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Geometric Simplification in Humanoid Robot Facial Design: A Cross-Cultural Study of Emotion Recognition

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ABSTRACT

This study investigates facial expression recognition in humanoid robot design to clarify cultural differences in emotional perception and establish design guidelines for effective nonverbal communication. As robots become increasingly integrated into daily life, facial expressions play an important role in conveying emotions and social intentions. However, highly humanlike appearances may evoke psychological discomfort, known as the Uncanny Valley phenomenon. To address this issue, this study proposes a design approach emphasizing simplicity and artifact-like familiarity rather than direct imitation of human appearance. Based on the concept of characterization, simplified geometric facial designs were developed using minimal facial elements consisting of eyes and a mouth derived from circular shapes. Parameters such as aspect ratio, inclination, and curvature were systematically manipulated to examine how geometric features influence emotional recognition. A previous comparative experiment involving university students in Denmark and Japan evaluated recognition of Ekman's six basic emotions and neutral expressions. Results showed little cultural variation in happiness, anger, sadness, and neutral expressions, whereas disgust, fear, and surprise demonstrated significant differences. These findings suggest that simplified facial expressions can communicate some emotions across cultures, while others require culturally sensitive design approaches. Building on these findings, this study conducted an additional investigation involving Japanese participants. The results showed patterns similar to the previous study, indicating that participants consistently classified similar facial expressions into similar emotional categories. These findings support the reliability of simplified geometric facial designs and contribute to humanoid robot design that balances cultural adaptability and universal interpretability.

Keywords: Humanoid robot, Facial expression recognition, Emotional perception, Cultural differences, Geometric facial design

INTRODUCTION

When human beings communicate with each other, their faces convey the most important and richest information, and their facial expressions are by far the most essential element for understanding the other's emotion. Various elements such as the eyes, mouth, and nose are contained in the face, and these are transformed to form facial expressions. For many primates

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including human beings, the eyes are one of the most important factor used to recognize a face as a face. Visual preference for facial figures and research on perceptions of upside-down faces are well known regarding facial recognition. These researches have also suggested that the eyes and the mouth are the most important elements for the primates (Darwin, 1872) (Diamond, 1986) (Ellis, 1979) (Keating, 1975) (Shepherd, 1981) (Slater, 1993) (Yin, 1969) (Young, 1985).

There have been two theories regarding the recognition of facial expressions: the category perception theory and the dimension theory. The category perception theory states that human beings judge the meaning of facial expressions through 7 ± 2 universal categories common to all human beings. This theory is based on an idea stemmed from evolutionary theory. This theory indicates that facial expression is a discrete (not continuous) status. In terms of emotional categories, the six basic emotions (happy, angry, sad, disgust, fear, and surprise) advocated by Ekman and many other researchers are the most typical. Basic emotions synchronize with physiological responses and signals to the body such as facial expressions, and it is proposed that facial expressions can be classified under one of the six basic emotions without exception irrespective of culture (Ekman, 2005) (Smith, 1985) (Yamada, 2000) (Yin, 1969).

The dimension theory proposes that facial expressions are points in a continuous space of possible facial expressions, and people recognize the emotions after they locate the points. Dimension theory begins with Schlosberg's theory of the dimension of emotion, for example the circular ring model comprising two dimensions, namely pleasant vs. unpleasant and attention vs. rejection, and the circular cone model comprising the previous two dimensions plus tension vs. sleep. Since this research, many researchers have discussed such affective meaning dimensions and have repeatedly encountered three dimensions: the pleasantness dimension (pleasant vs. unpleasant), the attention vs. rejection dimension, and the activeness (awareness) dimension (aware vs. asleep). The circumplex model comprising a pleasantness dimension and an awareness dimension suggested by Russell has been validated in terms of its universality and robustness by many previous researches (Russell, 1997) (Schlosberg, 1954) (Shah, 2003) (Smith, 1985) (Takehara, 2001) (Yamada, 2000).

Yamada conducted a study to clarify visual information (the physical variable) related to the cognition of facial expressions using a line-drawing figure in which eight points of the eyebrows, eyes and mouth are manipulated. From the results, two physical variables have been found: slantedness, meaning the curve and indication of face elements; and openness and curvedness, meaning the level of curve and openness of facial elements. Based on this knowledge, they proposed that there are three processes used to cognize facial expressions: (1) acknowledgement of visual information (the physical variable) of the face, (2) evaluation of affective meaning based on the physical variable, and (3) judgment of the emotional category based on affective meaning (Watanabe, 2001) (Yamada, 2000).

MINIMAL FACIAL EXPRESSIONS

We validate the relationship between the physical variable and the affective variable discovered by previous researches using geometrical faces, and to apply the existing knowledge to robot facial design. Clarification of this relationship is one of the most important aspects for research on cognition of facial expression. The geometrical face used for this article is comprised of the minimum necessary elements for recognizing the face, and the elements are transformed geometrically to form the various facial expression patterns. We introduce the physical variables, slantedness and openness, to the geometrical transformation. These facial patterns are classified by basic emotions, and evaluation of the relationship between the physical and affective variables is conducted by applying principal component analysis to the facial expression space centered on physical variables. Based on the results of the research, we finally developed a model to create facial expressions. By using simplified faical design, and employing geometrical transformation, the relationship between the facial expression will be shown clearly. In addition, the result will be easily used for design of humanoids and other human-like robotic designs.

The elements composing the face are limited to just three: the two eyes and the mouth, composed of precise circles and placed on the top of the upside-down triangle, the face figure (Fig. 1). Facial expression patterns are made by adding transformations to the three elements within the two parameters of slantedness and openness, comprising the physical variable for cognition of facial expressions. Slantedness of the eyes is a parameter that expresses the curve according to the opening of the eyes by their rotational deformation, while slantedness of the mouth expresses the rise or fall of the corners of the mouth. Openness is a parameter that expresses the change in the opening state of the eyes and mouth by the change in the vertically scaling transformation of the precise circle. Fig. 2 Left and Right show the changes to the eyes and mouth according to the value of the parameters. The eyes make 19 patterns and mouth makes 7 patterns as shown in Fig. 2 Left and Right, making a total of 133 expression patterns. The facial expression is assumed to be completely facing the observer, and all faces are symmetrical.

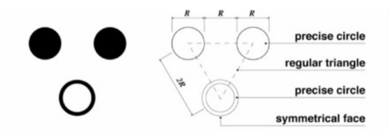


Figure 1: Left: basic face before transformation; right: transformation of eyes by each parameter.

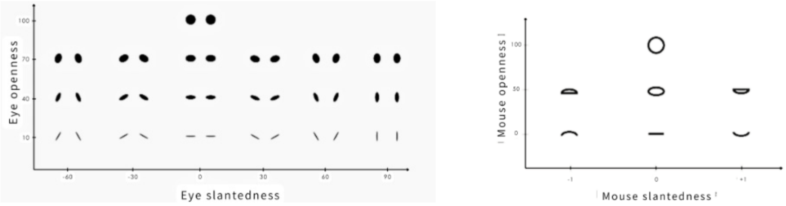


Figure 2: Left: transformation of eyes by each parameter; right: transformation of mouth by each parameter.

Thus, each facial expression is defined by four values: two parameters of the eyes and two of the mouth, namely slantedness and openness respectively.

CLASSIFICATION OF FACIAL EXPRESSION PATTERNS

The obtained expression patterns are classified by emotional category. For the emotional categories, we use the six basic emotions (happy, angry, sad, disgust, fear, and surprised) advocated by Ekman and many other researchers. In this article, we additionally utilizes a neutral (pleasant) emotion, displaying no emotion but showing a pleasant expression, and a neutral (unpleasant) emotion, showing no emotion but displaying an unpleasant expression, to research the facial expressions of neutral emotions. Clarification of the neutral face is important for robot faces, especially for humanoid robots without the function of forming facial expressions. In total, the eight emotional categories are defined.

Classification of facial expression patterns is conducted through an identification task. There are three rules for this task as follows: (1) the answerer must choose one emotion category for one face; (2) the answerer may adopt the same emotion category for more than one face; (3) the answerer does not need to select an emotion category if no category fits the face.

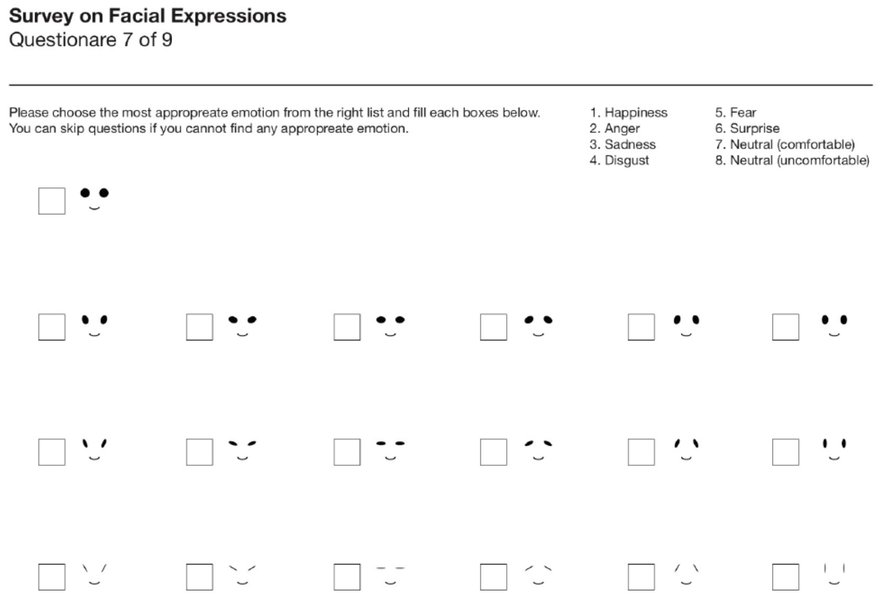
RESULTS

Our previous study was a comparative survey experiment involving university students in Denmark and Japan. The results indicated that there were virtually no cultural differences in the recognition of expressions of happiness, anger, sadness, and neutral emotions. In contrast, significant differences were observed in the recognition of disgust, fear, and surprise, suggesting that these emotions are more strongly influenced by cultural or contextual factors.

In this study, we conducted a follow-up investigation of our previous research and further analyzed the results.

We tallied responses that accounted for at least half (2/M) of the maximum number of emotions selected. We conducted a new survey of Japanese college students (B) and junior high school students (C). We compared these results with those from the previous survey, which included Japanese college students (A).

- There was significant overlap in the responses from (A), (B), and (C).
- Regarding fear, it was not included in the tally for any of the response groups (A, B, C), as no emotion received the most frequent responses.
- Regarding page 7 of the questionnaire, "happiness" was selected most frequently in all response groups (A, B, and C).


Survey on Facial Expressions
Questionare 7 of 9

Please choose the most appropreate emotion from the right list and fill each boxes below.
You can skip questions if you cannot find any appropreate emotion.

1. Happiness
2. Anger
3. Sadness
4. Disgust
5. Fear
6. Surprise
7. Neutral (comfortable)
8. Neutral (uncomfortable)

Figure 3: Page 7 of the survey form.

CONCLUSION

- These results appear to align with the arousal levels described in Russell's two-dimensional psychological space.
- Across all respondent groups, the seventh expression was selected as representing happiness. This is likely because the mouth is smiling.
- Regarding fear, the insufficient number of responses can be attributed to the fact that, within Russell's two-dimensional psychological space, this expression is similar to anger and surprise, which are in the same quadrant (arousal–dislike).

In this study, we conducted a supplementary survey in addition to the previous findings and compared the results among Japanese respondents.

The results showed that there were no significant differences between junior high school students and college students in Japan.

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