An Emotional Model Based on Multiple Factors

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Abstract In the research of emotional simulation, the existing emotional models, such as the emotional model based on cognition, the emotional model based on probability, multilayer emotional model and so on, always put particular emphasis on one or some factors and cannot describe complicated emotions; in addition, they do not consider the subconsciousness' impact on emotion. This paper comes from emotional space which based on dimensions, integrates heterogeneous personality factor, introduces the cognitive and non-cognitive factors of emotion's generation, and combines the factors such as character's influence components of emotion, decay of emotion, mutual influence between emotions, outside stimulus, subconsciousness, builds a personalized emotional model. At last, this model is used to simulate a crowd scene, which indicates that this emotion model can reflect different emotions generally.

Keywords Emotional model · Subconsciousness · Personality · Complicated emotions

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1 Introduction

In the virtual humans' simulation, emotion computation is a highly integrated research topic, the main research content includes emotion mechanism's researchment, emotion signal's acquisition, emotion signal's analysis, modeling and recognition, emotion understanding, emotion expression, and emotion computation's research focus is on acquisition of physiology and behavioral traits signals caused by emotion from many sensors, building the emotion model, generating the personal computer system which can react intelligently, sensitively, friendly to the users' emotion.

Emotion has complexity and fuzzy, in order to implement the intelligent system, an emotion model should be built first, building a reasonable math model to describe the emotion is the critical problem of emotion modeling's research, several models have been proposed for emotion, such as the OCC model, HMM model and so on.

2 Problem Description and Approach

2.1 Problem Description

The existing emotion models have many advantages and disadvantages, some of which will be introduced in detail. First, the emotional model based on cognition will be introduced, its most typical model is the OCC model [1], which only considered the emotion's cognition factor and its generating mechanism, but did not consider emotion's non-cognitive factor, such as the character's influence. Second, the emotional model based on probability's most typical model is the HMM model [2], and it simulated the emotion only from probability, while did not consider emotion's cognitive and non-cognitive factors, leading to the result that for the same stimulus, HMM model's perceptive situations are the same. The emotional model based on dimensions described the emotion by presuming a small number of discrete emotion and small-scale range of emotion variation, while did not consider emotion's non-cognitive factor. At last, the multilayer emotional model of "character-mood-emotion-expression" presented by Kshirsagar is the emotion model which related the character and emotion firstly and applied itself to virtual human's face expression successfully [3], but it deals with the mood obscurely and cannot describe the complex emotion.

In order to resolve the problems of these models, a new emotion model is introduced here, which considered many crucial factors. This emotion model includes perception module, inside variable module, character module, and mood module, and every module will be introduced in detail in the following part.

2.2 Perception Module

The perception module's function is perceiving the outside environment and obtaining its information; in here, the virtual human does not need to pay close attention to all the objects, suppose that the main concerned objects include the other virtual humans, static obstacles. The perception of the outside environment can be classified to five kinds: visual perception, auditory perception, smelling perception, tasting perception, and tactile perception, which can be defined as follows:

$$\text{Set}i = \{aj \mid aj \in \text{ElemSet}, \quad j = 1, 2, \ldots, n, \quad n \geq 0\} \tag{1}$$

Set$i$ denotes five kinds of perception, $i \in [1, 5]$, aj denotes a perception event, and ElemSet denotes the set of event element.

2.3 Subconscious Module

According to biological studies, emotion is formed before cognition in subconscious state, and some of the emotional reactions which are under the conscious control are the results of cognitive activities, but some of the emotions are stored in the brain by the way of conditioned responses. Once the conditioned stimulus is touched, these emotions will be realized automatically, which usually cannot be controlled or noticed by oneself. The latter one is called conditioned emotional response [4], some of which are related to the virtual human, after the perceived objects' visibility testing in perception module, their emotional effects will be proceed firstly in here. Suppose at time $t0$, a conditioned stimulus of ai is perceived; if ai is visual stimulus, $ai \in \text{Set}1$, the emotion intensity caused by it can be formulated as follows:

$$\text{ConFo}(\text{dis}) = \begin{cases} 0, \text{dis} > \text{MAXR} \\ k * \text{Cp}, \text{dis} \leq \text{MAXR} \end{cases} \tag{2}$$

ConFo(dis) denotes the emotion intensity caused by ai, dis denotes the distance between visual-conditioned stimulus and virtual human, and k is the environmental impact factor. Cp is the former emotion intensity which has formed when virtual human got the stimulus similar to ai; MAXR is the maximum distance in which the conditioned stimulus can take effect. If ai is the other stimulus, $ai \in \text{Set}2 \cup \text{Set}3 \cup \text{Set}4 \cup \text{Set}5$, its duration is Δt, the emotion intensity caused by it at time t is computed as follows:

$$\mathrm{ConFo}(t) = \begin{cases} 0, t \le t0 \\ k * \mathrm{Cp}, t0 < t < t0 + \Delta t \\ k * \mathrm{Cp} * e^{\Lambda}(-b(t - t0)),\ t \ge t0 + \Delta t \end{cases} \tag{3}$$

ConFo(t) denotes the emotion intensity caused by ai, k is the environmental impact factor, Cp is identical with the one in formula (2), and b is the coefficient of mood attenuation.

2.4 Inside Variable Module

Inside variable module mainly includes some physiological variable and social variable, based on the Maslow's theory of a hierarchy of needs to be satisfied, and physiological variable includes the basic physiological needs; we consider three kinds of physiological demands, including fatigue, hunger, and thirsty. Social variable includes security requirement, respect demands, self-fulfillment; in here, we only consider the safe demand. Values of inside variables' demand intensity range from 0 to 1. 0 denote that demand intensity is very low, 1 denotes it is very high.

We presume that the distance between virtual human and outside stimulus is dis; in here, outside stimulus are the ones which can affect its physiological demands, the maximum distance in which these outside stimulus can affect virtual human is MAXR. The effect strength function to the virtual human is as follows:

$$\mathrm{Ivo}(\mathrm{dis}) = \begin{cases} 0, \mathrm{dis} \ge \mathrm{MAXR} \\ \frac{\mathrm{Ivi}(t) \times k}{\mathrm{dis}},\ \mathrm{MINR} \le \mathrm{dis} \le \mathrm{MAXR} \\ \mathrm{Ivi}(t) \times k,\ \mathrm{dis} \le \mathrm{MINR} \end{cases} \tag{4}$$

K is a constant, which denotes the effect strength of the outside stimulus to the virtual role. Ivi(t) denotes inside physiological demand intensity of the virtual human at the moment of t, Ivi(t) ∈ [0, 1]. Ivi(t) varies with time; it can be denoted as follows:

$$\mathrm{Ivi}(t) = \min\{\mathrm{Ivi}(t - 1) + \Delta M,\ 1\} \tag{5}$$

ΔM denotes inside physiological demand's increment within the time span from $t - 1$ to t. The overall inside physiological demand intensity is the sum of its own physiological demand intensity and the effect strength of outside stimulus to it. It can be denoted as follows:

$$\mathrm{Ivs}(t) = \min\{\mathrm{Ivi}(t) + \mathrm{Ivo}(t),\ 1\} \tag{6}$$

Ivs(t) denotes the overall inside physiological demand intensity of the virtual human, Ivs(t) ∈ [0, 1].The thresholds of fatigue, hunger, and thirsty are set, when one or some of them are exceeded, the virtual human's emotion will be affected.

Table 1 Effective values range of behavior parameters

Parameter	Min	Max	Unit
Max.neighborsdist	3	30	m
Max.num.neighbors	1	100	n/a
Planning horizon	1	30	s
Agent radius	0.3	2.0	m
Preferred speed	1.2	2.2	m/s

Table 2 Mapping between adjectives and PEN factors

Trait	Adjectives
Psychoticism	Aggressive, impulsive
Extraversion	Assertive, active
Neuroticism	Shy, tense

Although virtual human may have many kinds of motives at the same time, when in the face of danger, it will consider the safety as the most important things, security needs will play a leading role; when it has no security needs and the needs intensity value of fatigue, hunger, or thirsty is bigger than the threshold, needs of fatigue, hunger or thirsty will play a leading role.

2.5 Character Module

Character module mainly includes the virtual human's character; different characteristics of the virtual persons are created according to three factors model's mapping between the mood and parameter. PEN model is used as the virtual human's character data. PEN model's three factors are psychoticism, extraversion, and neuroticism.

Guy et al. research explored the effect of the crowd's behavior parameters to the perceived behaviors, five behavior parameters in Table 1 were used. The effective values range of behavior parameters was obtained by data analysis, and it is shown in Table 1, which will be used as empirical data in this paper [5].

Perceived behaviors are described by six adjectives: aggressive, assertive, shy, active, tense, and impulsive. Virtual humans of different personalities are generated as follows: First, behavior parameters and perceived behavior's mapping are generated by linear regression model. Second, behavior parameters and PEN model's mapping are generated so that the virtual humans have different personalities. This is based on the research finding of Pervin, and six adjectives of behaviors are corresponding to three characteristic factors in Table 2.

2.6 Mood Module

The mood has an important influence on the emotion, good mood can repress negative emotions, and bad mood can repress positive emotions. Mood intensity expressed as Im, Im$\in [-1, 1]$; positive value of Im denotes that virtual human is in a good state of mind, and negative value of Im represents the virtual human is in a bad mood. The greater the absolute value of Mood intensity, the stronger the influence to the emotion, conversely, the weaker the absolute value of Mood intensity, the stronger the influence to the emotion.

Mood space's selection. In our research, the mood model uses "pleasure," "arousal," and "dominance" to constitute a three-dimensional mood space, which is also called PAD space. The initial mood intensity values are inputted by the user to guide and control virtual human's emotion tendency to some extent.

Mood intensity can be represented by PAD space as: $\mathrm{Im}(t) = [\mathrm{Ip}(t), \mathrm{Ia}(t), \mathrm{Id}(t)]$. When mood intensity is equal to [0, 0, 0], it denotes the mood in peace.

Mood attenuation function. As time went on, the mood will gradually decay, this means mood intensity will tend to [0, 0, 0], which represents the state of calm. Suppose at time $t0$ user input the mood intensity of initial value, the following is mood intensity at time t:

$$\mathrm{Im}(t) = \varphi(\mathrm{Im}(t0)) = \mathrm{Im}(t0) \times \mathrm{e}^{-b(t-t0)} \tag{7}$$

b is the coefficient of mood attenuation, which controls the mood attenuation speed, and different character has different value of b.

Mood strength update equation.

$$\mathrm{Im}(t) = \varphi(\mathrm{Im}(t0)) + R(\mu) \tag{8}$$

$\varphi(\mathrm{Im}(t0))$ denotes the mood intensity after the mood attenuation, $R(\mu)$ denotes the influence function of outside stimulus to mood. It can be represented as follows:

$$R(\mu) = \omega m \times \mathrm{PAD}^{*} \times \rho^{T} \tag{9}$$

In the above formulate, PAD* denotes the mapping matrix between emotion and mood, ρ^T is the outside stimulus of emotion, and ωm is the influence coefficient of outside stimulus to the fluctuation of mood. It is decided by character.

2.7 Emotion Module

Emotion space's selection. In this study, the Ekman's six basic emotions are as follows: happy, sad, anger, surprise, fear, and disgust constitute six-dimensional emotion space, so emotion vector is represented as follows:

$$E(t) = (E\mathrm{hap}(t), E\mathrm{sad}(t), E\mathrm{ang}(t), E\mathrm{sur}(t), E\mathrm{fear}(t), E\mathrm{dis}(t)) \tag{10}$$

Emotion intensity can be represented as follows:

$$\mathrm{Ie}(t) = (\mathrm{I1}(t), \mathrm{I2}(t), \mathrm{I3}(t), \mathrm{I4}(t), \mathrm{I5}(t), \mathrm{I6}(t)) \quad (11)$$

Basic emotions' representation. Each component of emotion vector is computed by the following expression:

$$\mathrm{Ei}(t) = f(\mathrm{Iei}(t), \omega 0) = \begin{cases} 1, \ \mathrm{Iei}(t) \geq \omega 0 \\ 0, \ \mathrm{Iei}(t) < \omega 0 \end{cases} \quad (12)$$

$\mathrm{Iei}(t)$ denotes the individual's value of emotion intensity, $\omega 0$ denotes the active threshold, $i \in [1, 6]$.

Emotion's outside external stimulus. Because the outside stimulation directly leads to generation and change of mood, it is represented as follows:

$$\rho = (\mathrm{eo1}, \mathrm{eo2}, \ldots, \mathrm{eo6}) \quad (13)$$

$\mathrm{eoi} \in [0, 1]$, eoi denotes the outside stimulation intensity of the number i basic emotion, and $\mathrm{i} \in [1, 6]$, i denotes the basic emotion's number.

Interactive influence factor matrix between emotions [6]. Human's emotions often influence each other, suppose emotional interactive influence factor matrix is λ, $\lambda = \begin{bmatrix} \lambda 11 & \cdots & \lambda n1 \\ \vdots & \ddots & \vdots \\ \lambda n1 & \cdots & \lambda nn \end{bmatrix}$, n is the basic emotion's number, $\lambda ij \in [-1, \ 1]$, it represents the factor matrix of emotion i to emotion j, $i \in [1, n]$, $j \in [1, n]$ [6].

Mood space and emotional space. According to Gebhard's research, mood space and emotional space have mapping matrix and the computing method of Gebhard is used in our work [7].

Emotion's self-attenuation and update. Emotion's self-attenuation and update equations can be expressed as follows:

$$\mathrm{Ie}(t) = \mathrm{Ie}(t0) \times e^{-ai(t-t0)} \quad (14)$$

$\mathrm{Ie}(t)$ is the emotion's intensity at time t, ai is emotion's attenuation coefficient, which is different according to different characters.

Emotion's intensity and emotion status's update. Emotion's intensity and emotion status' update can be computed by Eqs. (15) and (16).

$$\mathrm{Ie}(t) = \alpha(\rho) + \beta(\rho) + \phi(\mathrm{Ie}(t-1)) + \mathrm{Iepad} + \psi(\mathrm{Iez}) \quad (15)$$

$$E'(t) = (f(\mathrm{Ie1}, \gamma), \mathrm{f}(\mathrm{Ie2}, \gamma), \mathrm{f}(\mathrm{Ie3}, \gamma), \mathrm{f}(\mathrm{Ie4}, \gamma), \mathrm{f}(\mathrm{Ie5}, \gamma), \mathrm{f}(\mathrm{Ie6}, \gamma)) \quad (16)$$

$\alpha(\rho)$ is the emotion value caused by conditioned emotional response, $\beta(\rho)$ is the emotion value caused by consciousness, $(\mathrm{Ie}(t-1))$is the emotion value after emotion's attenuation at previous moment, Iepad is the influence of current mood on emotional fluctuations, and $\psi(\mathrm{Iez})$ is the interaction between different emotions. In formula (16), $E'(t)$ is the emotion status at time t and γ is the activation threshold.

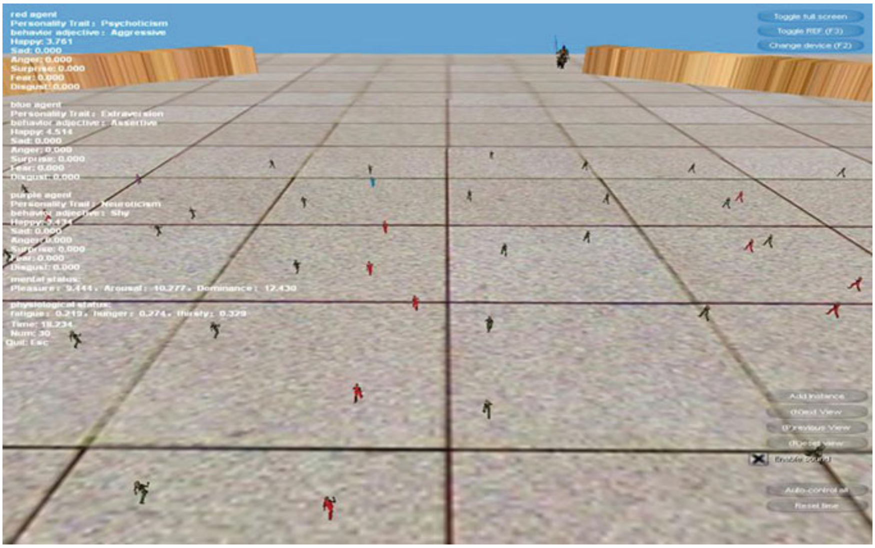

Fig. 1 Crossing scene of different kinds of agents

2.8 Behavior Module

When meeting the stimulus, different virtual human may have different behavior, which can be displayed by velocity, path selection, expression, language, etc. In here, the emotions' changes are mainly represented by path selection.

3 Experiments and Results

3.1 Experiments

In the experiment, there are 136 agents crossing a narrow passage, including virtual humans of three different personality traits, which are psychoticism, extraversion, and neuroticism according to the Eysnek 3-factor personality model. A dangerous source which is a knight with sword is at the end of the narrow passage, a red agent, a blue agent, and a purple agent is tested from the start position to the end position, the red agent is high psychoticism in personality trait and it is aggressive, the blue agent is high extraversion in personality trait and it is assertive, and the purple agent is high neuroticism in personality trait and it is shy, but it has ever been injured by a knight in the battle. They are probably in the second row of the crowd and must walk through the dangerous source. According to this emotion model, the six values of happy, sad, anger, surprise, fear, and disgust are recorded and displayed in the user interface of the simulation system. The crossing scene is displayed as Fig. 1.

Table 3 Agent of high psychoticism's status values

Time	Recorded variables				
	Happy	Fear	Pleasure	Arousal	Dominance
$t = 0.15$	0.65	0	13.54	14.73	17.81
$t = 61.35$	0.00	0.80	2.16	2.35	2.84
$t = 82.57$	0.335	0.20	1.14	1.24	1.50

Table 4 Agent of high extraversion's status values

Time	Recorded variables				
	Happy	Fear	Pleasure	Arousal	Dominance
$t = 0.14$	0.648	0	13.56	14.76	17.85
$t = 125.84$	0.035	0.171	1.10	1.19	1.44
$t = 145.0$	0.020	0.162	0.74	0.81	0.98

Table 5 Agent of high neuroticism's status values

Time	Recorded variables				
	Happy	Fear	Pleasure	Arousal	Dominance
$t = 0.13$	0.647	0	13.54	14.73	17.82
$t = 20.39$	0.00	0.90	5.59	6.09	7.36
$t = 70.42$	0.041	0.139	1.16	1.26	1.52

3.2 Results

When crossing the dangerous source, three recorded agents' emotion values are displayed in Tables 3, 4 and 5, and their paths are displayed as Fig. 2. Because the testing time is very short, physiological status' impact has been overlooked.

From the above three tables, we can see during the first part of time, all of the agents' fear values are increased when they come closer to the dangerous source, at the second record time, fear values reach their maximum values, conversely, during the latter part of time, fear values are decreased when they get farther to the dangerous source, although the purple agent is the furthest one from the dangerous source, but it has the biggest fear value at the shortest time, because it has ever been injured by a knight and has the conditioned emotional response to the dangerous source. The purple agent's status value has the biggest percentage change, next is the agent of high psychoticism, and last is the agent of high extraversion; the values of these agents' mental status also have the same trend.

In Fig. 2, three recorded agents' paths are shown: black lines on two sides represent the narrow passage, red line at the far right is the red agent's path, it is high psychoticism and aggressive, green line in the middle is the blue agent's path, it is high extraversion and assertive, purple line at the far left is the purple agent's

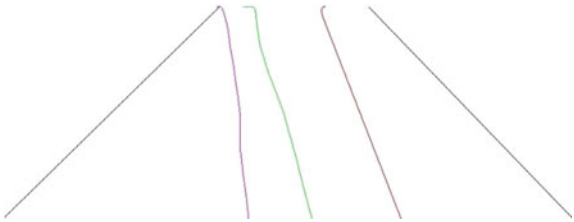

Fig. 2 Three recorded agents' paths

path, it is high neuroticism and shy. When meeting the dangerous resource, aggressive agent move toward the dangerous resource, assertive agent move away the dangerous resource, affected by conditioned emotional response, shy agent move away the dangerous resource along the edge of the narrow passage in the shortest time.

4 Conclusions

This emotion model considers various factors affecting the emotion, including the decay of emotion, mutual influence between emotions, outside stimulus, subconsciousness; the final three components of emotion are reflected by computed values, and the complex mood can be reflected to a certain extent, but this emotion model also has many limitations, for example, there may be more of the emotion components; furthermore, the emotions of human have uncertainty, and facial expression is not included, etc.; in the future work, these aspects should also be considered.

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