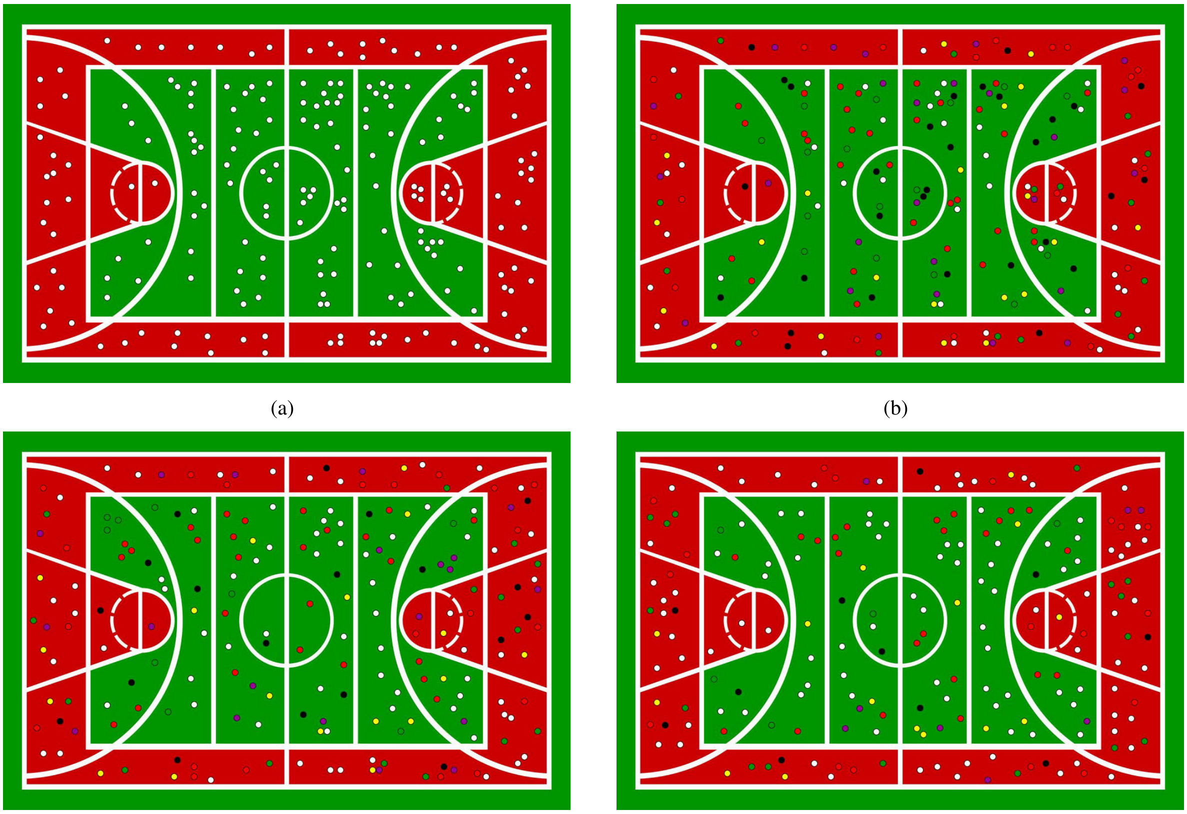
(f) method in [55] at frame 347

FIGURE 5. The influence of emotion contagion.

simulation after a sudden fire in a subway station experimental scenario. There are two escape exits in the subway station. When the subway stopped, a fire broke out, and passengers in the subway and passengers waiting for the subway were evacuated to escape. Passengers waiting for the subway are shown in white, and those who escape from the subway are

TABLE 3. Simulation comparison.

	Evacuation time-consuming	Average evacuation speed	Frame rate
Our method	18.13s	0.98m/s	38.26fps
Method in [55]	25.37s	0.85m/s	29.71fps



(a) (b) (c) (d)

FIGURE 6. The impact of emotion contagion and update on emergency evacuation.

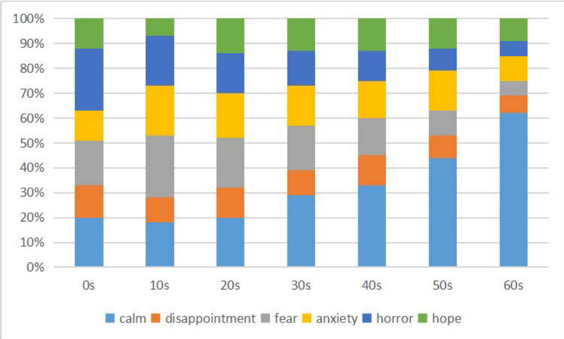
red. Fig.5(a) is the initial scene, and Fig.5(b) is the scene when a fire occurs. Fig.5(c) and (d) show the simulation results of this method and the clustering method [55] at frame 154. Fig.5(e) and (f) show the simulation results of this method and the clustering method [55] at frame 347.

Table 3 shows the comparison of the average evacuation performance under the same conditions of the evacuation individuals under the same conditions as the cluster method [55]. It can be seen from Fig. 5 and Table 3 that under the same frame number method, more individuals reach the escape exits, and the evacuation effect is better. Although the cluster method [55] can also achieve the effect of evacuation, it ignores the individual's emotional changes during the evacuation process and lacks authenticity. And in real life, group behavior interaction mainly depends on the transmission of emotions. The method in this paper improves the computational complexity of the simulation under the premise of considering the authenticity, thereby realizing the simulation.

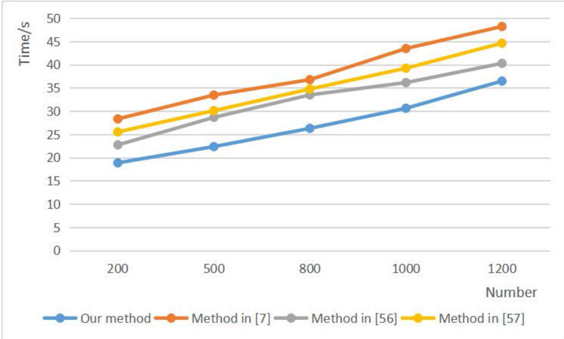
2) THE IMPACT OF EMOTION UPDATE ON EMERGENCY EVACUATION

Simulating the emotional transmission process in the 150m*280m stadium scene. Individuals are labelled as different colors depending on the type of emotions, with white for calm, purple for disappointment, black for fear, yellow for anxiety, red for horror, and green for hope. The initial perience and panic level, the emotions are updated. In the process, the individual emotions are constantly changing. As shown in Fig.6(d), the finally emotion gradually become calm. Fig.7(a) shows the change in the proportion of various emotions over time. The experiment results show that the emotion contagion model can achieve emotion contagion faster, and the effectiveness of the individual tends to calm down for emergency evacuation.

We recorded the simulation evacuation time of our proposed method and other method proposed in [7], [56] and [57]. As shown in Table 4, with the increasing of the number of simulated individuals, the frame rates will decrease. Under



(a) The proportion of emotion.



(b) The compares of simulation time.

FIGURE 7. **The differents of emotion and time on emergency evacuation.**

TABLE 4. **Different methods of emotional infection evacuation time.**

	200	500	800	1000	1200
Our method	18.12s	32.74s	48.18s	78.46s	125.61s
Method in [7]	30.33s	57.47s	124.22s	152.21s	220.79s
Method in [56]	21.25s	39.61s	57.39s	94.98s	141.32s
Method in [57]	26.48s	47.53s	66.76s	123.77s	180.83s

TABLE 5. **Emotion update factor ratio.**

	Accident experience	Panic level	Evacuation time
8(a)	0.66	0.37	26.64s
8(b)	0.59	0.41	31.77s
8(c)	0.43	0.67	42.13s

the setting of the same experimental environment, the frame rate of our method is the highest, that is because the environmental familiarity is used in our method for individual path planning. Individuals with higher environmental familiarity (whole spatial cognition or higher sense of direction) will quickly find the way out. In [7], the algorithm not only consider obstacle avoidance, but also consider the electric energy for solar-powered UAV, which is more complex than which used in our method. Besides, compared with the directly storing of the navigation information in the cognitive knowledge base of the individual, the density information is introduced in [56] for avoiding congestion, but the simulation cost will be high when simulate thousands of individuals. The method proposed in [57] only consider the emotion contagion, its simulation rates is lower than both of methods proposed by this paper and in [56]. And it can be also seen from Fig.7(b) of the time-consuming situation of the different methods, our improved CA-SIRS model has lower computational complexity and can effectively simulate the emotion contagion in emergency evacuation.

C. THE EFFECT OF EMOTION UPDATE FACTORS ON EMERGENCY EVACUATION

Two factors affecting emotion update, such as the accident experience and the panic level, were used as research objects. The simulations were carried out in a museum environment with the individual number of 200 and the scene of 60 m*80 m.

Fig.8 (a), (b), and (c) are the cases of different rates of emotion update factors in emergency evacuation simulation. Observe the simulation process by taking screen shots of the 125th, 347th, and 568th frames. Table 5 reflects the emotional proportion of emotion update factors and the impact of emotion update factors on evacuation time.

It can be seen from the experimental results that different proportions of emotion update factors can significantly change the evacuation situation. There was a positive correlation between the accident experience and emergency evacuation, and panic level was negatively correlated with it. Individuals with a rich experience and low panic level can escape the danger zone in a short period of time, thus improving evacuation efficiency.

D. IMPACT OF PATH PLANNING ON EMERGENCY EVACUATION

Path planning is the key to emergency evacuation and escape evacuation. Different path planning models can bring different evacuation effects. Environmental familiarity can affect the path selection of individuals or groups. Generally, individuals with higher environmental familiarity can perform better path planning in a shorter period of time, and have stronger predictions on the safety and time-consuming nature of the path. The nearby flow factor is also an important measure of path planning, mainly to discuss the degree of congestion. Fig.9 shows the relationship between environmental familiarity and nearby flow factors and evacuation time.

The different path planning models were simulated in a 60m*80m museum experiment scene with a simulated number of individuals of 100 people. Set the same experiment environment and character status, and only discuss the path planning model.

Reference [7] is a path planning model without adding environmental familiarity and nearby flow factors. Table 6 is

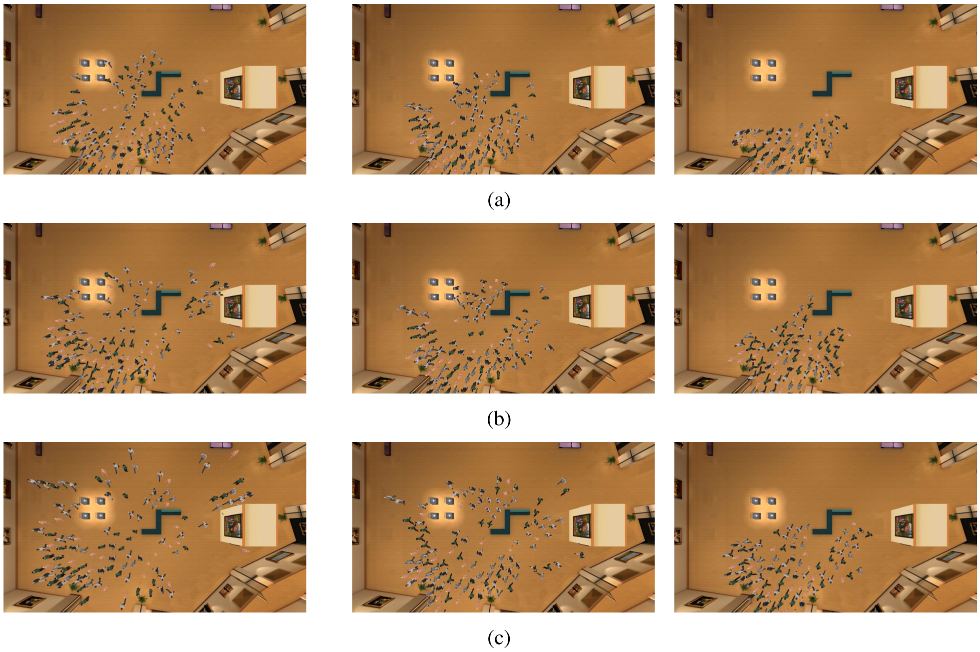


FIGURE 8. Emergency evacuation under different situations.

TABLE 6. Path planning simulation experiment comparison results.

	Time	Frame rate	Personnel speed	Personnel density
Our method	20.11s	42.55fps	0.98m/s	$\approx$3 persons/m^2
Method in [7]	22.34s	38.47fps	0.92m/s	$\approx$4 persons/m^2

TABLE 7. Four scenarios with varying levels of intimacy and environmental familiarity were used to validate our algorithm in a simulation environment.

Scenarios	Description	Level
Scene 1	Pedestrians walked with high intimacy and environmental familiarity	Highest
Scene 2	Pedestrians had the Scene 1 trajectories and movement with less intimacy and environmental familiarity	High
Scene 3	Pedestrians walked with varying trajectories and movement with intimacy and environmental familiarity	Medium
Scene 4	Pedestrians had the Scene 3 trajectories and movement with less intimacy and environmental familiarity	Low

TABLE 8. Statistical data.

	Six-point scale					
Method	1	2	3	4	5	6
Our method	4.74%	6.25%	10.33%	16.28%	30.56%	31.84%
Method in [7]	10.66%	12.47%	15.82%	16.04%	23.55%	21.06%
Method in [56]	6.98%	9.21%	13.46%	17.59%	25.97%	26.79%
Method in [57]	8.02%	11.53%	13.60%	17.78%	23.92%	25.15%

the comparison result of simulation experiments. By comparing the time, frame rate, personnel speed and personnel density at the exit, the environmental familiarity and nearby flow factors can increase the speed of evacuation and reduce the evacuation time, thus improving the evacuation efficiency.

E. AUTHENTICITY COMPARISON

We launched a voluntary call for participants from the Internet. A total of 203 participants participated. These participants were 18-65 years old and had different occupations. There are 101 males and 102 females. Participants were 18-25 years old: 40; 26-35 years old: 62; 36-45 years old: 50;

TABLE 9. Reflect data.

	Situation reflect			
Method	Reasonable	Matchable	Mitigable	Real
Our method	85.33%	82.15%	90.01%	82.51%
Method in [7]	65.87%	70.94%	78.31%	74.88%
Method in [56]	73.16%	76.27%	86.54%	79.03%
Method in [57]	66.51%	72.84%	77.69%	72.96%

TABLE 10. Emergency evacuation simulation data set.

	Personality traits					Emotion contagion		Emotion update		Main	Path planning		Simulation
	O	C	E	A	N	ε	λ	ϕ^{δ}	ϕ^{ϑ}	emotions	M	L	time
Group 1	0.33	0.15	0.21	0.17	0.14	0.68	0.49	0.53	0.47	clam, anxiety	0.34	0.66	23.76s
Group 2	0.18	0.13	0.36	0.23	0.10	0.32	0.68	0.28	0.72	anxiety, horror	0.17	0.83	30.64s
Group 3	0.24	0.07	0.26	0.38	0.05	0.55	0.45	0.49	0.51	fear, anxiety	0.34	0.66	28.09s
Group 4	0.04	0.31	0.28	0.04	0.33	0.77	0.51	0.15	0.85	hope, clam	0.63	0.27	20.47s
Group 5	0.42	0.09	0.18	0.18	0.13	0.40	0.54	0.69	0.31	hope, anxiety	0.22	0.78	25.34s
Group 6	0.25	0.37	0.06	0.13	0.19	0.23	0.38	0.17	0.83	clam, hope	0.35	0.65	22.16s
Group 7	0.12	0.24	0.22	0.16	0.26	0.61	0.56	0.30	0.70	clam, fear	0.39	0.61	29.41s
Group 8	0.07	0.39	0.43	0.05	0.06	0.58	0.42	0.24	0.76	hope, anxiety	0.19	0.81	24.35s
Group 9	0.19	0.08	0.32	0.20	0.21	0.16	0.35	0.43	0.57	clam, anxiety	0.75	0.25	24.82s
Group 10	0.34	0.25	0.14	0.13	0.14	0.30	0.46	0.22	0.78	hope, fear	0.44	0.56	27.79s

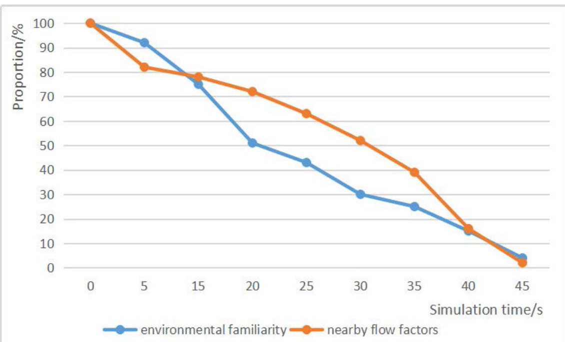


FIGURE 9. The proportion of emotion.

46-65 years old: 51. The ratio of male to female in all age groups is roughly 1: 1.

At first, participants were asked to watch the simulation methods of our method and method in [7], method in [56] and method in [57]. Contains a total of 16 videos. Each method has 4 videos, and these 16 videos are randomly arranged. Then, after watching each video, the participants will record the feeling information at that time. Feelings about the rationality of evacuation, the rationality of simulated characters, the degree of evacuation anxiety, individual distance, behavioral interaction, peer emotional interaction, and evacuation speed during emergency evacuation. Finally, the method is used to analyze the authenticity and rationality of the method.

For each video experiment, participants were compared on a six-point scale "strongly disagree (1)-strongly agree (6)". It mainly contains 4 questions:

1 Does emergency evacuation seem reasonable?
2 Does the simulation experiment characters attribute match the individual in reality?
3 If you are in this emergency evacuation, will your anxiety be reduced?
4 The individual behavior interaction is real?

The study involved 4 scenarios with each scenario containing 100 characters. Each scenario had different intimacy and environmental familiarity (Table 7). Table 8 shows the statistics about the six-point scale. Table 9 shows the average response of the participants to the simulation scenarios (divided into reasonable, matchable, mitigable, and real). The result of Table 8 reflect the degree of acceptance of the participants on the realness of the scene in the simulation. As can be seen from Table 8 and Table 9, the experimental results of different simulation methods are different. The method in this paper can reflect the evacuation behavior in real life through the intimacy and emotional interaction of peers. It is more reasonable and effective in emergency evacuation.

F. SIMULATION OF EMOTION CHANGE PROCESS

Under the influence of personality traits, emotion contagion, emotion update and path planning, the emergency evacuation simulation model has been well studied. This section conducts a large number of random experiments on these factors, and the number of simulated individuals is 200, and the data set is obtained. The data set is analyzed to realize the simulation method of emergency evacuation affective computing combined with personality traits and emotion contagion. Table 10 shows the results of 10 random sets of data. The convergence of our proposed method is shown in Fig.10, we simulate the spread of panic emotion within 200 individuals

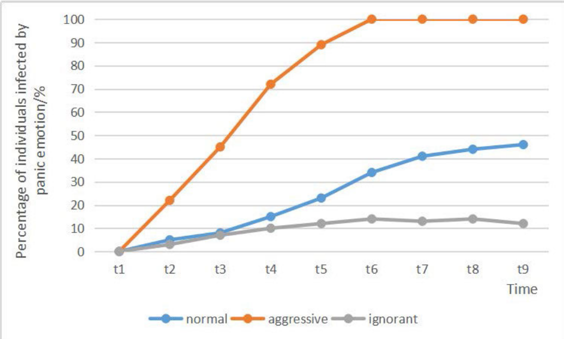


FIGURE 10. **The compares of simulation time.**

with three most representative personalities: normal crowd ($\psi^{O,\,C,\,E\text{ and }N=1}$ satisfies random distribution), aggressive crowds ($\psi^{O,\,E\text{ and }N=1}$), and ignorant crowds ($\psi^{C\text{ and }A=1}$). With the simulation goes on, the panic emotion of normal crowds will stabilize to a certain extent, while the aggressive crowd will become extremely panic, that is because all the individuals are very sensitive, their intimacy become the main factor to accelerate panic emotion contagion. Only a few ignorant individuals will be infected as the personality become the main factor affects emotion contagion.

VI. CONCLUSION

This paper proposed an emotion contagion method for emergency evacuation based on personality traits and emotion contagion. This method analyzes the group's emergency evacuation behavior from the perspective of psychology and sociology. Analysis of intimacy, emotional intensity and panic level make simulation authentic and reasonable. Imitation and sensation by simulating through accident experience, environmental familiarity and nearby flow factors. In the same experiment environment, the efficiency of simulation can be improved, the computational complexity of the computer can be reduced, and the actual situation can be more realistic. Moreover, the popularity of emotion-based affective computing method can effectively promote the development of artificial intelligence.

This paper only considers the influence of personality traits and emotional contagion on individual behavior in terms of emotional factors. However, in real life, the influence of emotions on individuals is multi-faceted, such as the conformity of emotions and the correlation between emotions. In addition, emotions are not limited to the six categories studied in this article. Subtle emotional differences can be the key to affecting individual behavior. At the same time, the optimization algorithm of individual motion trajectories is also the key direction we should consider. How to reduce the computational complexity in achieving efficient performance is the most important thing to improve the simulation model.

In the future, on the one hand, we intend to combine emotions with machine learning to give individuals the ability to learn and determine the best direction of movement for the individual. Based on the previous work [28], we will study on how to establish learning algorithms for computers to learn about individual emotions. The algorithm can enhance individual robustness by observing individual characteristics. And with the familiarity of the environment, machine learning can act on collision avoidance. On the other hand, we will consider the detailed modeling and analysis of each social relationship based on the research of psychology and improve the emotion contagion model to generate more realistic simulation results.

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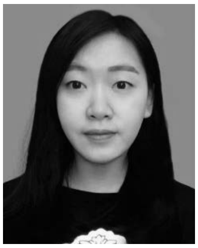

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