Emotional Gait Generation for a Humanoid Robot

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Abstract: In this paper, an emotional mathematical model and affective state probability description space of a humanoid robot are set up on the basis of psycho-dynamics’ psychological energy and affective energy conservation law. The emotional state transferring process and hidden Markov chain algorithm of stimulating transition process are then studied. The simulation results show that the mathematical model is applicable to the authentic affective state change rule of human beings. Finally, the gait generation experiment results of control signal and electric current tracking wave-form are presented to demonstrate the validity of the proposed mathematical model.

Keywords: Emotional mathematical model, humanoid robot, hidden Markov chain, stimulating transition process, gait generation.

1 Introduction

Researchers always have a dream that humanoid robots’ appearance characteristics, gait, etc., can be similar to those of human beings. In the future, humanoid robots will be able to walk and climb the stairs. Additionally, they will have visual, olfactory, tactile, imaginative and talkative abilities; especially, they can work in a dangerous and extreme environment[1]. Cabrol et al.[2] described specific constraints of vision systems which are embedded in humanoid robots. A hybrid method based on rough sets and genetic algorithms is proposed to raise the speed of humanoid robots’ path planning[3]. A robust nonlinear analytical redundancy (RLNAR) technique is presented to detect and isolate component faults in humanoid robots[4].

One of the state-of-the-art hot spots in the robotics’ fields is to enable robots to have the emotional interactive ability[5]. This paper establishes a humanoid robot emotional gait planning and generation based on psycho-dynamics’ psychological energy and affective energy conservation law. The humanoid robots’ research platform is established by means of humanoid robots’ gait planning integrated with mathematical simulation and physical realization of emotion changing process. The platform also provides an application and theoretical research basis for harmonious human-robot interaction.

The remainder of this paper is organized as follows. Section 2 presents emotional energy distribution and emotional state description space. Then, the hidden Markov model (HMM) of emotional state stimulating transition process is described in Section 3. Next, the simulation of emotional state stimulating transition process is made in Section 4. The method of humanoid robots’ gait generation is proposed, and experimental results are given in Section 5. Finally, some concluding remarks and future work are given in Section 6.

2 Emotional space

In this section, emotional state description space is set up according to psycho-dynamics’ psychological energy and affective energy conservation law specified as follows.

2.1 Emotional energy distribution

According to the psycho-dynamics theory[6], individual’s different emotional processes are a process of dynamically allocating active emotional energy $E_p$ among different emotional states. The dynamic distribution expression of $E_p$ is defined as $E_p^a = [E_{p1}^a, E_{p2}^a, \ldots, E_{PN}^a]$. The expression is emotional energy absolute distribution vector under actual performance at time $t$. The expression defined as $e_p^t = [e_{p1}^t, e_{p2}^t, \ldots, e_{pN}^t]$ is the emotional energy relative distribution vector under actual performance at time $t$. The ratio can be calculated by $e_{pi}^t = E_{pi}^a / E_p^a$. The dynamic allocation process shows different performances because of different static distribution structures of $E_p^a$. There are two ways of describing the allocation of $E_p^a$. One is emotional energy absolute, and the other is emotional energy relative[7].

According to the emotional energy conservation law, we have

$$\sum_{i=1}^{N} E_{pi}^a = E_p^a.$$  \hspace{2cm} (1)

According to (1), we have

$$\sum_{i=1}^{N} e_{pi}^t = 1.$$  \hspace{2cm} (2)

Individual’s different emotional states at time $t$ are determined by the relative values of various components of $E_p^a$ or $e_p^t$.

2.2 Emotional state description space

1) Emotional energy description space

According to the above-mentioned expressions, we have

$$E_{p1}^a + E_{p2}^a + \ldots + E_{PN}^a = E_p^a \leq (1 - \lambda + \gamma\lambda)E$$  \hspace{2cm} (3)

$$0 \leq E_{pi}^a \leq E_p^a, \quad 0 \leq e_{pi}^t \leq 1, \quad 0 \leq E_{pi}^a \leq E_p^a$$  \hspace{2cm} (4)

$$e_{p1}^t + e_{p2}^t + \ldots + e_{pN}^t = 1 \text{ (0 \leq e_{pi}^t \leq 1)}.$$  \hspace{2cm} (5)
Equation (3) is an absolute emotional energy distribution equation, where \( \lambda \) is the psychology emotional excitement degree, \( \gamma \) is the psychology emotional suppression degree, and \( \alpha (0 \leq \alpha < 1) \) is the physiological wake-up degree. Formula (5) is a relative emotional energy distribution equation. Geometric spaces of (3) and (5) are, respectively, the absolute emotional energy distribution space and the relative emotional energy distribution space\(^8\).

When \( \gamma \) and \( \lambda \) are both constant coefficients, \( \omega \) will be changed from 1 to 0 gradually. These values correspond to the maximal emotional state space, and \( \Omega^\lambda_1 \) is the maximal emotional state space.

2) Probability space of emotional state

Equation (5) determines affective energy distribution ratio among different emotional states. \( e_n^\lambda \) can be seen as a probability function. \( P^\lambda = [p_1^\lambda, p_2^\lambda, \ldots, p_N^\lambda] \) is used to describe the probability distribution vector for emotional state. \( p_i^\lambda = e_n^\lambda \) is used to describe the probability function of emotion mode at time \( t \). Individual's emotional state can be determined according to the relative size of each component in \( P^\lambda \). Accordingly, the emotional state of the probability space can be defined as follows.

Basic emotional state space set is \( S = \{S_1, S_2, \ldots, S_N\} \). \( S_i = i \) \( (i = 1, 2, \ldots, N) \), \( N \) describes the number of basic emotional states, and random variable \( X \) is an emotional state variable. \( P_i \) \( (i = 1, 2, \ldots, N) \) is assumed to be the probability. When \( X \) is the \( i \)-th kind of emotional state, we have

\[
\sum_{i=1}^{N} P_i = P_1 + P_2 + \cdots + P_N = 1, \\
0 \leq P_i \leq 1 \quad (i = 1, 2, \ldots, N).
\]

Equation (6) shows the emotional state probability distribution. Then, the probability space model of emotional state can be calculated by

\[
\begin{pmatrix}
S \\
P
\end{pmatrix} =
\begin{pmatrix}
S_1 & S_2 & \cdots & S_N \\
P_1 & P_2 & \cdots & P_N
\end{pmatrix}.
\]

Fig. 1 shows the transferring relation among different emotional states. \( a_{ij} \) denotes the affective energy distribution ratio transferred from \( i \)-th kind of emotional state to \( j \)-th kind of emotional state at a certain moment of time\(^9\).

3 Emotion stimulation transferring

HMM is utilized to describe the emotional state stimulation transferring process specified as follows. A typical HMM's parameters can be described as follows\(^{10} \):

1) \( N \) stands for the number of Markov chain states. \( S = \{S_1, S_2, \ldots, S_N\} \) denotes the state space, and \( q_i \) denotes the state of Markov chain at time \( t \).

2) \( M \) stands for the number of possible observable values of each state. \( V = \{V_1, V_2, \ldots, V_M\} \). \( M \) denotes the observable values, and \( O^t \) denotes the observable values at time \( t \). \( O^t \) set belongs to \( V \) set.

3) \( \pi \) is the probability distribution vector of initial state. \( \pi = [\pi_1, \pi_2, \ldots, \pi_N] \), and

\[
\pi_j = P(q_0 = S_j), \quad 1 \leq i \leq N.
\]

4) \( \hat{A} \) is the state transition probability matrix. \( \hat{A} = (\hat{a}_{ij})_{N \times N} \), and

\[
\hat{a}_{ij} = P(q_{t+1} = S_j | q_t = S_i), \quad 1 \leq i, j \leq N.
\]

5) \( B \) is the probability matrix of observable values.

\[
B = \{b_j(k)\}_{j \times k}, \quad b_j(k) = P(V_t | q_t = S_j), \quad 1 \leq j \leq N, \quad 1 \leq k \leq M.
\]

As discussed above, HMM is fully determined by two parameters \( N \) and \( M \), and three probabilities \( \hat{A}, B, \pi \). In this way, an HMM can be expressed as

\[
\lambda = (N, M, \pi, \hat{A}, B).
\]

4 The basic idea of modeling

The probability space of emotional state is utilized to set up the model. In (11), \( N \) is the number of emotional states. The number \( (N) \) of emotional states can be given by

\[
S = (S_1, S_2, \ldots, S_N) = (1, 2, \ldots, N), \\
S_i = i \quad (i = 1, 2, \ldots, N).
\]

In the emotional state stimulation transferring process\(^{11} \), the state probability distribution \( P = [P_1, P_2, \ldots, P_N] \) can be described by the following two kinds of probability distributions. \( \pi = [\pi_1, \pi_2, \ldots, \pi_N] \) presents the initial state probability distribution. \( \pi \) is the initial probability distribution in HMM model that should be equal to \( P^t = [P_1^T, P_2^T, \ldots, P_N^T] \). \( P^{(T)} = [P_1^{(T)}, P_2^{(T)}, \ldots, P_N^{(T)}] \) presents the current emotional state probability distribution. The emotional state corresponds to the type of external stimulation and intensity \( T \).

The external stimulation can be described by observable matrix, observable values and sequence in HMM model. The observable value set and the stimulation set are specified as follows:

\[
V = (V_1, V_2, \ldots, V_M) = (1, 2, \ldots, M), \\
V_m = m \quad (m = 1, 2, \ldots, M).
\]

It is assumed that one kind of stimulus causes only a certain kind of emotion. \( V_i \) only leads to the emotion \( i \), so