Robot’s Emotion Decision using Energy and Entropy Concepts

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Abstract — This study is for introducing concepts of energy and entropy to describe a robot’s emotion decision. There are several kinds of approaches to explain the emotional structure. The dimensional approach based on factors of pleasure and arousal is chosen for the merit of the interpolation between emotions. Specifically, Circumplex model which has also two axes: pleasure and arousal is used. Besides, the model indicates how emotions are distributed in the two-dimensional plane. Psychological energy is introduced and divided into two kinds of energy states: mental energy and physical energy by the definition of psychodynamics. Then the energy states: mental energy and physical energy are matched to pleasure and arousal respectively that are the basis of Circumplex model. The mental energy is updated by the result of Prospect theory which measures the value of gain and loss as pleasure factor. And the physical energy is updated by the result of hedonic scaling which measures levels of arousal from pleasure computed by Prospect theory, and the result of intensity of stimuli. Then the energy states are fed by entropy. The feedback loop by entropy satisfies the 2nd law of thermodynamics. The energy states generated by stimuli and fed by entropy take a position in the plane of Circumplex model. Then distances between the current position and other emotions are computed to get a level of each emotion, proportional to the inverse of the distance.

Keywords — Robot’s Emotion; Emotion Generation; Emotion Decision; Energy and Entropy

Nowadays robot’s status has been changed and expanded from the industrial fields to the service areas. Thus, human and robot are interacting with each other personally, socially, and universally. We call the interaction between human and robot HRI. One of the ways of HRI is using emotion to express robot’s status or communicate with human intuitively. Emotion can help robot be able to perform the social roles in human society. In the intelligent study field, emotion sometimes can be used to make fast decision in a complex environment. Therefore the study of robot’s emotion generation is important for implementing social robots.

1 Introduction

1.1 Necessity for Study of Robot’s Emotion

Fig. 1 Transition of robot’s status and the necessity of emotion study

1.2 Scope of Emotion Research

Research of robot’s emotion has been studied for several parts: cognition, generation, and expression, according to the need and improvement of technology. Cognition part is of analysing external stimuli to meaningful data. Following data from the cognition part, generation part determines a corresponding emotion or intensity of emotions. Generated emotions are displayed or expressed by hardware or software simulator, which is the expression part. In this paper, the generation part will be discussed.

The most famous study of emotion generation is to use cognitive approach which evaluates stimuli and matches which emotion will be correspondingly occurred. OCC model is one of the famous models of this approach[1]. This model, however, is incongruent to implement relations and transition between generated emotions[2]. In the other side, there exists dimensional approach that selects primary factors for
emotion and organizes them as axes in a space. This approach has a merit to implement continuous transition of emotions by using interpolation in the space. But this needs to be improved about how to convert stimuli to each axis factor. There also are other approaches: multi-layer approach, mathematical approach, and so on. This paper chose the dimensional approach for the easiness of implementing transition of emotions.

![Fig. 2 Scope of Emotion Study](image)

Among researches of the dimensional approach, some models are implemented in robot researches: AVS model applied to KISMET in MIT, Takanishi’s model applied to WE-4R in Waseda Univ., etc. Additionally there exist studies that define emotional space through from two dimensional models to five dimensional models. These have commonly arousal and pleasure factors. Moreover, Russell suggests Circumplex model that defines how emotions are distributed in the space consisting of the arousal and pleasure factor. This paper takes Circumplex model to get emotions.

1.3 Problem Statement

The dimensional approach needs to be studied how to get each factor from external stimuli and how to describe transitions between emotions.

This paper will introduce energy and entropy concepts to describe the determination process that converts stimuli to factors in Circumplex model, and the transition process by feeding energy states.

2 Proposed Algorithm

2.1 Energy State

Physicists believe that everything’s composed with energy, and any experiment can be carried out in principle. Now we can conclude that our body also composed with energy and emotion is also energy state or change of it.

Studies that try to explain emotion is a kind of energy have been continued. Freud insisted Hydraulic theory, and developed Psychodynamics. Psychodynamic introduces psychological energy and divide it into mental energy and physical energy. By the definition of energy in Psychodynamics, mental energy matches to pleasure factor, and physical energy matches to arousal factor.

2.2 Entropy Feedback

Entropy is used to describe transitions of energy states satisfying the 2nd law of Thermodynamics. This concept is also considered as a tool to explain the universal phenomenon including the flow of information on which Information theory has been established. Steven Pinker says that emotion is a kind of information. So entropy can be calculated by the equation from Information theory.

2.3 Energy State Equation

Energy states are updated by following equation

\[
E_k(t + T_s) = E_k(t) + \alpha_k f_{k,\text{determination}} + f_{k,\text{feedback}}
\]

where \( E_k \) is each energy state, \( k \) is index indicating mental and physical energy, \( f_{k,\text{determination}} \) is a function that determines energy states from stimuli, \( \alpha_k \) is acceptance of the determination function, \( f_{k,\text{feedback}} \) is a feedback function from entropy, and \( T_s \) is sampling time.

2.4 Determination Process

The determination process is in charge of how to determine energy states from stimuli. So it contains the pleasure process which determines the mental energy state, the arousal process which determines the physical energy state, and additionally the hedonic scaling that describes the relations between pleasure and arousal.

The pleasure process takes Prospect theory from Behavioral economics. The theory measures the worth of stimuli when gain/loss is known following equation below.

\[
Pl = \begin{cases} 
  x^\alpha & (x \geq 0) \\
  -\lambda (-x)^\beta & (x < 0) 
\end{cases}
\]

where \( Pl \) is the measurement of the worth, \( x \) is the gain/loss, \( \alpha = \beta = 0.88 \), \( \lambda = 2.25 \).

The arousal process measures the degree of arousal based on the intensity of stimuli and additional states like the rest of battery or durability, etc.

\[
Ar = \chi A^2 f^2 + B
\]

where \( Ar \) is the degree of arousal, \( A \) is magnitude of the stimuli, \( f \) is frequency of the stimuli, \( \chi \) is constant, and \( B \) indicates the additional states.
The hedonic scaling measures arousal from the pleasure obtained from the pleasure process.

\[ He = e^{\delta P} \]  
where \( He \) is arousal from pleasure, and \( \delta = 2.3026 \) \(^{[14]}\).  

Finally the determination function can be constructed with functions explained above.

\[ f_{k, \text{determination}} = Pl + Ar + He \]  

### 2.5 Feedback Process

Feedback process evaluates the energy states and controls them. Considering energy states as quantity of information, entropy can be calculated based on the Information theory\(^{[15]}\).

\[ \text{Ent}(E_k) = -\sum_{x=1}^{2} p_x \log(p_x) \]  
where \( \text{Ent}(E_k) \) is the measured entropy with energy \( E_k \), \( p_1 \) is magnitude of an energy state, and \( p_2 \) is changing rate of an energy state.

Energy states are fed by calculated entropy and changes to satisfy the 2\(^{nd}\) law of Thermodynamics. Therefore an energy state decreases if its magnitude is too high. If an energy state has low value, the acceptance of the determination function increases to gain the energy state easily from stimuli. On the changing rate of an energy state, the acceptance of the determination function will decreases if the energy state’s changed too strongly by stimuli. Otherwise, the acceptance increases and the energy state will vary more easily. Thus the feedback function can be described as

\[ f_{k, \text{feedback}} = c_k \text{Ent}(E_k) - \text{Ent}_{\text{max}} \]  
where \( \text{Ent}_{\text{max}} \) is the maximum value of \( \text{Ent}(E_k) \).  

### 2.6 Emotion Mapping

In accordance with Circumplex model, 28 emotions are positioned in the two dimensional plane consisting of pleasure and arousal factors\(^{[8]}\). When the mental energy and physical energy are determined, they indicate a point in the plane so that we can calculate distances from the point to the emotions distributed in the plane. And intensities of the emotions are obtained proportional to the inverse of the distances.

\[ e_i = \frac{1 / \|t_i - c\|}{\sum_{i=1}^{28} (1 / \|t_i - c\|)} \]  
where \( e_i \) is the \( i \)-th emotion, \( t_i \) is the position of the \( i \)-th emotion in the plane, and \( c \) is current position vector \([E_{\text{mental}}, E_{\text{physical}}]\).

### 3 Experimental Results

#### 3.1 Settings

First, types of stimuli were defined. Each stimulus is classified whether it increases or decreases the energy states.  

<table>
<thead>
<tr>
<th></th>
<th>Physical</th>
<th>Mental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Praise</td>
<td>Encouragement</td>
</tr>
<tr>
<td>Neutral</td>
<td>Rest</td>
<td>-</td>
</tr>
<tr>
<td>Negative</td>
<td>Hit</td>
<td>Scolding</td>
</tr>
</tbody>
</table>

Second, scenario was composed to make every stimulus happen at least once. The scenario is [Study → Rest → Disease → Encouragement → Praise → Exercise → Hit → Scolding → Praise].

Third, only Ekman’s six basic emotions are taken for simplicity.

#### 3.2 Result

Stimuli are given as Fig.4, and correspondent energy, entropy, and generated emotions are shown in Fig.5, Fig.6, and Fig.7, respectively.
4 Conclusions

This paper is for describing how to determine emotions by introducing energy and entropy concepts. As the result, followings are concluded. First, correspondent emotions are generated in accordance with various stimuli, and maximum 28 kinds of emotions can be generated by following Circumplex model not only Ekman’s six basic emotions. Second, generated emotions vary with characteristics of the energy states upon the entropy. Third, various emotions can even match up to same stimulus. Fourth, the proposed algorithm can generalize various kinds of stimuli to a form of gain and loss, and intensity. Therefore, it’s easy to apply the proposed model to many kinds of emotional systems which have a cognition module converting stimuli to gain and loss value.

Further works through this study are followings. First, it needs a proper emotional expression method to express and verify its reliability. Second, entropy is not enough to fully feedback energy states because of the lack of reductionism. There must be another feedback factor such as homeostasis so that the robot behaves like living organism. Finally, integration with the cognition part and expression part, and implementation on a hardware robot are remaining works.

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