Determining Color and Blinking to Support Facial Expression of a Robot for Conveying Emotional Intensity

Min-kyu Kim, Hui Sung Lee, Member, IEEE, Jeong Woo Park, Su Hun Jo, and Myung Jin Chung, Senior Member, IEEE

Abstract—In the field of HRI, to take advantage of people’s innate ability of communication, researchers have thus far concentrated on facial expression in facilitating human robot communication. However, for the robot to express emotional intensity, other modalities such as gestures, movement, sound, and color are also needed. This paper suggests that the intensity of emotion can be expressed with color and blinking, which are applicable on robots via LED. Although color and emotion have certain relations, it is difficult to implement the findings of previous research in this area due to a lack of quantitative data. In this paper, we determined RGB values of color and blinking period to effectively express intensities of six basic emotions based on quantitative data. Color and blinking are implemented on an avatar and the intensities of emotions are evaluated through surveys with the avatar. It was found that color and blinking helped the avatar express emotional intensity of surprise, happiness, disgust, and anger. For fear, and sadness, the color and blinking did not play a significant role.

Index Terms—Color, Blinking, Emotional Intensity, Multimodality.

I. INTRODUCTION

Humans and robots will have a closer relationship in the future, and the interaction between them is expected to be more important. As an intuitive communication method is required for such interaction, numerous researchers have focused on the use of facial expression to allow robots to express emotion. It is possible to express basic emotions with facial expression alone [1]-[3]. However, the expression of the emotional category as such is not sufficient considering that people show not only their emotions but also the intensity of these emotions with various modalities. For example, when a person is only somewhat angry, she can make an angry face; however, when she becomes angrier, her face may turn red, or her behavior could become violent. Thus, we can say that people express the degree of emotion as well as the emotional category.

A situation where a robot plays a role of an assistant is an example of human-robot interaction. For example, when a person has an appointment, the robot simply notifies the user of the appointment 30 minutes in advance; however, it should raise the intensity of notification 10 minutes prior to the appointment, and it should show urgency 5 minutes before the appointment. From this example, we can see that the robot needs to express emotional intensity.

To express emotional intensity, robots can exploit multimodality as humans do. The robot can use LED (color), sound, movement, arm gestures, etc. for emotional intensity.

The relationship between color and emotion was researched by Valdez [5], Mahnke [6], Birren [7] and others. Valdez researched how the saturation and brightness of color affect PAD (Pleasure-Arousal-Dominance) [9]. Mahnke and Birren found that the principal colors induce certain emotions. However, previous works lack quantitative data, making it difficult to implement their findings on a robot.

Ekman [10] investigated how emotion influences autonomic nervous system activity. According to his results, anger, fear, and sadness accelerate the heart rate whereas surprise, happiness, and disgust do not significantly change the heart rate.

From those outcomes, we can predict that it will be possible for people to sense the emotional intensity of the robot through color and blinking.

Ogata exploited color to express emotion[11]. They associated colors with the hormone parameters which determine the emotional state of robot. However, they focused on expressing emotional category and did not evaluate the effectiveness for expressing emotional intensity, and the color value was not quantitative.

This paper researched color and blinking so that robots can express the intensity of emotion with LED. LED is an effective modality to express emotional intensity; LED is safe and cost-efficient because it does not have mechanically moving parts and it is applicable under diverse conditions.

We selected six basic emotions set forth by Ekman [4] (Surprise, Happiness, Disgust, Anger, Sadness and Fear) to express intensity. Color and blinking is implemented on the ears of an avatar which was designed on the basis of mascot-type robot, Doldori [3]. From survey results, it was found that it is possible to increase the intensities of four emotions (surprise, happiness, disgust, and anger) with color and blinking.
II. PROCEDURE FOR IMPLEMENTATION

In this work, color and blinking are used to express intensities of emotions, where the six basic emotions suggested by Ekman and Friesen [4] are employed. The procedures for determining RGB values of color and the blinking period for each emotion are as follows.

A. Determining Blinking Period for Emotions

From the research of Ekman [10] presented in Fig. 1, it is seen that emotion influences autonomic nervous system activity. Anger, fear, and sadness accelerate the heart rate whereas happiness, surprise, and disgust do not significantly change the heart rate. Such heart rate changes can be emulated by LED blinking in robots, which will help people perceive the robot’s emotion.

The blinking period was determined as follows. The human resting heart rate is 70~75bpm (beats per minute) on average. The heart rate is accelerated by 7~8bpm by anger, fear, or sadness, according to the results of Ekman. If this amount of change were applied, however, it would be difficult to distinguish the variance owing to the small increment. Thus, the change is exaggerated as follows: 20% faster (85bpm) than the resting heart rate for anger, fear, and sadness, respectively, and 20% slower (55bpm) than the resting heart rate of human for happiness, surprise, and disgust, respectively.

B. Determining RGB-values of Color for Emotions

Researchers have attempted to identify the relationship between color and emotion.[5]-[8] However, there is a lack of quantitative and detailed data in the literature to implement existing results on robots. Thus, this paper collected and analyzed previous outcomes and determined RGB values for emotions.

According to Valdez [5], saturation and brightness, rather than hue, of color impact the relationship between color and emotion. Valdez suggested (1)-(3) for the effects of saturation and brightness on PAD values (Pleasure-Arousal-Dominance) of emotion.

\[
P = 0.69 \times B + 0.22 \times S \\
A = -0.31 \times B + 0.60 \times S \\
D = -0.76 \times B + 0.32 \times S
\]  \( (1) \) \( (2) \) \( (3) \)

where, P, A, and D are pleasure, arousal, and dominance in the PAD scale, and B and S are brightness and saturation of color.

To use these equations, it is necessary to know the PAD values of emotions; however, this is not known precisely, because the PAD scale is not quantitatively defined. This paper uses the findings of Havlena [12] for PAD values of emotions as given in Table 1.

The pseudo-inverse matrix of (4) is then applied to the results of Valdez and Havlena in order to obtain the saturation and brightness of each emotion.

\[
\hat{x} = (A^T A)^{-1} A^T b
\]  \( (4) \)

where, \( A = \begin{bmatrix} 0.69 & 0.22 \\ -0.31 & 0.60 \\ -0.76 & 0.32 \end{bmatrix} \)

\[
b = \begin{bmatrix} P_i \\ A_i \\ D_i \end{bmatrix} \]

\[
\hat{x} = \begin{bmatrix} B_i \\ S_i \end{bmatrix}
\]

\[ i = \text{Surprise, Happiness, Disgust, Anger, Sadness, Fear} \]

where \( P_i, A_i, \) and \( D_i \) are pleasure, arousal and dominance values in the PAD scale, and \( B_i \) and \( S_i \) are brightness and saturation values for emotion.

From the above results of a linear least square regression, the positions of emotions on the brightness-saturation plane were identified, as shown in Fig. 2.

It is possible to determine the qualitative meaning of each axis of Fig. 2 (x-axis for brightness, y-axis for saturation); however, we cannot find the quantitative meaning.

![Fig. 1. Heart rate changes according to emotions [10]. Anger, fear and sadness accelerate the heart rate. Happiness, surprise, and disgust do not significantly change the heart rate.](image-url)
Furthermore, even if we can identify the meaning, it is almost impossible to realize the color exactly. In the case of an avatar, the color varies according to the used monitor, and in the case of LED, the color varies according to the products.

Thus, from the results of Fig. 2, six emotions are categorized into two sets. Happiness belongs to the category of bright and saturated, and the others (surprise, disgust, anger, sadness, fear) are categorized as dark and unsaturated, as presented in Table 2.

Three parameters, hue-saturation-brightness, are required to calculate the RGB values. Saturation and luminance values have been obtained thus far, and thus hue information is now needed.

Hues for emotions are extracted from the works of Mahnke [6] and Birren [7]. Both Mahnke and Birren discussed the relationship between color and emotion; however, they did not suggest detailed color information but only rough hue information. Mahnke and Birren associated color with basic emotions, as presented in Table 3.

Mahnke and Birren associated five out of six basic emotions with hues. They did not give the hue for surprise; yellow is used in this paper.

An avatar displayed on a monitor can show black; however, a LED cannot display black, because the all-turned-off-status of a LED is not black. Hues for emotion were chosen as given in Table 4 considering such constraints of LED.

From Table 2 and Table 4, the RGB values can be calculated. To calculate these values, numerical values of saturation and brightness are necessary; however, they cannot be found objectively. In this paper, we used 130 for high brightness, 240 for high saturation, 70 for low brightness and 150 for low saturation. These HSL (Hue, saturation, and luminance) values are then converted into RGB values [13]. The RGB value range is 0 to 255 so as to permit use with an avatar on a PC. The results of the calculation are given in Table 5.

III. EXPERIMENT METHOD AND RESULTS

A. Experiment Platform: Doldori’s Avatar

It is well known to robot researchers that there is an “uncanny valley” effect when robots’ appearance or behavior closely resembles that of a human. In this case, the robot can completely and suddenly lose its friendliness qualities. Therefore, a mascot type was developed. Doldori in Fig. 3, is the mascot type robot, which was modeled with 5- to 6-year-old child’s facial proportions [3].

The control points (CPs) of Doldori are organized on the basis of the AU’s that can realize the six basic expressions. Those CPs are shown in Fig. 4. Eyebrow has 1 DOF for each, eyelid has 2 DOF for each, and mouth has 4 DOF. In total, Doldori contains 10 DC motors, which are controlled by DSP.

### Table 2

<table>
<thead>
<tr>
<th>Category</th>
<th>Emotions</th>
<th>Brightness</th>
<th>Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright and Saturated</td>
<td>Happiness</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Dark and Unsaturated</td>
<td>Surprise, Disgust, Anger, Sadness, Fear</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Mahnke’s Result</th>
<th>Birren’s Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise</td>
<td>N/A*</td>
<td>N/A*</td>
</tr>
<tr>
<td>Happiness</td>
<td>Yellow, Red</td>
<td>Yellow</td>
</tr>
<tr>
<td>Disgust</td>
<td>Red, Black**</td>
<td>N/A*</td>
</tr>
<tr>
<td>Anger</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Sadness</td>
<td>Violet, Blue, Brown, Violet</td>
<td>Blue</td>
</tr>
<tr>
<td>Fear</td>
<td>Black**</td>
<td>Blue</td>
</tr>
</tbody>
</table>

* For this emotion, an appropriate color was not noted  
** Black cannot be expressed with LED as the all-turned-off-status of LED is not black

### Table 4

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Surprise</th>
<th>Happiness</th>
<th>Disgust</th>
<th>Anger</th>
<th>Sadness</th>
<th>Fear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hue</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Red</td>
<td>Red</td>
<td>Violet</td>
<td>Blue</td>
</tr>
<tr>
<td>Luminance</td>
<td>70</td>
<td>70</td>
<td>130</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Saturation</td>
<td>150</td>
<td>150</td>
<td>240</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Hue*</th>
<th>Luminance*</th>
<th>Saturation*</th>
<th>RGB value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise</td>
<td>40</td>
<td>70</td>
<td>150</td>
<td>(154, 154, 27)</td>
</tr>
<tr>
<td>Happiness</td>
<td>40</td>
<td>130</td>
<td>240</td>
<td>(255, 255, 21)</td>
</tr>
<tr>
<td>Disgust</td>
<td>0</td>
<td>70</td>
<td>150</td>
<td>(121, 28, 28)</td>
</tr>
<tr>
<td>Anger</td>
<td>0</td>
<td>70</td>
<td>150</td>
<td>(121, 28, 28)</td>
</tr>
<tr>
<td>Sadness</td>
<td>200</td>
<td>70</td>
<td>150</td>
<td>(121, 28, 121)</td>
</tr>
<tr>
<td>Fear</td>
<td>160</td>
<td>70</td>
<td>150</td>
<td>(27, 27, 154)</td>
</tr>
</tbody>
</table>

* Value of hue, luminance and saturation ranges from 0 to 240  
** Each of RGB value ranges from 0 to 255

Fig. 2. Positions of Emotions on Brightness-Saturation Plane. While it is possible to determine the qualitative meaning of each axis, the quantitative meaning cannot be exactly identified.
Doldori’s ears are made of semi-transparent plastic material. A RGB-LEDs is installed inside each ear. In this experiment, not the actual robot, but the avatar of Doldori was used. The avatar of Doldori, shown in Fig. 4, has the same appearance as the actual robot.

B. Experiment Method

The RGB values for emotions were determined in Chapter II. These results are applied to the ears of Doldori’s avatar, as in Fig. 5, and a survey was carried out with this avatar.

The background of the avatar was painted with mid-tone gray (RGB values: 128, 128, 128), and the ears flash with RGB values corresponding to each emotion in Table 5. When the color of emotion is not painted, in other words, when the LED is turned off, dark gray (RGB values: 64, 64, 64), which has half brightness of the background, is used for the ears. The emotional category was exposed to the participants at the left-bottom of the avatar. An image of a happy avatar when the LED is turned off is shown in Fig. 5 as an example.

The six emotions of Ekman and Friesen were employed, and the geometric intensities of the facial expressions were 100% and 70%, as shown in Fig. 6 and Fig. 7. The expressions of 70% geometric intensity are made by moving each control point by an amount of 70% compared to the 100%-intensity expression. Three queries for the six emotions, 18 questions in total, were presented to the participants, as outlined in Table 6.

In a given question, two images, one from the reference-image set and the other from the test-image set, were displayed for at least two seconds. The following question was then presented, in Korean, to the participants: “Between the image on the left and the image on right, which one presents a more intensive emotion?” Thus, the participants were required to evaluate the perceived intensity of emotion. The answers were “Left image”, “I do not know”, and “Right image”, also in Korean. Positions of the reference

and CPLD. Doldori’s ears are made by semi-transparent plastic material. A RGB-LEDs is installed inside each ear.

In this experiment, not the actual robot, but the avatar of Doldori was used. The avatar of Doldori, shown in Fig. 4, has the same appearance with the actual robot.

**Fig. 3.** Mascot-type facial robot, Doldori: It was designed in order to express six basic emotions. Eyebrow has 1 DOF for each, eyelid has 2 DOF for each, and mouth has 4 DOF. In total, Doldori contains 10 DC motors. Each ear contains a RGB LED.

**Fig. 4.** Avatar and configuration of the CPs in Doldori. It is possible to create CP variation through the use of slide bars on the right side: $a_1$ is the rotation of the brows; $a_2$, $a_5$, $a_6$, $a_8$, and $a_9$ are the vertical movements of the inner eyelids, that of the outer eyelids, and that of the upper lip, the lower lip, the lip corners, and the lower lid, respectively; $a_{10}$ is used only in this avatar to test the effects of CPs and is not adopted to an actual robot system.

**Fig. 5.** Sample image of avatar for survey. The background is painted mid-gray. The category of emotion is displayed on the left-bottom.

**Fig. 6.** Six basic facial expressions with 100% geometric intensities.

**Fig. 7.** Six basic facial expressions with 70% geometric intensities. This facial expression was made by moving each control point in the amount of 70% compared to 100% expression in Fig. 6.

<table>
<thead>
<tr>
<th>Table 6 Categories of Survey Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Image</td>
</tr>
<tr>
<td>100% Expression W/O LED</td>
</tr>
<tr>
<td>100% Expression W/O LED</td>
</tr>
<tr>
<td>100% Expression W/O LED</td>
</tr>
</tbody>
</table>
image and the test image were exchanged randomly.

Each answer was scored as 2 points for choosing the test image, 1 point for choosing “I do not know”, and 0 points for choosing the reference image.

C. Experiment Results

Using the 18 questions noted above, 30 participants were surveyed. All of the subjects were in their 20s or 30s in age.

The average scores for each question are depicted in Fig. 8. If the intensity of the emotion is 0, it means every participant evaluated the intensity of the test image as being lower than that of the reference image. If the intensity of the emotion is 1, participants perceived the emotional intensities of the reference image and test image as being equivalent. If the intensity of the emotion is 2, every participant evaluated the intensity of the test image as being greater than that of the reference. As the intensity of the reference image (100% W/O LED) was treated as 1, the levels of emotional intensities of the reference images are shown as 1 in the survey results shown in Fig. 8.

For the emotions of surprise and happiness, color and blinking substantially increased the intensity of the emotion. Assuming the intensity of 100% expression W/O LED as 1, that of 100% happiness W/ LED was 1.63 and that of 100% surprise W/ LED was 1.73. For 70% expression of surprise and happiness, color and blinking also considerably raised the intensity. For disgust of 100% intensity, color and blinking increased the emotional intensity up to 1.30. Anger presents interesting results: in the case of 100% expression of anger, color and blinking increased the emotional intensity of anger up to only 1.23, whereas in the case of 70% expression (intensity 0.17 W/O LED), color and blinking raised the emotional intensity up to 1.17, beyond the intensity of 100% expression W/O LED, close to the intensity of 100% anger W/ LED. The results of anger, which showed that color and blinking rather than geometric intensity have a significant impact, appears to have some relation with the characteristic that the human face may turn red when the person is angry [14]. Because of this phenomenon, the participant may naturally associate anger with the color red. Although color and blinking gave an increase of 0.50 for sadness of 70% expression, similar to the case of anger, color and blinking provided an increase of only 0.17 in the case of 100% sadness. The emotional intensity of fear was hardly affected by color and blinking. Fear of 70% expression was affected slightly by color and blinking; however, color and blinking faintly lowered the emotional intensity in the case of 100% expression of fear.

To evaluate the results of 100% W/ LED cases, hypothesis tests in Bernoulli population as shown in (5) were considered.

\[
H_0 : p \leq p_0 \quad \text{versus} \quad H_1 : p > p_0 \quad (5)
\]

where \(p_0\) is the probability of half-success which will be described below and \(p\) is the probability of success. In order to claim that the color and blinking is effective for expressing emotional intensity, \(H_0\) needs to be rejected.

The Bernoulli population originally deals with the events that have only two cases of results: success and failure. However, in our case, there exist three cases of result: 1) Reference image conveys more intense emotion, 2) The intensities of reference image and test image are similar and 3) Test image conveys more intense emotion. The first case is a failure. The second case is a success. The second case that the intensities of reference image and test image can be treated as half-success. Two half success is transformed into one success and one failure. One half-success was rounded off, treating as one success. In short, the probability of half-success (the intensity of reference image) was considered as 0.5, where the probability of success was treated as 1. As the objective is to find expressions which are more effective than the reference image, the hypothesis test in (5) should compare with respect to the level that has the intensity of reference (0.5).

The p-value is calculated as shown in (6)

\[
T = \frac{X - Np_0}{\sqrt{Np_0(1-p_0)}}
\]

where \(X\) is the number of successes, \(N\) is the number of trials, and \(p_0\) is the probability of half-success.

\[
p-value = 2(1 - P(T < |t|))
\]

The p-value is then compared with the level of 0.05. Table 7 shows the p-values for each emotion.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>No. of Successes for 100% W/ LED case</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surprise</td>
<td>26</td>
<td>0.00</td>
</tr>
<tr>
<td>Happiness</td>
<td>24</td>
<td>0.00</td>
</tr>
<tr>
<td>Disgust</td>
<td>20</td>
<td>0.08</td>
</tr>
<tr>
<td>Anger</td>
<td>19</td>
<td>0.10</td>
</tr>
<tr>
<td>Sadness</td>
<td>18</td>
<td>0.18</td>
</tr>
<tr>
<td>Fear</td>
<td>15</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Fig. 8. Results of survey: The Y axis is the intensity of emotion relative to 100% W/O LED, of which the intensity was treated as 1. Color and blinking could raise the intensities of emotions in the case of surprise, happiness, disgust, and anger by more than 20%. Color and blinking did not play a significant role for fear and sadness.
\[ p - value = P(B(n, p_0) \geq x) = \sum_{i=x}^{n} \binom{n}{i} p_0^i (1 - p_0)^{n-i} \]  

(6)

where, \( n \) is the number of samples (in this case: 30), \( x \) is the number of successes. The p-values of the results are shown in Table 7. From the p-values, the hypothesis \( H_0 \) is rejected for surprise, happiness, disgust and anger at the 10 percent level of significance, which means that it is possible to claim that the emotional intensities are increased for the four emotions.

In summary, from the survey, it was found that color and blinking can be usefully applied to express intensity of emotion. Color and blinking raised the emotional intensity of all six emotions in the case of 70% expression, by an amount of 0.55 on average. In the case of 100% emotional expression, color and blinking increased the emotional intensity of surprise, happiness, disgust and anger. However, color and blinking did not significantly enhance the emotional intensities for fear and sadness; other modalities such as sound, arm gestures, etc. may escalate the intensities of these emotions.

IV. CONCLUSION

This paper suggested RGB values of color and blinking period in order to effectively express the intensities of six basic emotions. Color and blinking were implemented and evaluated through a survey with the avatar. From the survey, it was found that color and blinking can increase emotional intensities for four emotions (surprise, happiness, disgust and anger). For fear and sadness, color and blinking did not significantly improve the emotional intensity. Other modalities such as sound or gestures may also be needed to express intensities of fear and sadness. It was difficult to distinguish the effectiveness of color and blinking separately because the effects of color and blinking together were evaluated at the same time.

REFERENCES