Design Support System for Emotional Expression of Robot Partners using Interactive Evolutionary Computation

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Abstract—Recently, the need of robot partners is increasing. Such robots should have an emotional model in order to co-exist and to realize the natural communication with people. In the communication, nonverbal communication and emotional expression based on emotional model are very important for robot partners. Moreover, facial and gestural expression should be adaptive to a user of the robot. Therefore, we propose a design support system of arm gestural and facial expression of robot partners based on interactive evolutionary computation and Laban features. Next, we conduct several experiments of the proposed method, and discuss the effectiveness of the proposed method.

Keywords- Robot Partners; Interactive Evolutionally Computation; Emotional Expressions; Emotional Model

I. INTRODUCTION

Recently, robot partners are wished to play roles at home. Such robots should have an emotional model in order to co-exist and to realize natural communication with people. If robot partners can perceive human behavior based on an emotional model, they could have the sympathetic understanding like people. The relationship between emotion and communication of human beings has been discussed from various kinds of viewpoints such as psychology, sociology, neurophysiology, and brain science [1-8]. In general, there are two approaches: macroscopic and microscopic discussions. In the discussion of emotion in psychology from the macroscopic point of view, a human body is considered as a black box, and the internal processing in mind has been discussed. The relationship between emotional expressions and social behaviors has been discussed in sociology. For example, Keltner and Kring discussed the roles of emotion from three different viewpoints in social interaction; (1) Informative functions, (2) Evocative functions, and (3) Incentive functions [5]. In informative functions of emotion, emotional expression conveys information about senders themselves and also about objects and events in the social environments. In evocative functions of emotion, one individual’s emotional expression serves as a social affordance that evokes “prepared” responses with others.

In incentive functions of emotion, an individual’s expression and experience of emotion may provide incentives or reinforce another individual’s social behavior within ongoing interactions. In this way, emotional expression plays very important role in social interactions. On the other hand, the emotion is discussed from the microscopic point of view as neurotransmitters and neuronal networks in brain science. In American heritage dictionary, emotion is defined as an intense mental state that arises subjectively rather than through conscious effort and is often accompanied by physiological changes. Furthermore, the constructivism approach on the emotion is often discussed from the viewpoint of modeling by mathematical models and systems model based on the theories discussed in psychology and brain science. To summarize, in the researches on the emotion, it is very important to analyze and understand the human body and human society.

Natural communication based on the emotion is one of important topics in the research of human-friendly robots [9-11]. In general, human communication is done through the perception of other’s intention and feeling. This indicates that the emotional model is very helpful for a human to understand the state of a robot. Furthermore, the emotions influence human actions like incentive functions of emotion.

Human emotion is complexly connected to facial expression and feature of body movement such as arm gesture. Human emotion influences emotional expression, while emotional expression influences human emotion. This is a mutually nesting structure. For example, emotion alters facial expression and feature of gesture unconsciously. To the contrary, facial expression and arm gesture cause emotion to correspond to emotional face and feature of gesture movement. Arm gesture has common sign and geometric information in addition to emotional information. Therefore we can know other’s emotion from visual information instinctively.

In this research, we focus on emotional expressions of human-like robot partners, because it is good for natural communication with people. If a robot partner has human-like...
features, the robot can communicate with people by the human-like way, and human can also communicate with the robot more naturally as if it were a human. In addition, human-like robot partner can express human-like emotion, because it has almost the same body parts as human. The human-like body allows people to recognize the emotion of robot instinctively. Furthermore, non-verbal communication such as gestural and facial expression is important in addition to verbal communication using direct linguistic expression. However it is difficult to make such a robot that can express human-like emotion, because human emotion is very complex and ambiguous. Therefore, the emotion expressions of robot should be variety too. Moreover, people could have a different feeling of the emotional expressions each other. It is unclear for a robot to understand what kind of emotion people feel from emotional expressions. Accordingly, the method to design emotional expressions suitable to each person is required.

The best way to design such expressions is the direct design by the person. However, a designer of robot’s motion must have special knowledge and skill. Therefore, it is difficult for unfamiliar people to design robot’s motion. On top of that, there is no method to design complex emotional expressions of gestural and face expression easily for non-expert people. It is too difficult and hard for them to program gestural and facial expression of robots. Therefore, we propose a design support system for non-expert people to easily design expression suitable to each person.

We proposed a design support system of robot partners based on interactive evolutionary computation (IEC) [3]. The advantage of IEC is the direct use of human evaluation, not only the evaluation of predefined fitness functions [12]. Actually, IEC has been applied to the design support based on human preferences such as glasses frame and tableware [12,13]. However, it takes much time and load to evaluate every design candidate. In order to reduce the time and load, we proposed an estimation method based on fuzzy inference and human evaluation [14]. In this paper, we propose an interactive design support system of gestures while estimating emotional states of gestures based on human evaluations. We discuss the effectiveness of the proposed system through experimental results.

II. INTERACTIVE DESIGN SUPPORT SYSTEM BASED ON SOFT COMPUTING

A. Robot Partner and Emotional Expressions

We are developing on-table small size of robot partners called iPhonoid and iPadrone (Fig.2 (a) and (b)). In order to popularize robot partners for home use, the price of a robot partner should be as low as possible. Since iPhone or iPad is equipped with various sensors such as gyro, accelerometer, illumination sensor, touch interface, compass, two cameras, and microphone, the robot itself is enough to be equipped with only cheap range sensors, e.g., Microsoft Kinect sensors. Furthermore, iPhone or iPad can be easily detached from the robot, and iPhonoid and iPadrone can also controlled in the detached state of iPhone and iPad.

In this research, we try to realize emotional expression of iPadrone. iPadrone has two arms consist of six servomotors and human-like face consists of two eyes and mouth on iPad. Therefore, iPadrone can make various gestures and facial expression.
B. Interactive Evolutionary Design

Soft computing including fuzzy computing, neural computing, and evolutionary computing was proposed to deal with vagueness and ambiguity of human thinking and unclear phenomena [15-24]. Evolutionary computing is used as a multi-point optimization technique imitating the process of natural evolution [21]. Various types of interactive evolutionary computation (IEC) have been applied to deal with human feelings and subjective impressions [12]. IEC can generate various types of design candidates based on the history of human vague evaluations. We also applied IEC to generate human-friendly motions of arms of human-like robot partner [14]. In order to reduce the times of human evaluations, we applied fuzzy modeling of human evaluation. In this method, we must deal with a difficult dilemma based on the mutually nesting structure of the generation and evaluation of candidate solutions. This means we must generate various types of candidate solutions to clarify unknown human evaluation and preference, while we must obtain various types of human evaluations to generate good candidate solutions. Therefore, the optimization process should be done deeply and widely on the search space. This is similar with the optimization process of reinforcement learning based on exploration and exploitation [24].

We use iPad for the simulation of robot partners to evaluate human preference, because we can easily use the touch interface and accelerometer as human input interface [25]. Figure 3 shows the overview of the interactive design support system. Since it is very difficult for a user to evaluate all of the candidate designs at the same time, the interactive design support system shows the 3D model of two design candidates in the main screen (Fig.4). A user inputs the evaluation value of the more preferable candidate of the two by a slider in the screen and touches the preferable candidate to give it the evaluation.

Figure 5 shows the hardware architecture of robot partners used in the design of emotional expression. Basically, the gestural expression is composed of rotation of shoulders and elbows, mouth picture, and eyes pictures. The arms can rotate within the blue axes as seen in Fig.5, therefore each gesture is expressed by six degree-of-freedom (DOF). The variables are maximum angles of each motor. The facial parts are chosen probabilistically from the four emotional face pictures (Fig.6). The selection of facial parts is done by the probability of the emotional state inferred from the Laban features of generated gestures. The system decides facial parts with the selection probability, because it is hard to design facial expression and gestural expression simultaneously for each user with IEC. In addition, when a real robot makes face to user in a practice, the facial parts can be changed flexibly considering the mood and the user’s condition.

C. Steady-State Genetic Algorithm for Interactive Design

We use a steady-state genetic algorithm (SSGA) [23] as an interactive evolutionary computing method to design emotional gestures corresponding to facial expressions. Each emotional gesture is represented by the joint angles of both arms. Therefore, the robot takes a target posture from initial position of both arms as a gesture. In SSGA, only a few existing solutions are replaced with the candidate generated by genetic operators in each generation (Fig.7). It is very difficult to evaluate all of candidate solutions generated by crossover and mutation, if we use a standard GA. In this study, the worst candidate solution is eliminated ("Delete least fitness" selection), and it is replaced with the candidate solution generated by the elitist crossover and adaptive mutation. The population size is $G (=10)$, and the chromosome length is $L (=6)$ corresponding to the number of joint angles of both hand. The $i$th individual is represented by $(g_{i,1}, g_{i,2}, \ldots, g_{i,L})$. The elitist crossover randomly selects one candidate solution, and generates a new candidate solution by combining genetic
information from randomly selected individual and the best individual. If the crossover probability per gene is satisfied, the elitist crossover is performed to its corresponding locus. Otherwise, a simple crossover is performed between two randomly selected individuals like a uniform crossover. Next, the following adaptive mutation is performed to the generated individual,

$$g_{i,j} \leftarrow g_{i,j} + \left( \beta_{i,j} \cdot \frac{f_{\text{max}} - f_{i,j} + \beta_{i,j}}{f_{\text{max}} - f_{\text{min}}} \right) \cdot N(0,1) \quad (1)$$

where $f_i$ is the fitness value of the $i$th individual; $f_{\text{max}}$ and $f_{\text{min}}$ are the maximum and minimum of fitness values in the population; $N(0,1)$ indicates a normal random variable with a mean of zero and a variance of one; $\beta_{i,j}$ ($\beta_{i,j}>0$) and $\beta_{i,j}$ ($\beta_{i,j}>0$) are the coefficient and offset, respectively. In the adaptive mutation, the variance of the normal random number is relatively changed according to the fitness values of the population in case of maximization problems.

![Fig.7. The overview of SSGA](image)

**D. Laban Features**

Laban system is one of movement analysis systems to deal with dynamical and geometrical features of body movement [24]. Feature values used in Laban system is called “Laban features.” The research on inference of emotion using Laban features and fuzzy inference has been done. These researches use the Russell’s model of emotion to reduce four dimensions of emotion to two. We also use the method of emotion inference using Laban features. However, we don’t use the Russell’s model, but use the four dimension of universal emotion of people such as pleasure, anger, sadness, and relaxed. In Russell’s model, although pleasure and anger are opposite emotions of sadness and relaxed, we don’t think it is not always true. Moreover, we mainly use Gaussian function to represent the correlation between Laban features and each emotion.

Next, we explain how to calculate six Laban features used in this research. We calculate them according to the original meaning of Laban features. Space is indicating the degree of directional deflection in body movement and is defined as the range of right and left hands. Inclination is indicating the degree of hurriedness in changes of movement and is defined as the time from a starting pose to an ending pose. Weight is indicating the degree of vigorousness of body movement and is defined as speed of hands. Inclination is indicating the bias for forward of posture and is defined as average position of hands. Area is indicating the area of horizontal body spread based on the triangle made by body and both hands.

**E. Inference of Emotion Based on Laban Features**

In this section, we propose an inference system for estimating emotions from Laban feature for each user. The proposed method calculates the probability of belonging to an emotional state from the user’s evaluation of 0 to 10 in the design process of emotional gestures using IEC.

First, we prepare four faces of four emotions (see Fig.6), and choose one of them. Second, the system displays two gestures of robot with its emotional face, and user designs the gesture of robot suitable to the emotional facial expression with IEC. The system updates the inference system with every evaluation in IEC. The mean $\mu$ and variance $\sigma^2$ of distribution are calculated as follows:

$$\mu_{i,j} = \frac{\sum_{t=1}^{T} L_{i,j,t} v_t}{\sum_{t=1}^{T} v_t} \quad (2)$$

$$E(L_{i,j,t}^2) = \frac{\sum_{t=1}^{T} L_{i,j,t}^2 v_t}{\sum_{t=1}^{T} v_t} - \mu_{i,j}^2 \quad (3)$$

where $i$ and $j$ are kind of emotional states and Laban features, respectively; $T$ is the total time of evaluation; $L$ is the value of Laban features between 0 and 1; $v$ is value of user’s evaluation. Therefore, the probability of including $j$th Laban feature in an emotional gesture calculated where the $i$th emotional state is given. The proposed method can exploit the user’s acceptability of emotional gestures.

Human beings have internal state of mood in addition to emotion and feeling. The state of mood is linked strongly with feeling and emotion. For example, angry people generally can’t be relaxed immediately because of the angry mood. Mood affects directionally to the human emotion and thought. In this study, we use the state of mood to enhance the design of gestures by sharing the mood between robot and its user explicitly. We use four kinds of moods corresponding to four emotions. Mood is increased as high evaluation of emotional expression, and is decreased as time passes. The update of mood is done as follows;

$$Mood_{i,T} = \alpha \cdot (Mood_{i,T-1} + EMO_{i,T-1} \cdot v_{T-1}) \quad (5)$$

where $Mood$ is the value of emotional mood; $i$ is kind of emotion; $T$ is the current number of generations (iterations) of GA; $\alpha$ is the temporal discount rate of mood; $EMO$ is the value of each emotion; $v$ is the evaluation value of the design of emotional expression of two gestures displayed in the simulator.

Finally, we explain how to calculate the probability of emotion from Laban features of gesture. The system outputs the probability of each emotion as strength of emotions from the six Laban features. We propose two different functions to estimate the emotional state. One is a Gaussian probability
density function and mood, and the other is Gaussian membership function and mood. Strengths of emotion are calculated with Gaussian probability density function as follows;

\[ EMO_i = \sum_{j=1}^{4} \frac{1 + Mood_{i,j} \cdot \exp \left( \frac{(-L_{i,j} - \mu_{i,j})^2}{2 \sigma_{i,j}^2} \right)}{\sqrt{2\pi\sigma_{i,j}}} \] (6)

\[ P_i = EMO_i \sum_{k=1}^{4} EMO_k \] (7)

where \( EMO \) is the strength of emotions; \( i \) and \( j \) are kind of emotion and Laban feature, respectively; \( P_i \) is ratio of each emotion. On the other hand, strengths of emotion are calculated with Gaussian membership function as follows.

\[ EMO_i = \sum_{j=1}^{4} \frac{1 + Mood_{i,j} \cdot \exp \left( \frac{(-L_{i,j} - \mu_{i,j})^2}{2 \sigma_{i,j}^2} \right)}{\sqrt{2\pi\sigma_{i,j}}} \] (8)

\[ P_i = EMO_i \sum_{k=1}^{4} EMO_k \] (9)

III. EXPERIMENTAL RESULTS

This section shows several experimental results of the proposed method. The total procedure of the proposed interactive evolutionary design system is shown as follows;

Step 1: Initialization
Step 2: Human Evaluation
Step 3: Update of Gaussian Functions
Step 4: IEC (SSGA)
  Step 4-1: Selection
  Step 4-2: Elite Crossover
  Step 4-3: Adaptive Mutation
  Step 4-4: Update of Design Parameters
Step 5: Go to Step 2

A. Exploitation of Relationship between Emotions and Laban Features

First, we conducted comparison experiments on two different functions of Gaussian probability density function and Gaussian membership function to represent relationship between emotions and Laban features according to a user’s sensitivity.

Figure 8 shows experimental results obtained by the Gaussian probability density functions according to a user’s evaluation value through the IEC design of emotional expression of the robot. In Fig.8, the value of Pleasure is large when the values of Inclination and Area are relatively large or the value of Space is relatively small. The value of Anger is large when the value of Space, Time, Weight and Height are relatively large, or the value of Area is relatively small.

Figure 9 shows experimental results obtained by the Gaussian membership functions according to a user’s evaluation value through the IEC design of emotional expression of the robot.
Fig. 9. Fuzzy membership functions (MF) of relationship between emotions and Laban features

![Fig. 9](image)

(a) Gaussian PDF         (b) Gaussian MF

Relaxation is max sadnes is max  Relaxation is max sadnes is max

Fig. 10. Two Weight distribution of Gaussian function and fuzzy membership function

Figure 10 shows a comparison result of Sadness and Relaxation between Gaussian PDF and Gaussian MF. The value of Relaxation is almost the same as Sadness value when the value of Sadness is maximum in Fig. 10 (a). On the other hand, in the case of Gaussian MF, the value of Relaxation is under half of maximum value when the value of Sadness is maximum. Gaussian MF is better than Gaussian PDF when we find the maximal point of each emotional state concerning with each Laban feature. On the other hand, Gaussian PDF is adequate for the optimization of the robot’s action to express emotion because we can clearly find the most important Laban feature from the variance. As the variance of a Laban feature is comparatively small, the Laban feature is important for the user.

B. Design of Emotional Face using Mood

In this experiment, the user designed robot emotional expression consisted of gesture and facial expression using the relationship between emotions and Laban features using fuzzy membership function obtained in the above experiment. In the experiment, the user designed emotional gestures of robot with IEC until he is satisfied. At the same time, the system calculates the emotional levels of candidates in IEC, and selected parts of eyes and mouth stochastically according to emotional levels of each emotion. Figure 11 shows the history of human evaluation values. Figure 12 shows an experimental result of emotional expression obtained by the proposed method. Figure 13 shows the change of mood in the optimization process. Since the mood can influence the human evaluation without direct consciousness to the mood that is shared with the robot, the proposed method can explicitly reflect the mood to human evaluation.

IV. SUMMARY

The paper proposed a design support system for robot’s emotional expression using interactive evolutionary computation. We proposed the design method of gesture and face mixed expression. The preliminary experimental results showed the effectiveness of the proposed method. A robot partner can express emotion properly according to the user’s evaluations. However, in this study the variation of the design is still restricted into simple movement and limited facial expression. Therefore, we will develop a design system of facial expression. Furthermore, the evolution of gesture parameters is dependent on the initial evaluation of the displayed models. Therefore, we will incorporate an initial selection method of the model templates based on the first impression.

As other future works, we must consider about the choice of Gaussian probability density functions and Gaussian membership functions for the design and analysis of gesture motions. Furthermore, we should investigate the effect of mood in this system, and consider how to use emotional models to the design of emotional expression in detail.

REFERENCES
