Simulating a crowd with dynamic emotional transmission based on Hidden Markov Model

Xueling Jiang[1, 2], Shuijie Qin[1*]

[1]*Laboratory for Photoelectric Technology and Application, Guizhou University, Guiyang, Guizhou, 550025, China*

[2]*College of Computer and Information Engineering, Guangxi Teachers Education University, Nanning, Guangxi, 530023, China*

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Abstract

Crowd simulation has been widely applied in computer animation and graphics rendering technology. However, the social communication and emotional characteristics are often unrecognized in crowd simulation. In psychology, there are two kinds of emotional factors for humans: the internal one from the individual, and the external one from the neighbours. To this end, in this work, we propose simulate a crowd using affective computing with dynamic emotional transmission. Specifically, we use Hidden Markov Model (HMM) to model the emotions for individuals with consideration of personality, and to capture the internal emotion state transfer. Besides, we abstract a two-layer transmission process to quantify the impact from highly active neighbours. In addition, we conduct some simulation experiments to evaluate our proposed model.

Keywords: Crowd simulation, Hidden Markov Model, Affective computing

1 Introduction

The process of reproducing real world systems based on specific model, and investigating the characteristics of the systems through experiments over the model, is called simulation [1]. With the rapid development of information technology and relevant techniques, simulation has become one of the important tools of improving the planning, designing and operating in various areas. For example, crowd animation simulation [2] is a significant direction in computer animation and graphics rendering technology, and it has been widely used in movies and games. Indeed in real life, the population of cities, the social communication and the crowd activities are all increasingly growing, which post a challenge in public security. Therefore, creating an effective crowd simulation model is necessary.

Existing research on crowd simulation can be grouped into three categories. (1) Macro models focus on the global perspective of the whole systems, such as speed, flow and density. However, macro models fail to describe the movements and activities of individuals in the crowd in details. (2) Micro models study on the individuals in the crowd, such as the characteristics (sex, age, psychology, etc.) as well as the environmental factors. (3) Meso models are defined between above two types. Meso model can describe the whole structure of the crowd, and meanwhile preserve the core data of micro model.

However, above existing efforts mainly investigate the path or movements of the crowd or individuals, without considering the emotional factor of each individual. Therefore, the simulation cannot precisely represent the process of decision making of the crowd. To this end, we propose to embrace affective computing technique to integrate emotional affects. The intuitive is that not only external environmental factors are important, but also the emotional ones. One reason is that only a small fraction of population is directly affected by the environment, while others are actually affected by other individual in the crowd. Another reason might be that some active people are more likely to affect others.

In this work, we propose to model the crowd simulation using affective computing to take into consideration of emotional factors. Specifically, we focus on the emotional transmission among crowd. Specifically, there are three issues included in emotional transmission. (1) How to model emotions of each individual? (2) How to capture the emotions transmitted by highly active individuals? (3) Will those transmitted emotions be accepted, given various personalities?

Generally, the emotional transmission is considered two-way in this work: (1) emotional state transfer among individuals, represented by the HMM model; and (2) emotional impact from other highly active individuals, simulated by the two-layer transfer process. Specifically, we propose the following solutions to solve the questions above. First, we try to model emotions using Hidden Markov Model (HMM) to capture the dynamic features of affective crowd. Second, we simulate emotional transmission as a two-layer transfer process, and quantify the amount of emotion transmission. Third, to differentiate the influences on individuals, we modify our emotion model by considering the personality of each individual.

[*] ***Corresponding author*** e-mail: shuijie@gmail.com

The rest of this paper is organized as follows. In Section 2 we provide some related work. Section 3 presents the individual affective model based on HMM, and Section 4 proposes the two-layer emotional transmission model. Simulation experiments are conducted in Section 5. Finally, the paper is concluded in Section 6.

2 Related work

Related work can be categorized into three groups: modelling the virtual environment of the crowd, simulating the crowd behaviour and synthetic crowd movement. Now we provide some literature review as follows.

There are basically two methods in virtual environment modelling is applied: geometrical and non-geometrical methods. The common spatial data structures for geometrical models include: bounding volume hierarchy [3-4], trees with binary space partitioning [5-8], and octree [9-10]. Non-geometrical method is typically employed in two fields: computer animation and robots. In the field of computer animation, Lamarche et al. proposed a topological structuring of the geometric environment to allow fast path finding as well as an efficient reactive navigation algorithm for virtual humans evolving inside a crowd [11]. Noser et al. employed synthetic vision for navigation by a digital actor [12]. Sung et al. proposed to combine the behaviour model of virtual agents with the environment model [13]. In the robots area, typical models include: Grid map proposed by Elfes et al [14], topological method [15], and Featuremap [16], etc.

Many efforts have been made in simulating behaviour of crowd. Reynolds et al pioneered in this field by simulating the behaviour of flocks and herds using a particle system [17]. Later agent theory has been applied to explore the crowd behaviour. For example, Alyett et al developed a sequence distribution graph using intelligent agents [18].

The third group of related work is about synthetic crowd movement. Some methods are based on graph structure [19-21], which represents the set of motion segments as a database with graph structure, and displacement mapping is performed to assemble the motion. Another method is procedural motion synthesis [22-23], which is more designed for real-time scenarios. Motion blending is also employed to motion synthesis [24-25], which could continuously simulate the motion routes of virtual human.

Unlike existing works, in this work, we focus on simulate a crowd with dynamic emotional transmission. Specifically, we capture that there are two types of transmission among the crowd. One is emotional state changing between individuals, and the other is emotional transmission among the whole crowd triggered by highly active individuals.

3 Individual affective model

In this section, we discuss how to model affection of each individual. A popular method is to construct emotions in a state space with transitions among different states based on Markov state model [26-27]. However, even though the existing model describes the probability of each emotional state, it fails to present the exact emotional changing, which is largely related to personality. To this end, we propose a HMM based emotion model with consideration of personality in this section.

3.1 EMOTION AND EMOTION SPACE

Emotions of human beings, such as angry, surprised, neutral, sad, happy, etc., makes up the emotion space, notated as $S_E = \{S_{E_i} \mid i = 1, 2, ..., N\}$ where S_{E_i} is the -th emotion state, and N is the size of basic emotions. Let X be a random variable, and the probability of is notates as P_i, and:

$$\sum_{i=1}^{N} P_i = 1,\ 0 \le P_i \le 1 \left(i = 1, 2, ..., N \right). \quad (1)$$

Therefore, the probability space model of emotion space can be represented as:

$$\begin{pmatrix} S_E \\ P \end{pmatrix} = \begin{pmatrix} S_{E_1} & S_{E_2} & ... & S_{E_N} \\ P_1 & P_2 & ... & P_N \end{pmatrix}. \quad (2)$$

3.2 PERSONALITY AND PERSONLAITY SPACE

Emotional response is greatly dependent on the personality of individuals. For example, a person with an optimistic personality is more likely to be bright, open minded and stepped forward, while a reserved person might be apathetic to everything. From above observations, we percept that with different personalities, the acceptance of emotional contagion originated from highly active people is different.

In the field of psychology, the Big Five personality traits explore five dimensions of personality to describe human personality, and the theory is called the Five Factor Model (FFM) [28]. According to FFM, there are five factors to represent the personality space, i.e., openness, conscientiousness, extraversion, agreeableness, and neuroticism. Therefore, any personality can be represented with above five dimensions:

$$S_P = (p_o, p_c, p_e, p_a, p_n), \quad (3)$$

where $p_o, p_c, p_e, p_a, p_n \in [-1,1]$ denote the value of openness, conscientiousness, extraversion, agreeableness, and neuroticism respectively. Note that we define values within [0,1] as positive personality, and [-1,0] as negative personality.

3.3 HMM MODEL WITH EMOTION AND PERSONALITY

Before constructing a HMM model with emotion and personality, we need to build a unified representation of emotion and personality. The PAD emotional state model [29] is an established method to describe and measure emotional states. Thus, in this work, we employ PAD model to map both emotions and personalities into a unified space.

There are three dimensions in PAD: (1) the Pleasure-Displeasure Scale measures how pleasant an emotion may be, (2) the Arousal-Nonarousal Scale measures the intensity of the emotion, and (3) the Dominance-Submissiveness Scale represents the controlling and dominant nature of the emotion. Every emotion is represented as a point in the 3-dimensional space, notated as $e=(e_p,e_a,e_d)$, where $e_p,e_a,e_d \in [-1,1]$. For example, Table 1 shows the PAD representation of eight basic emotions [30]

TABLE 1 Relationship between basic emotion and PAD space

Emotion	Pleasure	Arousal	Dominance	PAD subspace
Fear	-0.64	0.60	-0.43	Anxious
Angry	-0.51	0.59	0.25	Hostile
Happy	0.40	0.20	0.15	Exuberant
Bored	-0.65	-0.62	0.33	Disdainful
Curious	0.22	0.62	-0.01	Dependent
Sleepy	0.20	0.70	-0.44	Docile
Dignified	0.55	0.22	0.61	Exuberant
Elated	0.50	0.42	0.23	Exuberant

Then we consider mapping the 5-dimensional personality based on FFM model into 3-dimensional PAD space. The method we use in this study is inspired by [31]. The mapping from personality space to PAD space is performed as Table 2.

TABLE 2 Mapping from personality space to PAD space

	Openness	Conscientiousness	Extraversion	Agreeableness	Neuroticism
Pleasure	0	0	0.21	0.59	0.19
Arousal	0.15	0	0	0.3	-0.57
Dominance	0.25	0.17	0.6	-0.32	0

Therefore, the personality in Equation (3) can be represented as follows:

$$\begin{bmatrix} e_p \\ e_a \\ e_d \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0.21 & 0.59 & 0.19 \\ 0.15 & 0 & 0 & 0.3 & -0.57 \\ 0.25 & 0.17 & 0.60 & -0.32 & 0 \end{bmatrix} \begin{bmatrix} p_o \\ p_c \\ p_e \\ p_a \\ p_n \end{bmatrix}. \quad (4)$$

Now we have mapped all emotions and personalities into a 3-dimension coordinate space. Suppose $E^{(i)}=[e_p^{(i)},e_a^{(i)},e_d^{(i)}]$ is the probability distribution of emotional states at time i, and $E^{(0)}=[e_p^{(0)},e_a^{(0)},e_d^{(0)}]$ is the initialized probability distribution of emotional states.

Suppose $\lambda=(E,S,\pi,A)$, where X is the emotional space represented in PAD model, i.e., $\{(e_p,e_a,e_d)\}$, S is the set of external stimulations, and π is the initialized probability distribution of emotional states, i.e., $\pi=E^{(0)}=[e_p^{(0)},e_a^{(0)},e_d^{(0)}]$. A is the transition probability matrix, where element a_{ij} means the probability of emotional state $e^{(i)}$ transferred to $e^{(j)}$.

The basic equations of Markov model are as follows:

$$e_i^{(k+1)}=\sum_{j=1}^{N} e_j^{(i)} a_{ji}, \quad (5)$$

$$e_i^{(k)}=\sum_{j=1}^{N} e_j^{(0)} a_{ji}^{(k)}, \quad (6)$$

where e_i,e_j denote the emotion in the 3-dimensional emotion space. The corresponding matrix representation is:

$$E^{(k+1)}=E^{(k)}\bar{A}, \quad (7)$$

$$E^{(k)}=E^{(0)}\bar{A}^{(k)}. \quad (8)$$

Suppose the limit probability of $\bar{A}$ can be represented as $\bar{\pi}^{*}=\left[\bar{\pi}_1^{*}\bar{\pi}_2^{*}\bar{\pi}_3^{*}\right]=\left[1/3\ \ 1/3\ \ 1/3\right]$. Let

$$\bar{A}=\begin{bmatrix} \frac{L-2}{L} & \frac{1}{L} & \frac{1}{L} \\ \frac{1}{L} & \frac{L-2}{L} & \frac{1}{L} \\ \frac{1}{L} & \frac{1}{L} & \frac{L-2}{L} \end{bmatrix}, \quad (9)$$

where $L=\theta\bar{\pi}_i^{*}=\frac{\bar{\theta}}{3}\geq 2$. Solve the equation $|A(\lambda)|=|\lambda I-A|=(\lambda-1)\left(\lambda-\frac{L-3}{L}\right)^2=0$, we get the following characteristic roots: $\lambda_1 = 1, \lambda_2 = \lambda_3 = \frac{L-3}{L} = \delta$.

We can calculate $\bar{A}$ as follows:

$$a_{ij}^{(k)} = \pi_j + \Delta q_{ij}, \pi_j^* = \frac{\lambda^k A_{ji}(1)}{a_0(1)}, \quad \Delta q_{ij} = \sum \frac{1}{(m_i - 1)!} D_\lambda^{m_i - 1} \left[\frac{\lambda^k A_{ji}(\lambda)}{a_i(\lambda)} \right]_{\lambda = \lambda_i}. \tag{10}$$

Then we have the results:

$$\Delta q_{ij} = \begin{cases} \frac{2}{3}\delta^k = \frac{2}{3}(\frac{L-3}{L})^k, & i = j, \\ -\frac{1}{3}\delta^k = -\frac{1}{3}(\frac{L-3}{L})^k, & i \neq j. \end{cases} \tag{11}$$

And

$$\bar{A}^k = \begin{bmatrix} \frac{1}{3}+\frac{2}{3}\delta^k & \frac{1}{3}-\frac{1}{3}\delta^k & \frac{1}{3}-\frac{1}{3}\delta^k \\ \frac{1}{3}-\frac{1}{3}\delta^k & \frac{1}{3}+\frac{2}{3}\delta^k & \frac{1}{3}-\frac{1}{3}\delta^k \\ \frac{1}{3}-\frac{1}{3}\delta^k & \frac{1}{3}-\frac{1}{3}\delta^k & \frac{1}{3}+\frac{2}{3}\delta^k \end{bmatrix}. \tag{12}$$

Substitute into Equation (5), we have $e_i^{(k)} = \frac{1}{3} + (e_i^{(0)} - \frac{1}{3})\delta^k$, and

$$e_{i\Delta}^{(k)} = e_{i\Delta}^{(0)}\delta^k, e_{i\Delta}^{(k)} = e_i^{(k)} - \frac{1}{3}, e_{i\Delta}^{(0)} = e_i^{(0)} - \frac{1}{3}, \tag{13}$$

where $e_{i\Delta}^{(k)}, e_{i\Delta}^{(0)}$ denote the strength of i^{th} emotion at current and initialized state.

In this section, we have modelled the affection of individuals based on HMM with consideration of both emotion and personality. In next section, we will discuss the transmission among the crowd.

4 Dynamic emotional transmission model

In this study, we assume that the emotions could be transmitted among individuals, as proved in existing social psychology efforts [32]. Therefore, we consider the interactive emotional influences among each other by simulating the process as a two-layer transfer process. The basic assumption is that the crowd is dynamic and contagious. Specifically, the emotional transmission is conducted in a two-layer manner. We abstract the emotional transmission as a transmission layer, and the individuals with certain emotional state forms the crowd layer. First, individuals are sampled from the crowd layer. Then, internal emotional state transmission is performed among the individuals. After that, the changes of emotional state are returned to the crowd layer for updates. The process is illustrated in Figure 1.

We define the perception scope of emotional transmission at time t as $d(t)$. For individual b, the emotional influence sent by b can be calculated as $S = E_b^t / d(t)$, where E_b^t notates the emotional value. If individual a gets affected, then:

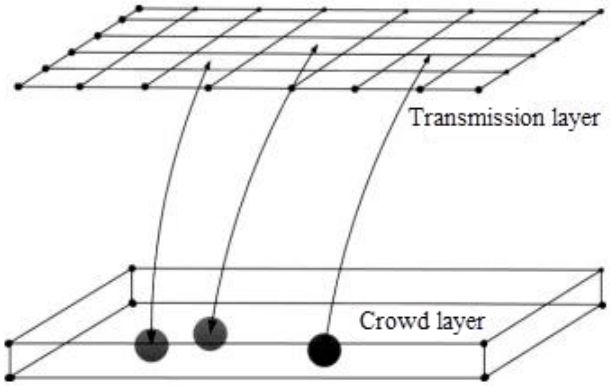

FIGURE 1 Illustration of the two-layer transfer process

$$E_a^{t+1} = \begin{cases} (1-\alpha_a)E_a^t + \alpha_a S_a^t, & \text{if } a,b \text{ have the same sign in the pleasure scale,} \\ (1-\alpha_a)E_a^t - \alpha_a S_a^t, & \text{else.} \end{cases} \tag{14}$$

Therefore, the emotional transmission equation is:

$$\frac{\partial E}{\partial t} = K\frac{\partial^2 E}{\partial^2 U} + E_e, \tag{15}$$

where K is the damping coefficient, and E_e is the external influence.

After transmission, the emotion state of individual is updates as follows:

$$E^t = \sum_{i=1}^{\theta} \frac{\sum_{i=1}^{\theta}(|c - c_i|) - |c - c_i|}{(\varepsilon - 1)\sum_{i=1}^{\theta}(|c - c_i|)} M_i^t, \tag{16}$$

where θ is the number of individuals within the influence scope, c_i is the position of neighbour individual, and M_i^t is emotional state of the transmission layer.

In summary, our proposed method can simulate a crowd with dynamic emotional transmission. Specifically, the affective model of each individual is built upon HMM model with consideration of both emotion and personality. After that, there are two types of emotional transmission: (1) inherent emotion state changes over time; and (2) impact from others such as highly active neighbours. Correspondingly, our solutions are: (1) probability transfer matrix in HMM, and (2) two-layer transmission model. Figure 2 summarizes the overall process flow of our method.

5 Experiment

In this section, we conduct several simulations to evaluate the effectiveness of our proposed model.

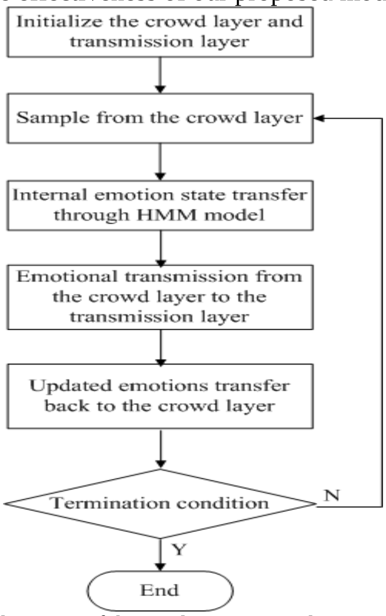

FIGURE 2 Illustration of the two-layer emotional transmission process

First of all, we simulate the influence of emotional transmission upon crowd. As shown in Figure 3, there are four groups of people formed at some time in the left figure, and then after a while, it turns into two groups in the right figure. This transition is caused by the dynamic emotional transmission among the crowd. Figure 4 shows a 3D example of emotional contagion. We can observe that, due the emotional transmission process, people transfer from one place to another.

We believe that, it is the highly active person who triggers the emotional transmission process. Figure 5 provides a crowd evacuation simulation with different percentage of highly active persons. From the left figure with many highly active persons, notated as circles, we can see that the crowd is evenly spread all over the space. However, as shown in the right figure, where the number of active persons is relatively small, the crowd seems to be grouped together towards the highly active centres. Therefore, we can observe that the impact of highly active people is significant and could influence the overall crowd.

Figure 6 illustrates the influence of personality in the process of emotional transmission, where the height denotes the emotional activity of each individual. The upper figures in Figure6 show the dynamic evolution of the crowd without personality consideration, while the lower figures are the changing with personality included. From those figures, we have the following observations. (1) If no personality considered, the emotion of the crowd is greatly dependent on the highly active person (notated as the green point in upper figures); and the transmission is approximately equal to all the neighbours. (2) When taking personality into consideration for emotional transmission, the overall activity of the crowd is increased, and the emotional state for each individual varies.

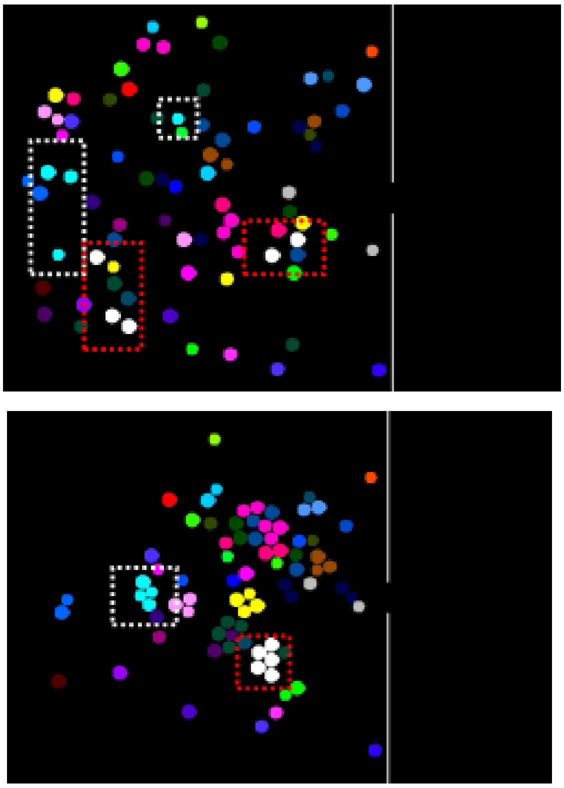

FIGURE 3 Influence of emotional transmission upon crowd

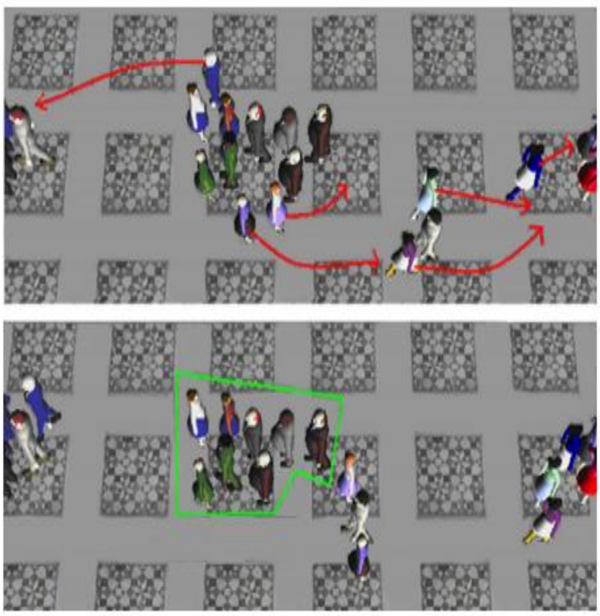

FIGURE 4 3D illustration of emotional transmission among crowd

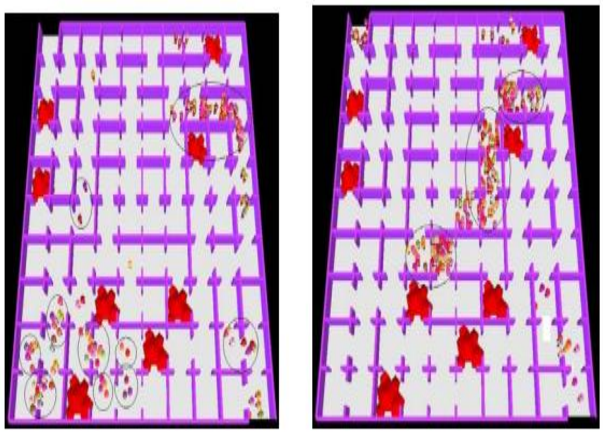

FIGURE 5 Crowd evacuation with high vs. low percentage of highly active persons

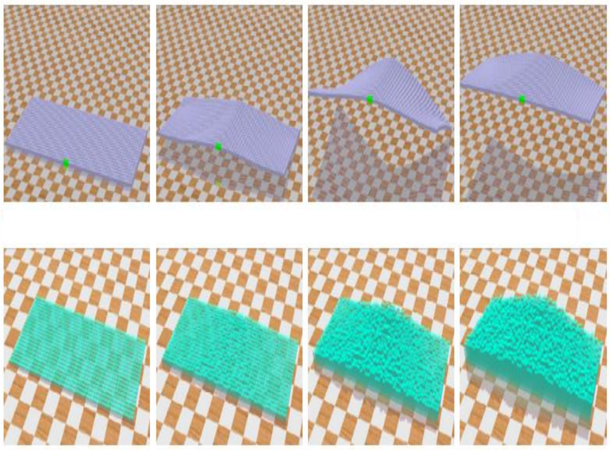

FIGURE 6 Influence of personality in emotional transmission

6 Conclusion

In this work, we focus on the problem of simulating a crowd with emotion and personality, as well as the emotional transmission among the individuals. Specifically, we first model the emotion and personality of each individual using HMM model. Also, the internal emotional changes of individual is naturally captured by the HMM transfer matrix. Then, we design a two-layer transmission model to simulate the process of emotional transmission among the crowd. Our simulation results prove the effectiveness of our method.

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Authors

Xueling Jiang, born on August 9, 1971, Xinjiang province, China

Current position, grades: doctoral candidates
University studies: Gui Zhou university
Scientific interest: Computer Simulation and Modelling

Publications:

[1] XueLing Jiang, ChaoYun Long, Shuijie Qin, Liping Wang, Jianghui Dong Pedestrian Evacuation Simulation Based on Dynamic Parameter model with Friction. Applied Mechanics and Materials Vols. 543-547 (2014) pp 1876-1879.

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Experience: She received her Me.Sc. in Computer Application (2006), now she is a PhD candidate in Mechanical and Automation at GuiZhou University in China. She work at College of Computer and Information Engineering, Guangxi Teachers Education University, Her current research interests include different aspects of Artificial Intelligence and Affective computing.

Shuijie Qin, born in October, 1963, Guangxi province, China

Current position, grades: professor
University studies: Guizhou university
Scientific interest: MEMS, Computer Simulation and Modelling

Publications:

1. S. J. Qin and Wen J. Li, "Formation Mechanism Analysis to Laser-Induced Splitting Nano Channels in Quartz Cubes", Accepted by Acta Mechanica Sinica (2003).
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Experience: She received her M.Sc. in Optical instruments (1989) and PhD in MEMS (2002) from Chinese University Hong Kong CN.