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Layered Fuzzy Facial Expression Generation: Social, Emotional and Physiological

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1. Introduction

Facial expression plays an important role in human's daily life, as indicated by (Mehrabian, 1968), in face-to-face human communication, only 7% of the communicative message is due to linguistic language, 38% is due to paralanguage, while 55% of it is transferred by facial expressions. Currently, facial expression has been widely researched in psychology, sociology, cognitive science, biology, pathology, neuroscience, computer science, and so on, thus different views of facial expressions have been formed.

Facial expression has been researched in the "Emotion View" for a long time. In the 19th century, kinds of facial expressions of emotions were studied by (Darwin, 1872), who argued that there is a link between emotions and expressive behaviour. Later, facial expressions of 6 basic emotions or fundamental emotions were pointed to be universally recognized in the cross culture studies by (Ekman & Friesen, 1971). However, the assumption of universality of human facial expressions of emotion was suggested to be premature by (Russell, 1994). As there are some shortcomings in the emotion view (Fridlund, 1997), the "Behavioral Ecology View" treats facial displays as social signals of intent. Facial display may depend upon the intent of the displayer, the topographic features of the niche, the behaviour of the recipient, and the context of the interaction (Fridlund, 1994). Recently, facial expressions have been considered as emotional activators and regulators (Lisetti & Schiano, 2000). It has been found that voluntary facial action can generate subjective experience of emotion and emotion specific autonomic nervous system activity.

Along with the rapid development of the research fields of computer science, human-computer interaction, affective computing, etc., the generation of facial expressions in computer has been actively researched. The Improvisational Animation system (Perlin, 1997) generated facial expressions such as angry, daydreaming, disgusted, distrustful, fiendish, haughty etc. by relating lower level layer facial movements to higher level moods and attitudes. (Yang et al., 1999) proposed a facial expression synthesis system, in which 34 facial expressions were generated by converting emotion into combination of upper, middle and lower expressions. The CharToon system (Hendrix & Ruttkay, 2000) generated kinds of facial expressions by interpolation between the 7 known expressions (neutral, sadness, happiness, anger, fear, disgust, and surprise) positioned on the emotion disc. (Bui et al., 2001) realized a fuzzy rule-based system, in which the animated agent's representations of 7 single expressions and blending expressions of 6 basic emotions were mapped onto muscle

contraction values. Recently, (Ochs et al., 2005) introduced emotional intelligence into an animated character to express felt emotions and expressed emotions. These works have developed kinds of methods for emotional facial expression generation. However there are some limits in the above researches.

1. The first limit is that most works of facial expression generation are constrained in the 6 basic emotions. In another word, they are in the "Basic Emotion View". Although some works try to generate mixed facial expressions simply through blending basic expressions, these expressions do not often appear in our daily life and cannot be well related to distinct emotional categories. It is necessary for computer to display lifelike facial expressions of abundant emotions like human does.

2. The second limit is that most works of facial expression generation are merely related to emotions. Generally speaking, they are in the "Emotion View". However, emotion is not the only source of facial expressions, and some facial expression can signal much. For example, one may wink just because he is too tired or is to give a hint to someone. Lifelike facial expression generation should be more complicated to accommodate the complex environment in human computer interaction.

3. The third limit is that facial expression generation is mostly monotone, or in the "Invariable View". They usually correlate one model of facial expression to one emotion, and generate facial animation based on that. However, human tend to act more complicatedly to express one emotion. For example, human display kinds of facial expressions to express happiness, such as smile with mouth open or closed, symmetrically or asymmetrically, even with head wobbled.

Meeting the above limits, (Heylen, 2003) has deduced some guiding principles for building embodied conversational agents, such as the inclusion of more than 6 basic emotions, the voluntary control of emotional expressions, and the variation in expression. Although some works have also been done in the non-emotional expressions, such as gaze and eye-movements (Cassell et al., 1999; Colburn et al., 2000), there are few works to overcome all the limits in one work.

This chapter aims at generating humanoid and expressive facial expressions of agent to achieve harmonious and affective human computer interface. Based on the cues of sources and characteristics of facial expression, we propose a novel model of layered fuzzy facial expression generation, in which the social, emotional and physiological layers contribute to the facial expression generation and fuzzy theory helps to generate mutative and rich facial expressions.

This chapter is organized as follows. In section 2, the model of layered fuzzy facial expression generation (LFFEG) is proposed. In section 3, the layered fuzzy facial expression generation system (LFFEGS) is founded, and the modules for social, emotional and physiological expression generation are described in detail. In section 4, evaluation of the generated facial expressions is carried out to prove the validity of the LFFEG model. Subsequently, potential applications of the LFFEG are illustrated. In section 5, the conclusion and future research are given.

2. Model of layered fuzzy facial expression generation

This section proposes a novel model of layered fuzzy facial expression generation for humanoid and lifelike facial expression generation of agent. Firstly, theoretic reasons of the model are given, and then detailed explanation of the model is introduced.

2.1 Fuzzy facial expression

Fuzziness is the ubiquitous character of human mind and common objects. Human displays facial expressions fuzzily in daily life. As human face is extremely expressive (Christine & Diane, 2000; Terzopoulos & Waters, 1993), it is impossible to relate an expression to an exact emotion or intention, thus facial expressions are usually classified into different families, such as happiness, sadness, etc. For example, more than 60 kinds of facial expressions about anger have been found (Ekman, 1992), and each of the anger expressions shares certain configurational features to differ from the family of other expressions. However, some facial expressions can be recognized as in different families. (Russell, 1997) argued that facial expressions are ambiguous, and its meaning can depend on the context. For example, the "expression of fear" can be chosen as "anger" if a story about the expresser's context is told to the observer. Also, the observer's context such as the relativity of judgement and response format can influence the judgement of facial expression. So, human facial expression has the character of fuzziness. Some examples of facial expressions from Beihang University Facial Expression Database (Xue, Mao, et al., 2006) are illustrated in figure 1.

Figure 1. Examples of fuzzy facial expressions

The fuzzy theory arises from the incessant human request for better understanding of mental processes and cognition. (Zadeh, 1965) proposed the idea of "fuzzy set" from the observation that classes of objects usually have no well-defined boundary. Currently, fuzzy systems have been successfully employed in modeling of many real-life phenomena involving uncertainty. Facial expression generation can be well managed by fuzzy theory.

2.2 What influence facial expression

(Fasel & Luettin, 2003) have concluded that the sources of facial expressions include mental states (e.g. felt emotions, conviction and cogitation), verbal communication (e.g. illustrators, listener responses and regulators), non-verbal communication (e.g. unfelt emotions, emblems and social winks), and physiological activities (e.g. manipulators, pain and tiredness). Herein, we conclude the factors that influence facial expressions into social, emotional and physiological factors, together with expression personality, as seen in figure 2.

The terms of illustrators, regulators, emblems and manipulators are what (Ekman & Friesen, 1969) suggested facial paralanguage, as seen in table 1, where illustrators, regulators and emblems are social communication related, while manipulators are physiological activities related.
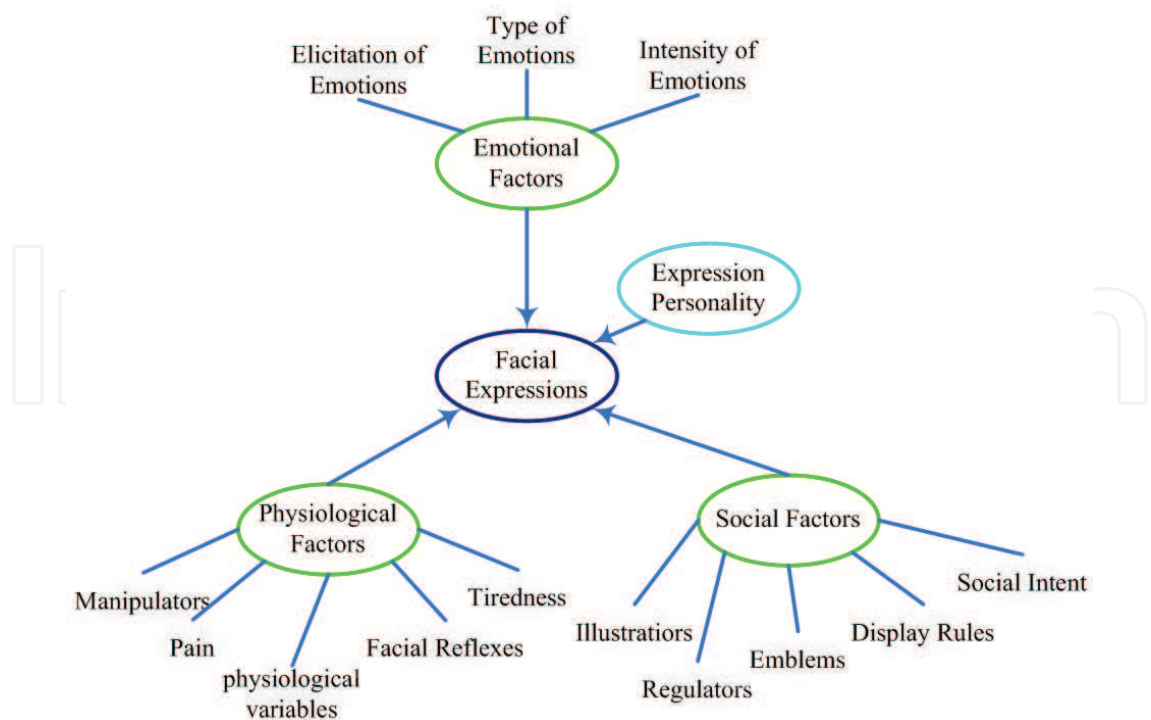
Figure 2. Factors that influence facial expressions

Facial Paralanguage	Short Description	Examples
illustrators	give vividness and energy to our spoken words	we raise our brows when we say beseechingly, "What do you want?" (Fridlund, 1994)
regulators	conversation requires regulation	with brow raises if we like what others are saying, with frowns and head shakes if we don't like it, with yawns if we find it tiresome (Rosenfeld, 1987)
emblems	symbolic gestures we enact with our faces	"facial shrug" which announces "I don't know" or "You've stumped me" (Ekman, 1985)
manipulators	self-manipulative facial actions	biting our lips, wiping our lips, running our tongues in the crevices between our teeth and cheeks, clamping and then widening our eyelids, working our jaws, and brushing our teeth (Ekman & Friesen, 1969)

Table 1. Explanation of facial paralanguage

Emotional factors are the most important factors for facial expression. In our daily life, we smile when we are happy, and cry when sad, so we call the facial expression that reflecting emotion the "emotional facial expression" or "facial expression of emotion". There are many factors that influence mapping emotional state to facial expression, such as the type and intensity of emotion, and how emotional state elicited (Picard, 1997).

Social factors include illustrators, regulators, emblems, social intent, and the "display rules" which designates attempts to manage involuntary expressions of emotion that include attenuating, amplifying, inhibiting or covering the involuntary expression with the sign of another emotion (Ekman & Friesen, 1969). Display rules specify not only what type of management is required, but when, in what social situation.

Physiological factors include manipulators, pain, tiredness, physiological variables, and "facial reflexes". Facial reflexes are considered innate and immutable, and characterized by few synapses in the human facial physiology (Fridlund, 1994). Sneezing to nasal membrane irritation, pupillary dilation to pain, jaw closure to tap, yawning and laughing are examples of facial reflexes (Fridlund, 1994; Provine & Hamernik, 1986).

Expression Personality describes the character of individual's facial expressions. For example, the speed, amount and duration of facial expression are different from individuals (Christine & Diane, 2000).

In summary, facial expressions are influenced by social, emotional, and physiological factors, and can vary with different expression personalities, thus these factors should be considered in the modeling of facial expression generation.

2.3 Facial expression generation via multiple mechanisms

In the book "Affective Computing" (Picard, 1997), emotion generation via multiple mechanisms was introduced, where human's emotion is generated not only by cognitive illation but also by low-level non-cognitive factors. An example is the three layered structure that includes reactive layer, deliberative layer and self-monitoring layer. In the structure, reactive layer is used to generate fast and first emotion; deliberative layer is related to second emotion generated by cognition; and the self-monitoring layer is the layer where self concept worked weightily.

Facial expression and emotion are alike in some aspects, such as the characteristics of innateness and sociality. (Darwin, 1872; Lorenz, 1965; Eibl-Eibesfeldt, 1972) argued that facial expressions are innate, evolved behaviour. (Klineberg, 1940; LaBarre, 1947; Birdwhistell, 1970) argued that facial expressions are socially learned, culturally controlled, and variable in meaning from one setting to another.

In the Emotion View, the well-known "two-factor" model emphasizes the influence of emotion and social conventions (Fridlund, 1991), where innate, prototype facial expressions namely "felt faces" are generated from emotional state, while learned, instrumental facial expressions namely "false faces" are modified by social conventions.

However, the Emotion View may fail to account for the poor relationship between emotions and facial displays (Fridlund, 1994). For example, the "cry" face is generally thought to be sadness. Nonetheless, we also cry when we are happy, angry, frightened, or relieved. The Behavioral Ecology View suggests the function of the cry-face display is to signal readiness to receive attention or succour, regardless of one's emotional status.

The Emotion View and Behavioral Ecology View can be regarded as the two mechanisms for facial expression generation. With both mechanisms, facial expression generation can be better explained than with any single mechanism. Nevertheless, the physiological aspect in facial expression generation can not be ignored.

As human's facial expression is innate and social, influenced by physiological, emotional and social factors, a layered structure for facial expression generation via mechanisms of low level of physiological factors, middle level of emotional factors, and high level of social factors is proposed. A comparison of the two-factor model and the layered model for facial expression generation is seen in figure 3.
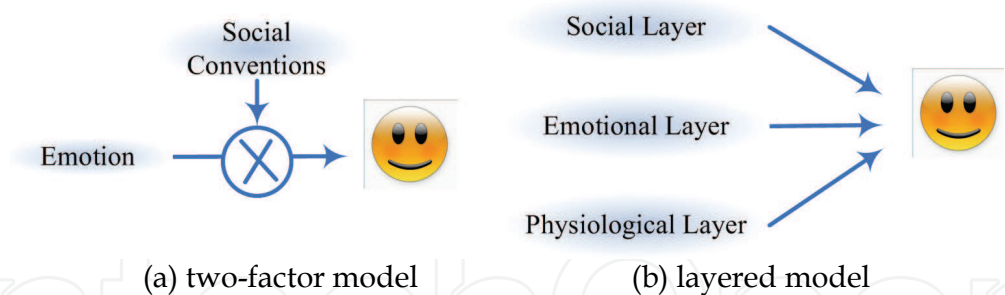
(a) two-factor model   (b) layered model

Figure 3. Two-factor model and layered model for facial expression generation

2.4 Layered fuzzy facial expression generation

Based on the fuzzy character of facial expression, kinds of factors that influence facial expression and the elicitation of generation via multiple mechanisms, the model of layered fuzzy facial expression generation is proposed (Xue, Mao, et al., 2007). As seen in figure 4, the physiological layer at low level, emotional layer at middle level and social layer at high level determine the fuzzy facial expression generation.
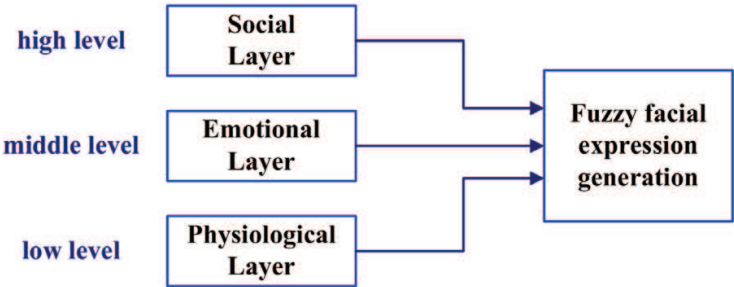

Figure 4. Model of layered fuzzy facial expression generation

The physiological layer includes physiological variables which influence human's emotion and expression. (Picard, 1997) recognized that hunger or pain can influence the activation of emotional states. For example, hunger can increase irritability, and pain can spur anger. Also, changes in brain blood temperature along with other physiological changes may lead to the feeling of excitation or depressed (Christine & Diane, 2000). In the LFFEG model, the physiological variables influence the emotional expressions or lead to physiological expressions such as grimace of pain; the physiological expressions such as facial reflexes can also be directly specified.

The emotional layer includes multiple emotions based on the OCC model (Ortony et al., 1988). As the 22 emotion types in OCC model are well accepted in the research of affective computing, it is reasonable to research the facial expressions to display the emotions. In the LFFEG model, multiple facial expressions can be fuzzily generated according to the emotions. For example, kinds of smile facial expressions can be elicited by the emotions such as joy, appreciation, gloating, satisfaction and happy-for, fuzzily controlled by the factors such as the intensity of the emotion, the type of the emotion and the expression personality.

The social layer includes social intent and display rules. When, where and how to express facial expressions is restricted by the social rules. A felt emotion may be masked by a fake emotion due to some display rules. In the LFFEG model, the social expressions generated by social rules can override the affect of the emotional layer. For example, whatever a waiter felt, he should show a smile of politeness to the customer.

The module of **fuzzy facial expression generation** maps one emotion type to different modes of facial expressions and realizes fuzzy intensity control through fuzzy theory, making facial expressions smart and expressive.

In the LFFEG model, **social expression**, **emotional expression** and **physiological expression** are generated from the social layer, emotional layer and physiological layer respectively, their relation is shown in figure 5. Social expressions are the facial expressions such as smile of politeness, social wink and social plea regardless of the emotion behind. Emotional expressions are the facial expressions elicited by kinds of emotions such as happiness, sadness and so on. Physiological expressions are the facial expressions elicited by physiological activities, alike facial reflexes, including quick expressions such as startle, horror and other expressions such as frown, blink and gape.
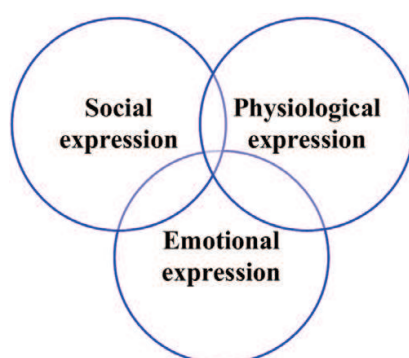

Figure 5. The relation of social, emotional and physiological expression

3. The layered fuzzy facial expression generation system

Based on the model of layered fuzzy facial expression generation, this section sets up a layered fuzzy facial expression generation system. Firstly, we give an overview of the system, and then the realization of each part is explained in detail.

3.1 System overview

The overview of the layered fuzzy facial expression generation system (LFFEGS) is shown in figure 6. The social layer, emotional layer and physiological layer have respective priority, denoting the weight of the layer at a time. The module of fuzzy facial expression generation processes the output of the three layers, giving the final facial expression. Social expression is determined by the parse module from the social layer. Emotional expression is determined by the fuzzy control function block from the emotional layer. Physiological expression is determined by the parse module from the physiological layer. According to the priorities of the three layers, final expression is determined from the social expression, emotional expression and physiological expression through the module of MUX.

The inputs of the facial expression generation are defined as followed:

1. Time: t;

2. Social layer parameters: $S(t) = \{S_P(t), S_E(t), S_R(t)\}$ is the interface of the social layer, where S_P: Priority, S_E: Social expressions, S_R:Social rules;

3. Emotional layer parameters: $E(t) = \{E_P(t), E_S(t), E_M(t), E_P(t)\}$ is the interface of the emotional layer, where E_P: Priority, E_S: Specific emotions, E_M: Mood, E_P: Expression personality;

4. Physiological layer parameters: $P(t) = \{P_P(t), P_E(t), P_V(t)\}$ is the interface of the physiological layer, where P_P: Priority, P_E: Physiological expressions, P_V: Physiological variables.

Consequently, the layered fuzzy facial expression generation function is:

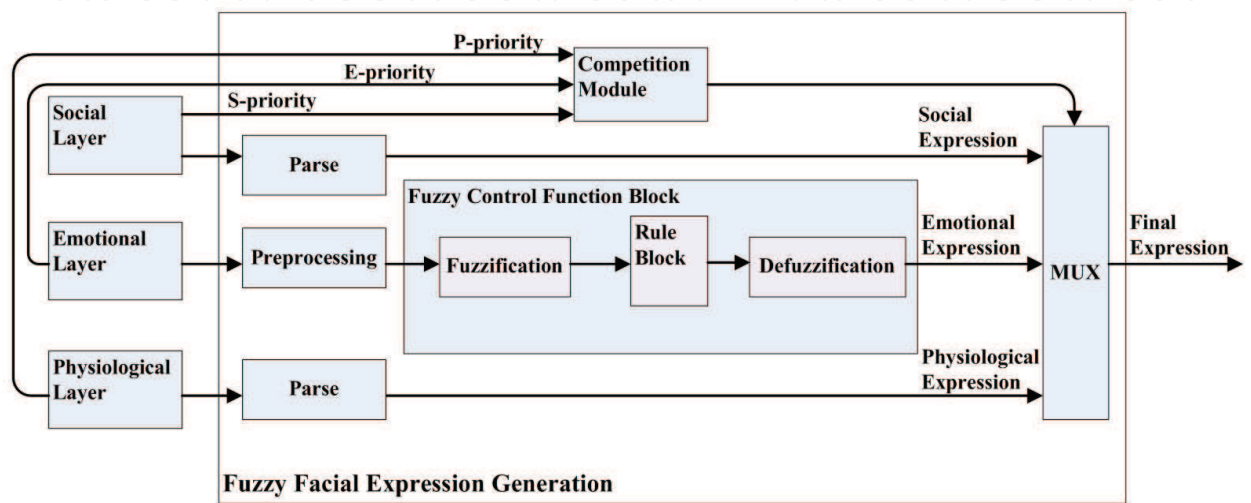$$F(t) = F(S(t), E(t), P(t)), \text{ where } F(t) \text{ is the fuzzy function.}$$

Figure 6. Overview of the Layered Fuzzy Facial Expression Generation System

3.2 The lingual realization of the LFFEGS

The LFFEGS is realized based on extensible markup language (XML), which provides an easy way to control the agent's behavior. Previous efforts in the XML-based languages are Human Markup Language (HML), Multimodal Presentation Markup Language (MPML) (Prendinger et al., 2004a), Synchronized Multichannel Integration Language (SMIL) (Not et al., 2005), etc. In this chapter, the Layered Fuzzy Facial Expression Generation Language (LFFEGL) is developed to realize the LFFEG model.

In the LFFEGL script, the tags of "social", "emotional" and "physiological" relate to the social layer, emotional layer and physiological layer respectively, as seen in figure 7. The attribute "priority" gives the weight of the layers.

```
<seq>
   <Social priority="0.7" positive_threshold="0.4" negative_threshold="0.3">
        <Smile intensity="0.5"/>
   </Social>
   <Emotional priority="0.5" mood="positive" positive_weight="1">
        <Joy intensity="0.5"/>
   </Emotional>
   <Physiological priority="0.9">
        <Pain intensity="1"/>
   </Physiological>
</seq>
```

Figure 7. Sample of LFFEGL Script

Possible parameters of the LFFEGL are shown in figure 8, where 6 social expressions are provided in the social layer, 26 emotions are provided in the emotional layer and 14 physiological variables are provided in the physiological layer. Note that the parameters can be easily extended according to the requirement.

```
<!-- specification of possible social expressions -->

<!ENTITY % Social
"(normal | smile | plea | agreement | disagreement | wink) ">

<!-- specification of possible emotions -->

<!ENTITY % Emotional
"(happyfor | pity | resentment | gloating | joy |distress | hope | fear | satisfaction |
  fearsconfirmed | relief | disappointed | pride | selfreproach | appreciation |
  reproach | gratitude | anger | gratification | remorse | liking | disliking | surprise |
  disgust | sadness | sorryfor) ">

<!-- specification of possible physiological variables -->

<!ENTITY % Physiological
"(adrenaline | bloodpressure | bloodsugar | dopamine | endorphine | energy | heartrate |
  respirationrate | temperature | vascularvolume | pain | tiredness | sneeze | yawning) ">
```

Figure 8. Specification of the Parameters in LFFEGL

(Ortony, Clore & Collins, 1988) suggested that the research for and postulation of basic emotions is not a profitable approach, as there are significant individual and cultural differences in the experience of emotions. Hence, according to the description of tokens of emotion types in (Ortony, Clore & Collins, 1988), numerous emotion words related to each of the 26 emotion types are accepted in the LFFEGL, as seen in table 2.

3.3 Facial expressions related to emotional layer
Based on the modules of fuzzy emotion-expression mapping, the novel arousal-valence-expressiveness emotion space, expression personality, and facial expression generation model, the fuzzy emotional facial expression generation subsystem is developed to generate lifelike emotional facial expressions, as seen in figure 9.
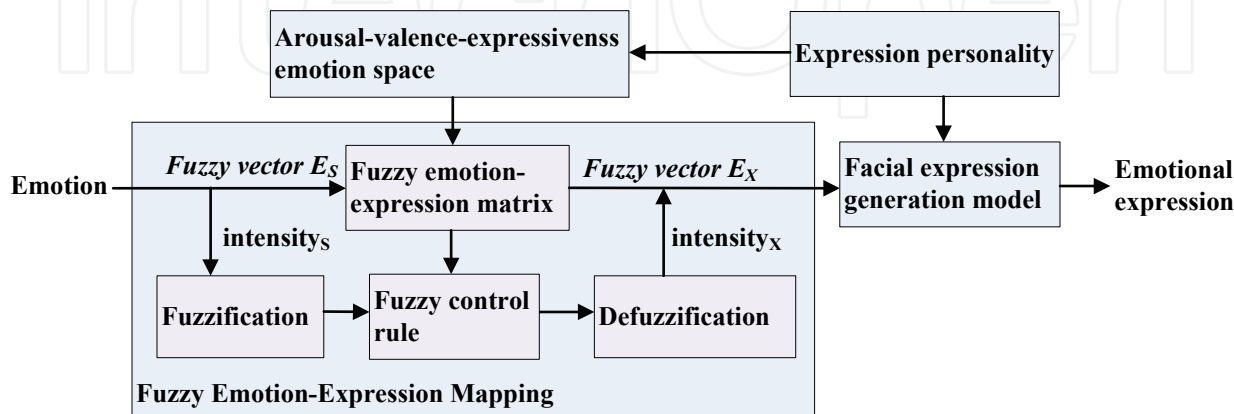

Figure 9. Overview of the fuzzy emotional facial expression generation system

Emotion type	Emotion words
Joy	contented, cheerful, delighted, ecstatic, elated, glad, happy, joyful, jubilant, pleased
Distress	depressed, distressed, displeased, dissatisfied, distraught, grief, miserable, sad, shock, uneasy, unhappy, upset
Happy-for	delighted-for, happy-for, pleased-for
Sorry-for	compassion, pity, sorry-for, sympathy
Resentment	envy, jealousy, resentment
Gloating	gloating, schadenfreude
Hope	anticipation, anticipatory excitement, expectancy, hope, hopeful, looking forward to
Fear	apprehensive, anxious, cowering, fear, fright, nervous, petrified, scared, terrified, timid, worried
Satisfaction	gratification, hopes-realized, satisfaction
Fears-confirmed	fears-confirmed
Relief	relief
Disappointment	despair, disappointment, frustration, heartbroken
Pride	pride
Self-reproach	embarrassment, guilty, mortified, self-blame, self-reproach, shame, uncomfortable, uneasy
Appreciation	admiration, appreciation, awe, esteem, respect
Reproach	appalled, contempt, despise, disdain, indignation, reproach
Gratitude	appreciation, gratitude, thankful
Anger	anger, annoyance, exasperation, fury, incensed, indignation, irritation, livid, offended, outrage, rage
Gratification	gratification, satisfaction, smug
Remorse	penitent, remorse
Liking	adore, affection, like, love
Disliking	aversion, detest, disgust, dislike, hate, loathe
Pity	pity, compassion, commiseration, sympathy, condolence, empathy
Surprise	surprise, astonish, amaze, astound, dumbfound, flabbergast
Disgust	disgust, nauseate, repel, revolt, sicken
Sadness	sad, melancholy, sorrowful, doleful, woebegone, desolate

Table 2. Emotion words of different emotion types

3.3.1 Fuzzy emotion-expression mapping

Fuzziness is one common characteristic of emotion and facial expression. There is also fuzzy relationship between emotion and facial expression. One emotion can be fuzzily expressed by multiple modes of facial expression, and one mode of facial expression can be fuzzily recognized as multiple emotions. (Baldwin at al., 1998) have suggested the mechanisms of a mapping of many expressions to a few emotions, a given expression mapped to more than

one emotional state, and a mapping from one expression to different emotional states. Here, we give the model of fuzzy emotion-expression mapping.

The mapping of emotion to expression is many-to-many. Firstly, one emotion can be mapped to many facial expressions. For example, the fuzzy emotional facial expression of happy-for can be expressed as formula (1). Secondly, a predefined facial expression can express many emotions. For example, the emotions of joy and happy-for can be expressed as the facial expression of "SmileOpen" with different intensities.

$$E_{\text{happyfor}} = \begin{cases} a, SmileClosed \\ b, SmileOpen \\ \cdots \end{cases} a, b, \cdots \in (0,1] \tag{1}$$

Where a, b are respectively the probabilities that happy-for is mapped to the facial expression of "SmileClosed" or "SmileOpen".

Fuzzy Emotion-Expression Matrix

Based on the correlation of multiple facial expressions of emotions, fuzzy emotion-expression mapping is proposed, in which emotion and facial expression are supposed to be fuzzy vectors, and a fuzzy relation matrix consisting of degrees of membership maps the fuzzy emotion vector to the fuzzy facial expression vector.

Define the emotion space as $X = \{x_1, x_2, \cdots, x_m\}$, where x_i is any emotion, such as surprise, disgust. Define the facial expression space as $Y = \{y_1, y_2, \cdots, y_n\}$, where y_i indicates any mode of facial expression.

The fuzzy relation $\widetilde{R}$ from the emotion space X to the facial expression space Y is shown in formula (2):

$$R = (r_{ij})_{m \times n} \tag{2}$$

where $r_{ij} = \widetilde{R}(x_i, y_j) \in [0,1]$ indicates the correlation degree of (x_i, y_i) to $\widetilde{R}$.

Some key frames of facial expressions with their memberships are shown in table 3. The memberships compose a sparse matrix R.

Emotion	Facial expression membership					
	y_1	y_2	y_3	y_4	y_5	y_6
Disliking (x_1)	0.6	0.8	1.0	1.0	0	0
Disgust (x_2)	0.3	0.5	1.0	1.0	0	0
Sadness (x_3)	0.4	0.7	0	0	0	0
Surprise (x_4)	0	0	0	0	0.9	1.0

Table 3. Membership of some facial expressions

Given the input emotional fuzzy vector E_S, the fuzzy facial vector E_X can be obtained via fuzzy mapping, as seen in formula (3).

$$E_X = E_s \circ R = (ex_1, ex_2, \cdots, ex_n) \tag{3}$$

where ex_i is the membership of the mode of facial expression y_i to the fuzzy facial expression $\widetilde{E}_X$, $\circ$ means the compositional operation of the fuzzy relations.

Once the fuzzy facial expression $\widetilde{E}_X$ is determined, its intensity will also be computed. The intensity of selected emotion x_i is fuzzified to the linguistic value, which is then mapped to the linguistic value of related facial expressions according to fuzzy control rule. The intensity of facial expression y_i is obtained by defuzzifying its linguistic value.

Emotion-Expression Intensity Mapping

Intensity control of predefined facial expression has been realized in (Not et al., 2005), however, the intensity of facial expression is not mapped directly to the intensity of the emotion. As seen in figure 10(a), the largest intensity of facial expression of "SmileClosed" may be not enough to express the largest intensity of happy-for. As seen in figure 10(b), moderate intensity of facial expression of "Disgust" may be enough to express the largest intensity of disliking.

If the emotion comes on slowly, or is less expressive, or is rather weak, the impulse might not be enough to trigger the expression, so sometimes there will be emotion without expression. Figure 10(c) shows that low intensity of love may not trigger expression, unless it achieves a certain level, the expression of SmileClosed plus Gaze appears. Similar in figure 10(d) that certain degree of hate may reveal low level of Disliking expression.
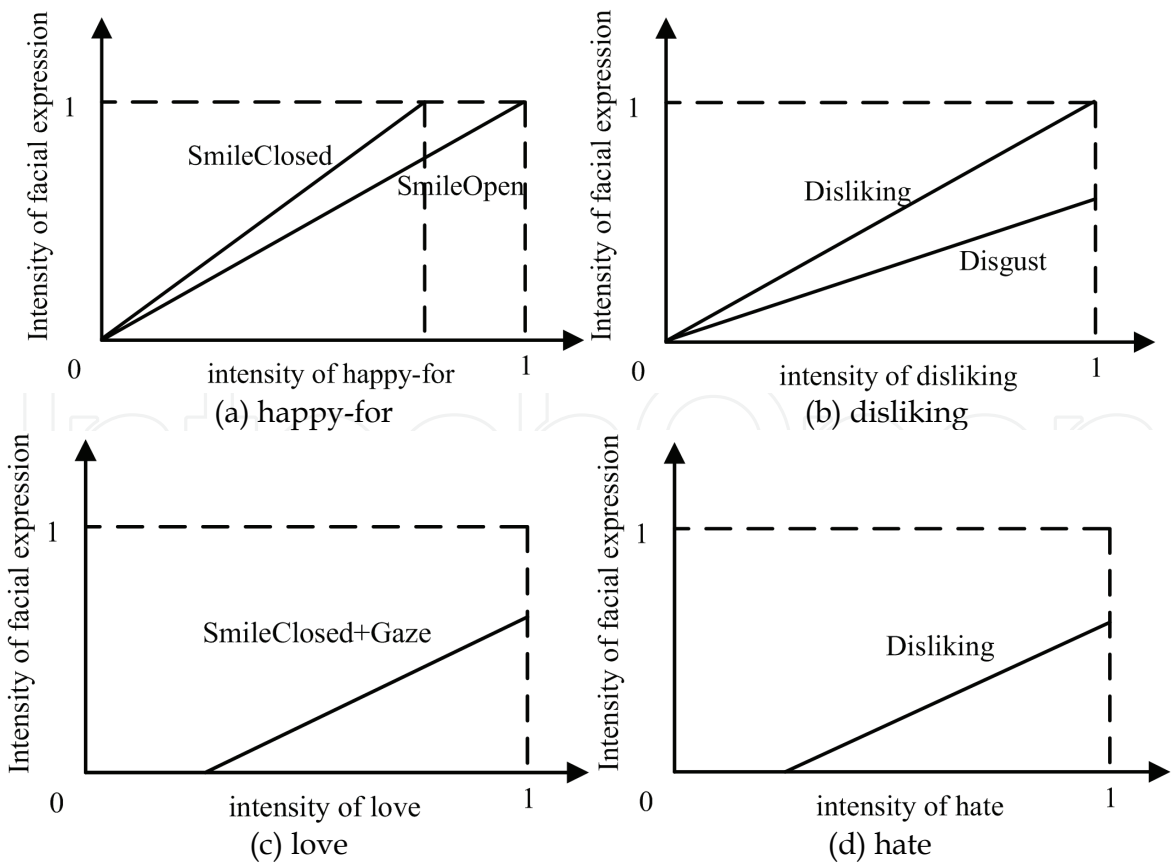

Figure 10. Mapping of intensity of emotions to intensity of facial expressions

Fuzzification of Emotion and Facial Expression

The emotion intensity and facial expression intensity also have fuzzy characteristics. The fuzzy linguistic values of emotion and facial expression are listed as very low, low, middle, high and very high, as seen in figure 11.
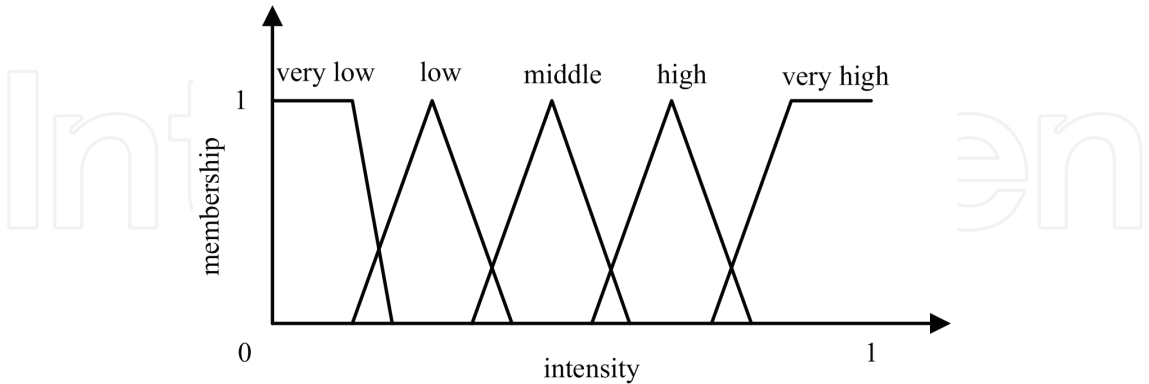

Figure 11. Memberships of linguistic values of emotion and facial expression

Fuzzy Control Rule

According to the emotion-expression intensity mapping, the mapping from linguistic value of emotion intensity to linguistic value of facial expression intensity was realized through fuzzy control. An example of fuzzy control rule is shown in table 4. Where emotion x_4 (surprise) can be fuzzily expressed by facial expression y_5 or y_6. The very low intensity of x_4 can be expressed by small intensity of y_5 or very small intensity of y_6.

Emotion x_4 (surprise)	Facial expression y_5	Facial expression y_6
Very low	small	Very small
low	middle	small
middle	large	middle
high	Very large	large
Very high	— —	Very large

Table 4. Fuzzy control rule for emotion-expression intensity mapping

3.3.2 The novel emotion space of arousal-valence-expressiveness

Given the emotion space X and the facial expression space Y, the fuzzy emotion-expression matrix R can be determined based on the novel arousal-valence-expressiveness emotion space. The expression personality has the function as scaling factor to the arousal-valence-expressiveness emotion space.

Expressive Difference of Emotions

Psychologists have acknowledged the sex differences in emotional expressiveness (Tucker & Friedman, 1993). For example, most studies find that women better convey emotions than men, though not in most cases and situations (Buck et al., 1974; Hall, 1984).

Besides the sex difference of emotional expressions, there are also expressive differences between different emotions. To look into the relation between emotion and facial expression, a questionnaire about how hard or easy to express an emotion through facial expression and recognize an emotion from facial expression was put to subjects. 51 subjects

gave their answers in ratings of very hard (1), hard (2), middle (3), easy (4), and very easy (5) on 23 emotions.

The result of the investigation is shown in figure 12. The line of how hard or easy to express emotion through facial expression is approximate to the line of how hard or easy to recognize emotion from facial expression. It demonstrates that some emotions such as happy-for, joy and anger are easy to express and be recognized, while some emotions such as jealousness, resentment and love are hard to express and be recognized. It is obvious that expressive differences of emotions exist on human face.
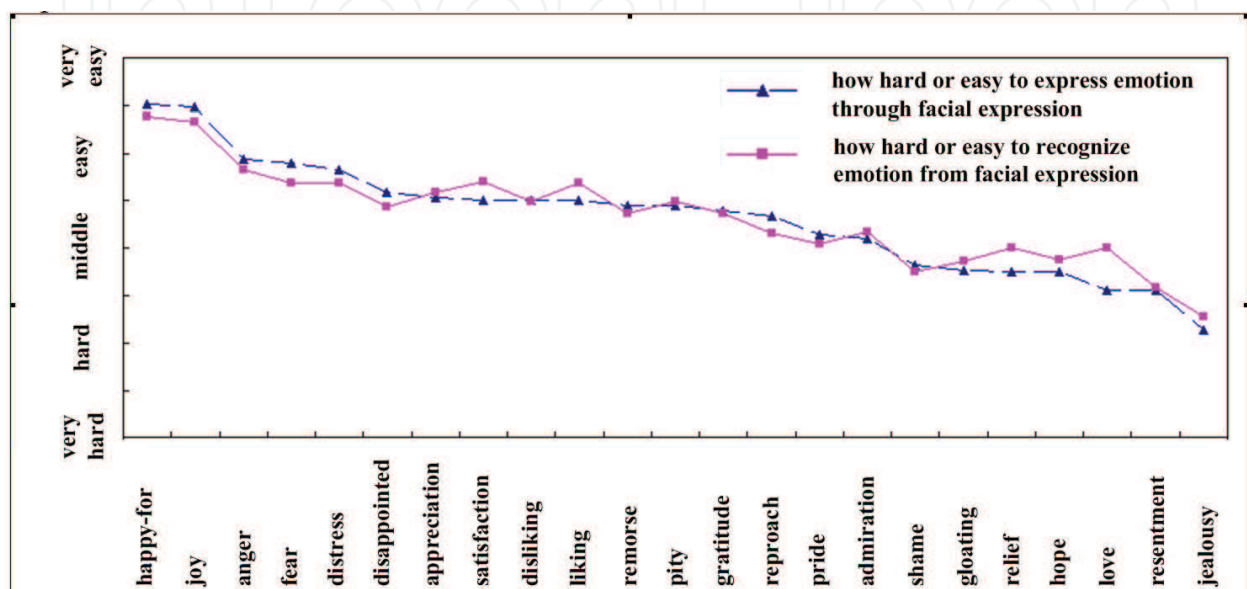

Figure 12. Mean value of how hard or easy to express or recognize emotion through facial expression

As to the expressive differences of emotions, it is further inferred that the emotions quickly aroused are easy to be expressed and recognized, or more expressive, while the emotions in a long term are hard to be expressed and recognized, or less expressive. For those categories of human emotional phenomena: specific emotions, moods and emotional dispositions (Sarmento, 2004), their expressiveness come down gradually.

Expressive differences exist not only in different emotions, but also in different persons. For example, one person may open his eyes and mouth widely and furrows deeply when he is in great anger, while another person just furrows with the same degree of anger. If you are not familiar with one's expression personality, you can not recognize his emotion from his facial expression exactly.

The Novel Arousal-Valence-Expressiveness Emotion Space

Kinds of emotion models have been proposed for affective reasoning, such as the arousal-valence emotional plane (Lang, 1995) and the PAD model (Mehrabian, 1996). In the arousal-valence emotional plane, valence denotes if the emotion is positive or negative, and arousal denotes the intensity of the emotion. In the PAD Emotional State Model, three nearly independent dimensions are used to describe and measure emotional states: pleasure vs. displeasure, arousal vs. nonarousal, and dominance vs. submissiveness. Pleasure-displeasure distinguishes the positive-negative affective quality of emotional states, arousal-nonarousal refers to a combination of physical activity and mental alertness, and dominance-submissiveness is defined in terms of control versus lack of control.

According to the different expressiveness of various emotions, a dimension of expressiveness is added to the arousal-valence emotion plane to compose a novel three-dimensional emotion space, which can be useful to found the relation between emotion and facial expression.

The dimensions of arousal and valence are necessary to the emotion-expression mapping, and the dimension of expressiveness is useful to map emotion intensity to facial expression intensity. For example, emotion with low expressiveness is mapped to the facial expression with low intensity, such as sadness, hate and love; emotion with high expressiveness is mapped to the facial expression with high intensity, such as fury and surprise. Thus, the new emotion space is called arousal-valence-expressiveness emotion space, as seen in figure 13. Expression personality can be reflected by the expressiveness distribution of emotions.
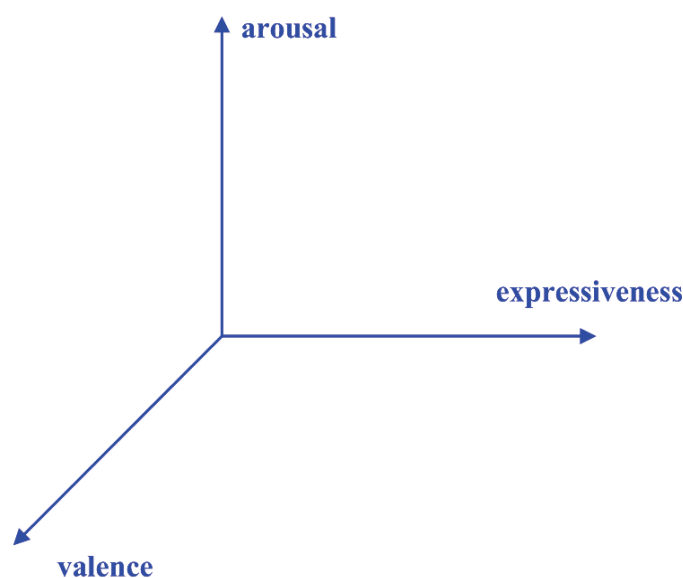

Figure 13. Arousal-valence-expressiveness emotion space

3.3.3 Expression personality

Facial expressiveness, like other forms of sentic modulation, is influenced by a person's innate physiology, which is related to temperament. Affected by the personality, different person with the same intensity of emotion may express facial expressions with different intensities. For example, inhibited ones have lower overall facial expressiveness than uninhibited ones.

To realize the personality in facial expression, (Miwa et al., 2001) introduced the module of Expression Personality in the signal processing structure of the robot, which is defined as a matrix of expression personality, weighting 7 emotions. Here, as there are more emotion types in this system, the intensity of the emotional expression is gained by weighting the positive emotion or negative emotion with the attribute of "positive_weight" or "negative_weight"; furthermore, even the weight of specific emotion such as "happyfor_weight" can be given. Thus the expression personality is realized.

Also, the fuzzy emotion-expression matrix can be variable according to different expression personalities or different expressiveness distribution of emotions, thus the output emotional expression can be different with the same input emotion.

3.3.4 Facial expression generation model

The facial expression generation model is the module that accepts input of the fuzzy facial expression $\widetilde{E}_X$ with its intensity and output the agent's facial expression animation. The facial expression generation model can also be regulated by expression personality. For example, different agents with the same emotion may exhibit very different facial actions, expression intensities and durations. Even the same agent's facial expressions can be modified by the user.

3.4 Facial expressions related to social layer

Until the late 1970s, there were few studies on facial displays in social settings (Chovil, 1997). Facial displays appear to be sensitive to the sociality of the situation. For example, smiles may occur more frequently when individuals are in social contact with others than when they are not facing or interacting with others. (Buck, 1991) argued that social factors can facilitate or inhibit facial expression depending upon the nature of emotion being expressed and the expresser's personal relationship with the other. (Fridlund, 1994) contended that facial expressions are inherently social. For example, even when someone is alone he is holding an internal dialogue with another person, or imaging himself in a social situation. The social communicative approach has provided an alternative to the emotional expression approach for understanding and studying facial displays.

(Matsumoto, 1990) has measured display rules by requesting subjects to judge the appropriateness of displaying emotions in different situations. When viewing the photo of each emotion, subjects were asked to rate how appropriate it was for them to express that emotion in eight social situations: alone, in public, with close friends, with family members, with casual acquaintances, with people of higher status, with people of lower status, and with children.
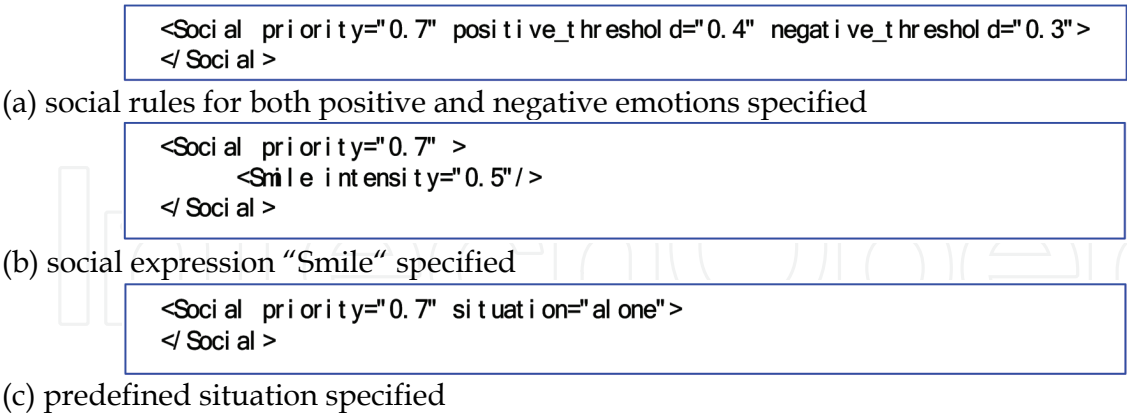
```
<Social priority="0.7" positive_threshold="0.4" negative_threshold="0.3">
</Social>
```

(a) social rules for both positive and negative emotions specified

```
<Social priority="0.7" >
      <Smile intensity="0.5"/>
</Social>
```

(b) social expression "Smile" specified

```
<Social priority="0.7" situation="alone">
</Social>
```

(c) predefined situation specified

Figure 14. Examples of LFFEGL scripts with tag "social"

In the LFFEGS, if the layer of social rules has higher priority than layer of emotional model, the attributes "positive_threshold" and "negative_threshold" will restrict the largest intensities of the positive facial expressions and negative facial expressions respectively, acting as inhibiting facial expression, as seen in figure 14(a). The element such as "smile" or "agreement" specifies social expression to take the place of emotional expression, sometimes

operates as facilitating facial expression, as seen in figure 14(b). Social rules can be predefined in a specific situation to adjust the expression of the agent. For example, figure 14(c) gives the situation of "alone" to specify the social rules related to that situation instead of the ways of "positive_threshold" or specified social expression "smile".

3.5 Facial expressions related to physiological layer

Kinds of facial expressions may occur when physiological state changes. For example, characteristics of facial expressions that occur most frequently in the headache state include furrowed eyebrows, closed eyes, slow eye blinks, lip pursing, facial grimacing, and flat facial affect (Anthony et al., 1991).

(Ekman, 1984) studied how a reflex differs from an emotion. For example, startle is considered a reflex, as it is very easy to elicit and cognition does not play a causal role in eliciting it. Although startle resembles surprise in some respect, it has much briefer latency than surprise.

The bodily reactions associated with emotions have been researched in psychophysiology and psychobiology. Many bodily or physiological responses may co-occur with an emotion or rapidly follows it. For example, essential hypertension is thought to be primarily due to chronic states of tension, stress, and anxiety (Grings & Dawson, 1978). Physiological responses such as sweaty palms and rapid heart beat inform our brain that we are aroused, and then the brain must appraise the situation we are in before it can label the state with an emotion such as fear or love (Schachter, 1964). So, it is inferred that facial expression of emotion with different physiological states may be different, thus physiological states may influence the facial expressions of emotions.

In the layer of physiological layer, the physiological variables are chosen based on (Grings & Dawson, 1978; Fridlund, 1994; Canamero, 1997). The physiological variables are adrenaline, blood pressure, blood sugar, dopamine, endorphine, energy, heart rate, respiration rate, temperature, vascular volume, pain, tiredness, sneeze and yawning, which may influence the emotional expressions or lead to physiological expressions. For example, high levels of endorphines can increase the expressiveness of positive emotions or decrease the expressiveness of negative emotions, or trigger a state of happiness. Some examples of LFFEGL scripts with tag "physiological" are shown in figure 15.
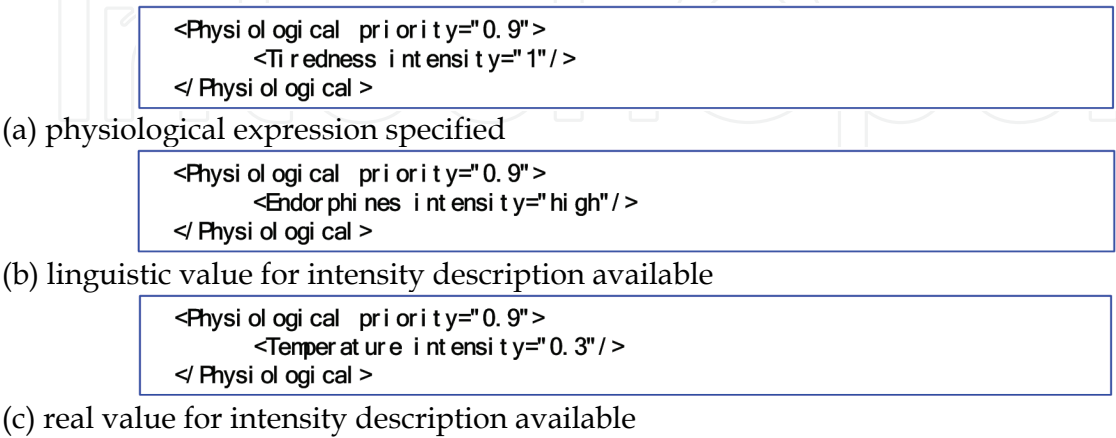
```
<Physiological priority="0.9">
        <Tiredness intensity="1"/>
</Physiological>
```

(a) physiological expression specified

```
<Physiological priority="0.9">
        <Endorphines intensity="high"/>
</Physiological>
```

(b) linguistic value for intensity description available

```
<Physiological priority="0.9">
        <Temperature intensity="0.3"/>
</Physiological>
```

(c) real value for intensity description available

Figure 15. Examples of LFFEGL scripts with tag "physiological"

3.6 Facial expression generation strategy

In the LFFEGS, facial expression is generated according to the priorities of different layers. The flow chart of the facial expression generation strategy is shown in figure 16. As seen in the figure, after the priority comparison in the competition module, the layers are arranged as layer 1, layer 2, and layer 3 with degressive priorities. If expression is generated in one layer, it will be modified considering the influence of the layer with higher priority, otherwise the next layer will be examined.

For example, in the LFFEGL script in figure 7, the physiological layer is first checked, as pain is specified, the expression "pain" will be generated with its intensity "very high". If the physiological priority changes to "0.3", the social layer will be first checked, and expression "smile" will be generated with its intensity "middle".
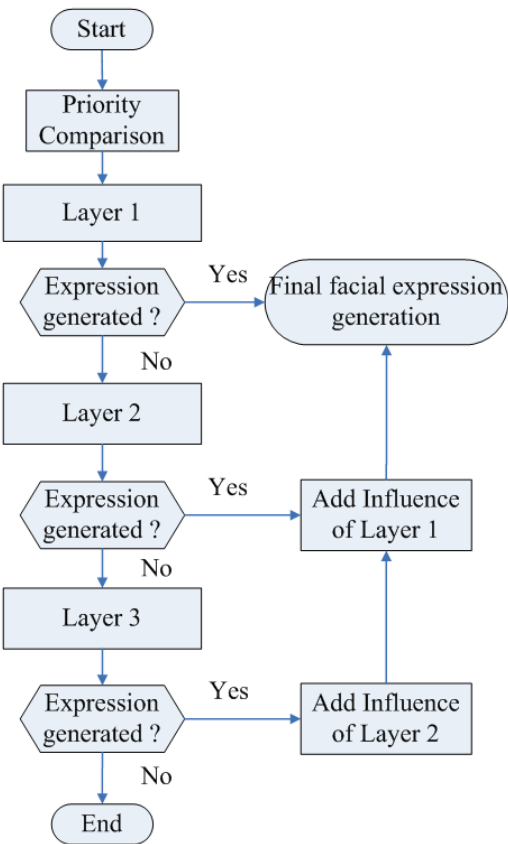

Figure 16. Facial expression generation strategy

4. Evaluation of the LFFEGS

To evaluate the LFFEGS, lively facial expression animations of the character should be presented to the subjects. Xface toolkit (Not et al., 2005) was utilized to generate keyframes of facial expressions to display kinds of emotions. The interface of the LFFEGS is shown in figure 17. The list of key frames of facial expressions can be seen in the top left of the interface, and the work space of the LFFEGL is positioned in the bottom left. Fuzzy facial expression animation can be generated through LFFEGL script, as seen in the right region of the interface. Some keyframes of facial expressions such as disgust, surprise, disliking, pain and tiredness are shown in figure 18.
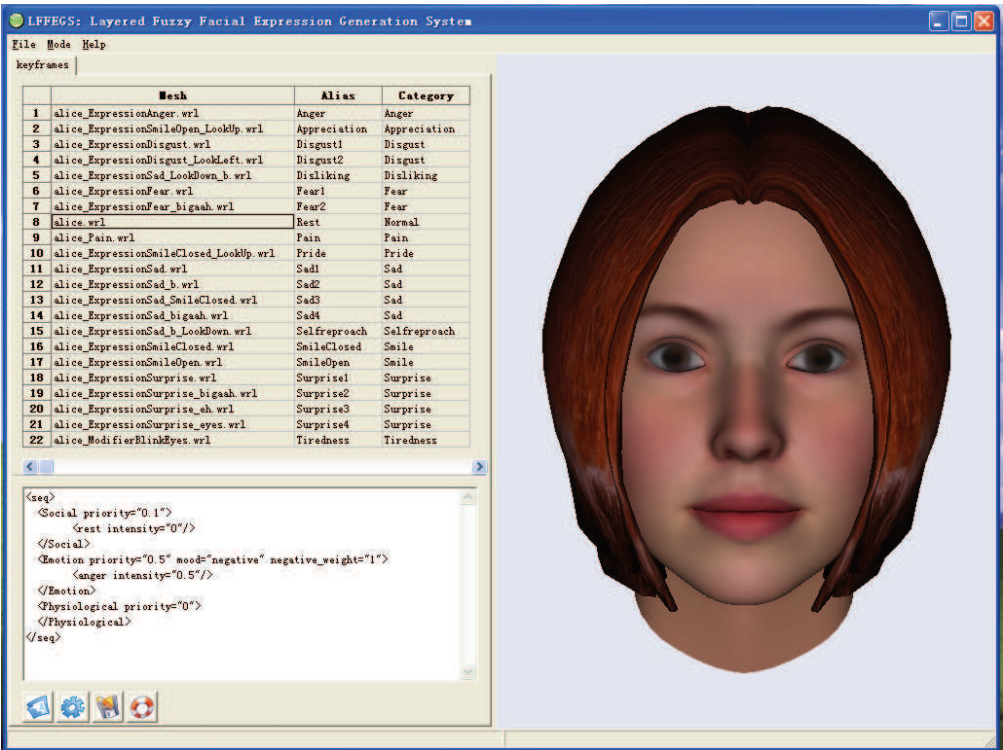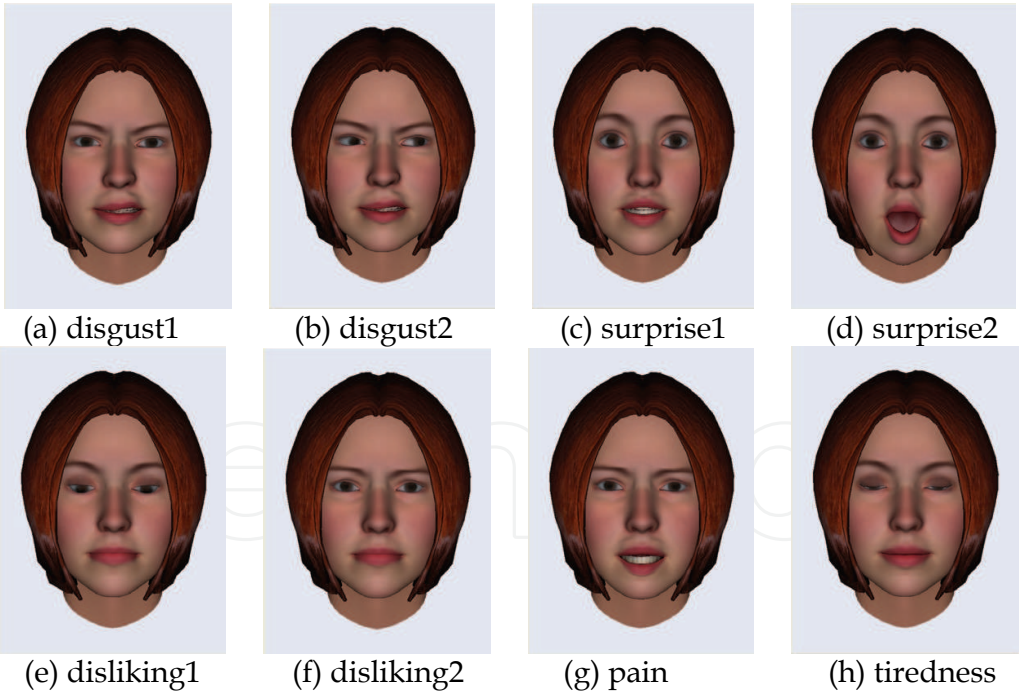
Figure 17. Interface of the LFFEGS

(a) disgust1   (b) disgust2   (c) surprise1   (d) surprise2

(e) disliking1   (f) disliking2   (g) pain   (h) tiredness

Figure 18. Some keyframes of facial expressions

Experiment 1

Although there are thousands of facial expressions, it is unnecessary for agent to present so many facial expressions as even human cannot distinguish them clearly. The important thing is to let user understand the agent's emotions and intentions. Dozens of prototype

facial expressions are competent to cover facial expression types defined in the system with the help of fuzzy mechanism of facial expression generation.

In the first experiment, 10 subjects were asked to judge 21 keyframes of facial expressions, giving what emotions each facial expression likely to present and the corresponding score of expressiveness from 1 (low) to 5 (high). According to the results, each emotion was related to some facial expressions and fuzzy parameters were determined in the LFFEGS.

Experiment 2

In the following experiment, 30 scripts were written in LFFEGL to generate fuzzy facial expression animations with middle intensity. 20 subjects were asked to run each script 5 times to evaluate the effect of the fuzzily generated facial expression animations, giving the score of satisfaction from 1 (low) to 5 (high). The results are showed in table 5, denoting that most facial expressions acted well. For those facial expressions with low scores, better keyframes should be taken to strengthen the expressiveness.

F.E.	S.	F.E.	S.	F.E.	S.	F.E.	S.	F.E.	S.
anger	3.9	disappointed	2.8	gratitude	2.9	sadness	3	agreement	4.8
fear	3.5	appreciation	3.3	happyfor	4.0	sorryfor	2.8	resentment	4.1
joy	4.0	fearsconfirmed	3.4	distress	3.3	relief	3	satisfaction	3.7
pity	3.2	disagreement	3.7	gloating	3.5	remorse	3.1	disgust	4.8
pride	4.2	gratification	3.7	disliking	3.2	liking	3.5	tiredness	4.0
hope	2.8	selfreproach	2.5	reproach	3.4	pain	4.6	surprise	4.3

Note: F.E.=facial expression, S.=score

Table 5. Score of satisfaction of fuzzily generated facial expressions

Comparison

Systems	Em. View	F.Ex	Ph.Ex.	S.Ex.	Ex.P.
Improvisational Animation system (Perlin, 1997)	others	—	Yes	—	—
(Yang et al., 1999)'s system	Basic Em.	—	—	—	—
CharToon system (Hendrix & Ruttkay, 2000)	Basic Em. +others	—	—	—	Yes
(Bui et al., 2001)'s system	Basic Em.	Yes	—	—	—
(Ochs et al., 2005)'s system	OCC's Em.	Yes	—	Yes	—
LFFEG system	OCC's Em.	Yes	Yes	Yes	Yes

Note: Em. =Emotional, Ex.=Expression, F.= Fuzzy, Ph.=Physiological, S.=Social, P.=Personality

Table 6. Comparison of facial expression generation systems

A comparison of facial expression generation systems was given in the items of Emotion View, Fuzzy Expression, Physiological Expression, Social Expression and Expression Personality, as seen in table 6. In the LFFEG system, facial expressions fuzzily generated by

the social, emotional and physiological layers in different levels are richer and more reasonable, tally well with the character of human.

Potential Applications

The LFFEG can help improving the intelligence of facial expression generation and will be useful in kinds of applications such as lifelike characters and robots.

Lifelike characters are one of the most exciting technologies for human computer interface applications (Prendinger & ishizuka, 2004b). Animating the visual appearance of life-like characters and integrating them into an application environment involves a large number of complex and highly inter-related tasks. The expression of personality and affective state by means of body movement, facial displays, and speech can easily be realized by emotional layer. The coordination of the bodily behaviour of multiple characters should be instructed by social rules. The characters also need to show their bodily state such as sleepy to coordinate the communication.

The humanoid shape has evolved over eons of interaction with the world to cope efficiently and effectively with it. So, (Norman, 2003) suggested that where the demands upon a robot are similar to those upon people, having a similar shape might be sensible. Thus, robot should display facial expression like human does to achieve similar intelligence. Recent research demonstrates that robot need emotion. Accompany with emotion, social intent and rules are necessary to instruct the robot to display appropriate expressions. As robot has its own body, if it is damaged somewhere, it can show facial expression such as pain to inform people that there is something wrong with it.

5. Conclusion

In this chapter, we proposed a novel model of layered fuzzy facial expression generation and developed the corresponding facial expression generation system. In the LFFEG model, the affects of the social, emotional and physiological factors are considered in different layers, and facial expressions are fuzzily generated. In the LFFEG system, the LFFEG language provides an easy way for facial expression generation, and the fuzzy emotion-expression mapping and the novel arousal-valence-expressiveness emotion space help realize the fuzzy facial expression with personality.

There are three primary novelties in our work: layered, fuzzy, and expression personality. Firstly, the factors that affect facial expression generation are considered in different layers, not only emotion but also social and physiological factors. Secondly, fuzzy facial expressions are realized to display multiple emotions, making the expression of the agent smart and rich. Thirdly, expression personality is realized via the expressiveness difference of emotions in the facial expression generation. So the facial expression generation of the agent is more like human, making the agent intelligent in displaying facial expressions in human computer interaction.

To achieve affective and harmonious human computer interaction, the LFFEG model can be further studied in the following directions:

• Further study the mechanisms of facial expression generation.

• Develop an effective way to generate various facial expressions of agent.

• Embed the LFFEG model in a multi-modal human computer interaction system.

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This book provides an overview of state of the art research in Affective Computing. It presents new ideas, original results and practical experiences in this increasingly important research field. The book consists of 23 chapters categorized into four sections. Since one of the most important means of human communication is facial expression, the first section of this book (Chapters 1 to 7) presents a research on synthesis and recognition of facial expressions. Given that we not only use the face but also body movements to express ourselves, in the second section (Chapters 8 to 11) we present a research on perception and generation of emotional expressions by using full-body motions. The third section of the book (Chapters 12 to 16) presents computational models on emotion, as well as findings from neuroscience research. In the last section of the book (Chapters 17 to 22) we present applications related to affective computing.

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