International Journal of Innovative Computing, Information and Control
Volume **20**, Number **1**, February **2024**

ICIC International ©2024 ISSN 1349-4198
pp. **61–73**

THE MODEL TO EXPRESS EMOTIONS FOR ROBOTS USING COLORS AND BLINKS

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Received April 2023; revised September 2023

Abstract. *Communication robots are useful in nursing care and mental health care. Emotional expressions are essential for them to communicate well with humans. However, many of the current methods of expression emotions for robots have the problem that they can only use by the robot that is shaped of living things or that can speak. There exists a method of expression emotions that use colors and the blinks for robots without these features. However, the simple and clear model has not been proposed, yet. In this paper, we overcome these problems and propose a method to express 8 emotions with 8 different colors and 3 levels of intensity with different blink speeds. Then, we evaluated this model for Japanese young people. Without using the face or the limbs, the proposed method can express emotions simply and exactly.*
Keywords: Robot, Emotion, LED, Color, Blink

1. **Introduction.** Nowadays, the robots that can be partner with human get attention. For example, some people have social anxiety like to speak more with robot having metal body than with human [1]. For the sake of them, a counseling method using robots was considered [2]. Besides, the robot partner that helps improve elderly people's mental health instead of person was proposed [3, 4]. Furthermore, pet robot is also utilized. People could get positive effects from contacting with animal [4, 5]. There exist some studies to substitute pet robots for animals in order to get the effect [5]. Altogether, the robots that can become partner with person are needed in various situation.

If the robot cannot communicate with human, it could not become a partner. Human communication will be done by language, facing expression, and motions. These bring us emotions. Expressing emotions by robots is necessary so that the robots take the better communication with a human, since people can predict these robots' actions and feel an affinity with these by expressing emotions [6].

Expressing the emotion of robots, some methods were often used, for example, language, facing expression, and motions. These methods are good for expressing emotion in terms of likeness of human. However, these are restrictive. For instance, it is necessary for robots to understand language in order to use language. Moreover, facing expressions require that

DOI: 10.24507/ijicic.20.01.61

the robots can move their eyes, mouth, and eyebrow. Moving expressions also require to move hands or legs freely. Hence, these methods of expressing emotion are not suitable for simple robots. The simple robots should adapt other method. For example, it is known that colors and emotions are related [7, 8]. Thus, the method using color is examined [6, 9, 10, 12].

Sugano and Ogata proposed a method that uses colors of the robot's head with other expression. Their robot expresses fear by blue, anger by red, and expectation and pleasure by yellow [9]. Gotoh et al. proposed a method that uses color of the head and the cheek with facing expression [10]. Their robot expresses anger by glowing red on its head, joy by glowing green on its head, and sadness by glowing its cheek. They thought that using color as one of the expressions, but did not consider using only color. The reason is that these researches express some emotions only. Therefore, they cannot express various emotions. This problem is important to solve.

In order to solve this problem and to express various emotions, we must consider to classify emotions. There exist some methods to classify emotions. For example, Plutchik defined 8 basic emotions: anger, anticipation, joy, trust, fear, surprise, sadness, and disgust [11]. He also defined those 24 emotions, which have three levels of strength to each 8 emotions as primary emotions. He also thought that all emotions are made by mixture of those primary emotions, just like the colors made by mixture of primary colors. Therefore, it is thought if we make the model of primary emotions, we can make the model expressing various emotions.

Yamauchi et al. [12] focused on dynamic color change itself, 24 emotions that proposed by Plutchik express as the only dynamic color change. This is superior to the point of applying various robots. The model is not practical since it uses just average of the result of study. For example, some patterns are similar, and different colors are used by the same basic emotions. Furthermore, the model could not express disgust correctly. In addition, as intensity, they said that the pattern that blink period is short and brightness is rapid expresses intensive emotion, but some emotions did not apply to that.

In this paper, in order to overcome these problems, we propose a model of expressing the 24 emotions proposed by Plutchik. This model is based on Yamauchi et al.'s model [12] and changed. First, we change all the patterns in this model in order to be distinguished visually. Next, we set rules for this model. Specifically, the basic emotions are expressed in color, and the strength of the emotion is expressed in the speed of blinking. These will improve the problem of their model, that there are similar models and it is difficult to use. In addition, we will re-evaluate this model. First, we check whether or not, basic emotions can be expressed by colors. Next, we check whether or not, the intensity of emotion can be expressed by the speed of blinking. If both give good results, then the model can express the 24 emotions. Moreover, if it is possible to express only with colors and blinking, it means that a simpler and cheaper emotion expression model can be created. In other words, it may be able to contribute to the creating of better communication robots.

This paper is organized as follows. Section 2 describes the model of previous research. In Section 3, we explain the model used in experiment. Section 4 gives experimental method. In Section 5, we summarize experimental results. In Section 6, we give some discussions from result in Section 6. Finally, Section 7 gives concluding remarks.

2. **The Model by Yamauchi et al. and the Purpose of This Paper.**

In this section, we summarize the model by Yamauchi et al. [12] and explain the problem and motivation of this paper.

Yamauchi et al. [12] proposed the model of expression for robot by dynamic color change. The model created by them is shown by Table 1. The color names of that table are the names in Munsell color system that correspond to the hue. This model was decided by experiment. 41 people (20 men and 21 women) participate in the experiment. Participants set the parameters to suit each presented emotion. The presented emotions are 24 emotions proposed by Plutchik. They watched the emotion names displayed on the tab and set the pattern to match. They converted the hue value to a unit vector as the argument, and treated the argument of the synthetic vector as the average of the hues. For waveforms, they just averaged the experimental values. When the results were evaluated, a significant difference was observed, so the average value was determined as the model. As a result, they obtained the result shown by Table 1. Moreover, short periods and rapid time change of luminance express strong emotion, and long period and gentle time change of luminance express weak emotions.

Table 1. Proposed emotion expression model [12]

Basic emotion	Emotion	Hue	Color name	Period [ms]	Waveform [%]
Anger	Rage	1	R (Red)	312	14
	Anger	4	R (Red)	896	20
	Annoyance	6	R (Red)	793	28
Anticipation	Vigilance	12	R (Red)	913	12
	Anticipation	54	YR (Yellow Red)	1702	37
	Interest	42	YR (Yellow Red)	1154	32
Joy	Ecstasy	42	YR (Yellow Red)	748	24
	Joy	37	YR (Yellow Red)	1123	35
	Serenity	154	G (Green)	4035	88
Trust	Admiration	57	Y (Yellow)	1487	43
	Trust	109	GY (Green Yellow)	2707	62
	Acceptance	108	GY (Green Yellow)	2601	50
Fear	Terror	280	P (Purple)	1220	40
	Fear	279	P (Purple)	1377	46
	Apprehension	225	B (Blue)	2387	64
Surprise	Amazement	24	YR (Yellow Red)	485	15
	Surprise	31	YR (Yellow Red)	747	10
	Distraction	19	YR (Yellow Red)	491	20
Sadness	Grief	242	PB (Purple Blue)	3124	78
	Sadness	245	PB (Purple Blue)	3310	73
	Pensiveness	248	PB (Purple Blue)	3954	80
Disgust	Loathing	312	RP (Red Purple)	1383	44
	Disgust	318	RP (Red Purple)	1645	42
	Boredom	251	PB (Purple Blue)	3474	58

After the model is created, they performed next experiment that evaluates the model. Participants are 20 people (18 men and 2 women), different from the previous experiment. This experiment examined the validity of this model. The pattern of strong emotions except for grief and admiration is shown and evaluated by them. Since grief and admiration are not suitable for representative, they used pensiveness and acceptance. They presented participants with patterns and asked them to rate how well they matched each basic

emotion on a five-point scale. The results were evaluated by multiple comparisons. As a result, ecstasy, acceptation, pensiveness and terror express exactly and uniquely. Rage, vigilance and amazement have problem with uniqueness, and loathing does not express exactly.

The purpose of this paper is to overcome problems in [12] and propose a new model to express emotion by using colors and blinks.

3. The Model of Emotions.

In this section, we propose a new model of emotion by using colors and blinks.

3.1. Robot.

Figure 1 shows the robot used for the experiment. There exists color development mechanism in the robot made of acrylic. USB cable connects the microcomputer and the external PC. LEDs are controlled by operating the PC. The target of this experiment is that the robot does not have a shape of creatures. Therefore, unnecessary parts are not attached to the robot in order to pay attention to the colors and blinks.

FIGURE 1. Robot appearance

There is color development mechanism consisting of RGB LED and microcomputer in the inside of the robot. RGB LEDs (OSTA5131A) are common cathode type that red, green and blue are united. When an electrical current of 20 [mA] flowed in one LED, red, green, and blue emit wavelength 635 [nm], 525 [nm] and 470 [nm]. Microcomputer (Arduino UNO) carries out PWM (pulse width modulation) control. Each three colors can change 256 grades between 0 [V] and 5 [V]. PNP type transistors (2SA1015) are used in order to control five LEDs connected in series at the same time.

Microcomputer and PC are connected by serial communication. Each patterns can be chosen by using Graphical User Interface (GUI) on the PC as shown in Figure 2. Pushing the buttons, the value that assigned to emotions convey to the microcomputer. According to the value, parameters set in microcomputer are called and LEDs blink.

3.2. Color and blink pattern.

The proposed emotion model is summarized in Table 2. The color names in this table also use Munsell color system. Color (R, G, B) expresses the parameter of PWM control given to the LEDs. The LEDs are common cathode type. Since it is controlled by PNP type transistors, they turn off when it is 255 (5 [V]) and brightest when it is 0 (0 [V]). The colors of 8 basic emotions are shown in Figure 3. The model is created to refer to the model by Yamauchi at al. [12]. The rules of creating model are as follows.

- The same group of fundamental emotions determined the same color.
- In each group of fundamental emotions, strong emotions determined shorter period of the blink than weak emotions.

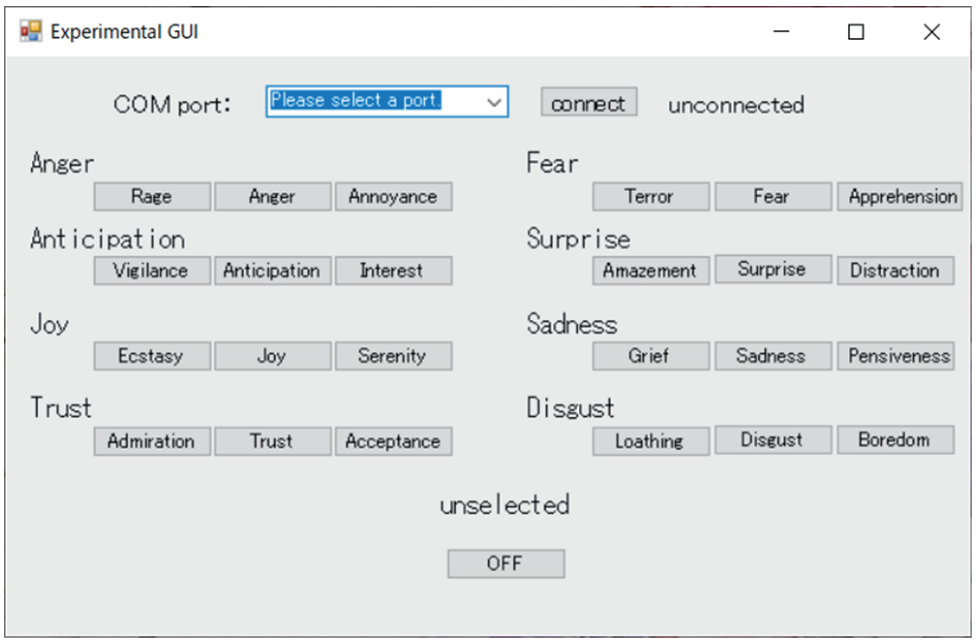

FIGURE 2. GUI for color control

TABLE 2. The model of 24 primary emotions

Basic emotion	Emotion	Color (R, G, B)	Color name	Period [ms]
Anger	Rage	(0, 255, 255)	R (Red)	300
	Anger			550
	Annoyance			800
Anticipation	Vigilance	(50, 220, 255)	YR (Yellow Red)	900
	Anticipation			1300
	Interest			1700
Joy	Ecstasy	(0, 150, 255)	Y (Yellow)	750
	Joy			1100
	Serenity			1450
Trust	Admiration	(150, 0, 255)	G (Green)	1500
	Trust			2100
	Acceptance			2700
Fear	Terror	(150, 255, 100)	PB (Purple Blue)	1200
	Fear			1800
	Apprehension			2400
Surprise	Amazement	(0, 230, 255)	YR (Yellow Red)	500
	Surprise			625
	Distraction			750
Sadness	Grief	(255, 255, 0)	B (Blue)	2500
	Sadness			3500
	Pensiveness			4000
Disgust	Loathing	(50, 255, 150)	RP (Red Purple)	1400
	Disgust			2450
	Boredom			3500

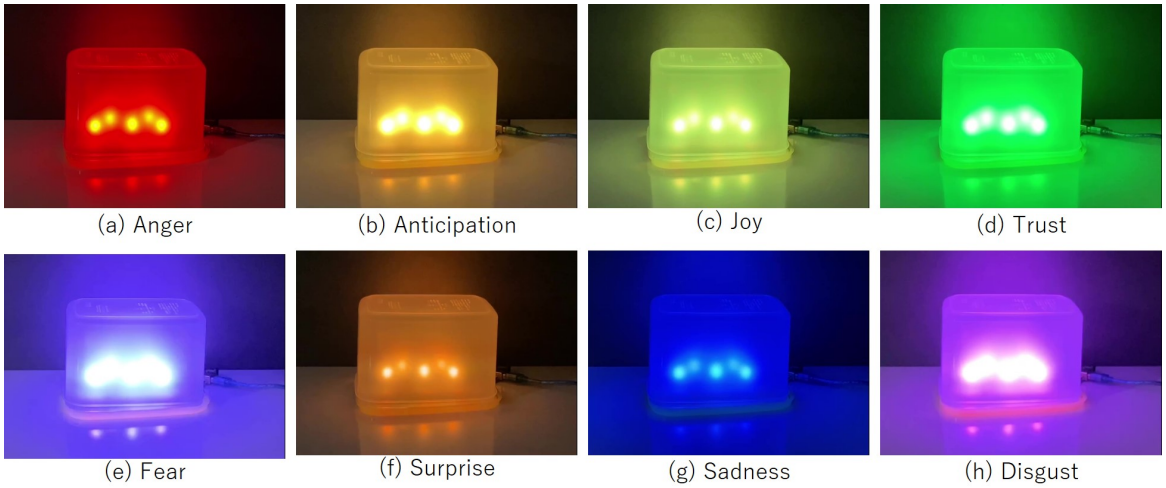

FIGURE 3. The model of basic emotions

- All emotions could be distinguished by looking.

Experiment by Yamauchi et al. [12] uses dynamic color change, namely color, period of the blink, and waveform. They insist that the influences by waveform are smaller than another factor. Therefore, this model does not consider waveform, and uses ON and OFF.

In their model, anticipation, joy, and surprise use YR (Yellow Red). Because they may not be identified, the color of joy is change to Y (Yellow). For the similar reason, the colors of fear and sadness are changed. Regarding disgust, they express that it cannot be expressed, but since there is no other suitable color, PR (Purple Red) is used in this study.

4. **Experimental Method.** In this section, we explain experimental method in order to clarify the effectiveness of the proposed model.

Two experiments are performed for 21 participants of 10 men and 11 women from 19-22 years old. All participants are Japanese. In this experiment, the participants' characteristics (country, age, etc.) were limited to a narrow range. This is because these characteristics are likely to make a difference. In other words, we thought that the results would be difficult to understand due to the large variability. If we get good results in a narrow range, you can say that people with similar characteristics feel the same emotions. In that case, we can conclude that it is possible to do re-experiment with the robot's target and create a good model. Therefore, in order to see trends, we first conducted experiments in a narrow range.

Experiment 1: research on relations between emotion and color
Experiment 2: research on relations between intensity and blink

Experiment 1 evaluates the differences between basic emotions. On the other hand, experiment 2 evaluates the differences between grades. The experiments are performed in dark room so that they can distinguish colors. The robot could be operated from PC by connecting the robot and PC with USB cable. The participants receive the answer sheets and received to the exposition. After that, they are asked to answer the questions on watching the robot.

4.1. **Experiment 1.** In this subsection, experimental method for experiment 1 is explained.

Experiment 1 is performed to research the relations between emotions and colors. First, one pattern of the patterns of basic emotions (anger, anticipation, joy, trust, fear, surprise,

sadness, disgust) is shown. Then, the participants evaluate it as 8 basic emotions with five grades (5. Very-suited, 4. Suited, 3. Not-sure, 2. Not-very-suited, 1. Not-suited). After they evaluate, next pattern is shown. The patterns are shown at random. The experiment 1 finishes when all 8 patterns are shown.

4.2. **Experiment 2.** In this subsection, experimental method for experiment 2 is explained.

Experiment 2 is performed to research the relations between intensity of emotion and speed of blink. Participants watch the strong emotion and weak emotion belonging to the same group of basic emotions. Then, they are asked to answer which emotions felt that express the strong emotions. Specifically, in the case of anger, they watch two of rage and annoyance, and are asked to answer which emotions felt that express rage. It is random whether the strong emotions or the weak emotions are shown first. Experiment 2 is performed after experiment 1, and in order of anger, anticipation, joy, trust, fear, surprise, sadness, and disgust.

5. **Experimental Result.** In this section, experimental results are summarized.

5.1. **Experiment 1.** Experimental results for experiment 1 are summarized in Figure 4. The abscissa of the graph is the evaluation emotions, and the ordinate represents the average of the evaluation value of presentment emotions. In other words, when the evaluation value is almost 5, many people felt that the presentment emotions expressed the evaluation emotions. Conversely, when the evaluation value is almost 1, many people felt that the presentment emotions did not express the evaluation emotions.

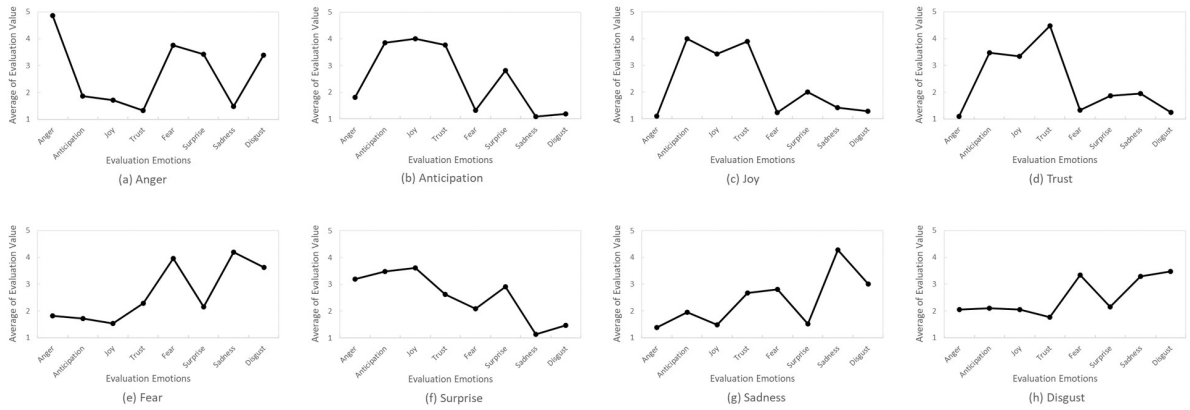

FIGURE 4. The result of experiment 1

As for some feelings, the presentment emotions accord with the emotions that average became the highest of the evaluation value: anger, trust, sadness, and disgust. On the contrary, anticipation, joy, fear, and surprise are not accorded. About anticipation, the average of joy became highest. Alternatively, the average of anticipation becomes highest about joy. Additionally, these two are the emotions that many people answered that they suit anticipation, joy and trust. As for trust, it is trust to be the highest in the average, but the average of anticipation and joy are also high. Therefore, the three emotions are likely to be confused. About fear, the average of sadness become the highest. However, as for sadness, the average of fear is not high. Therefore, fear is likely to be confused with sadness, but sadness is not likely to be confused and is exactly expressed. In addition, as for disgust, it is disgust to be the highest in the average, but the average of fear and sadness are also high, so that it is likely to be confused. About surprise, the average

of anger, anticipation, and joy are higher than surprise. This pattern is likely not to be expressed surprise.

In order to clarify whether or not, significant difference can be seen, one-way analysis of variance is performed for 8 emotions. Table 3 shows the p-value. As for all emotions, there are significant differences ($p < .01$). However, one-way analysis of variance checks whether there are the significant differences between two factors, and it does not know which two factors have differences. Because of this, multiple comparison is performed to check it between all elements. In this paper, Tukey's test is performed and the result is shown by Table 4. The cell where * is written is a part which significant difference is seen ($p < .05$). This model is likely to be confused with other emotions for all emotions, could not be expressed exactly. However, anger, fear, sadness, and disgust could be expressed roughly.

TABLE 3. P-value of basic emotions by one-way analysis of variance

Basic emotions	P-value	Basic emotions	P-value
Anger	1.25×10^{-28}	Fear	9.92×10^{-22}
Anticipation	3.74×10^{-30}	Surprise	2.94×10^{-11}
Joy	4.94×10^{-37}	Sadness	2.26×10^{-16}
Trust	1.39×10^{-35}	Disgust	1.16×10^{-6}

TABLE 4. P-value of basic emotions by Tukey's test

	Evaluation emotions							
Presentment emotions	Anger	Anticipation	Joy	Trust	Fear	Surprise	Sadness	Disgust
Anger	–	*	*	*			*	
Anticipation	*	–			*		*	*
Joy	*		–		*	*	*	*
Trust	*			–	*			
Fear	*	*	*	*	–	*		
Surprise						–	*	
Sadness	*	*	*	*	*	*	–	
Disgust	*	*	*	*				–

Additionally, Figure 5 shows the result that is separated by gender. According to Figure 5, there are many parts that differences are not seen in men and women. However, there are differences in surprise when anticipation and surprise are presented. There are also differences in disgust when anger and disgust are presented. Therefore, t-test is performed in order to confirm whether significant difference is seen. P-value of surprise when anticipation is presented is 0.0056, it of surprise when surprise is presented is 0.0054, and it of disgust when anger is presented is 0.0040. There are significant differences in these cases ($p < .05$). Moreover, p-value of disgust when disgust is presented is 0.064. The value is more than 5%, and there is not significant difference. However, people who chose 5 (Very-suited) as disgust are five people, and all the members are women. As a result, women feel that expressed surprise in YR (Yellow Red), and feel that expressed disgust in R (Red) and RP (Red Purple) compared with men.

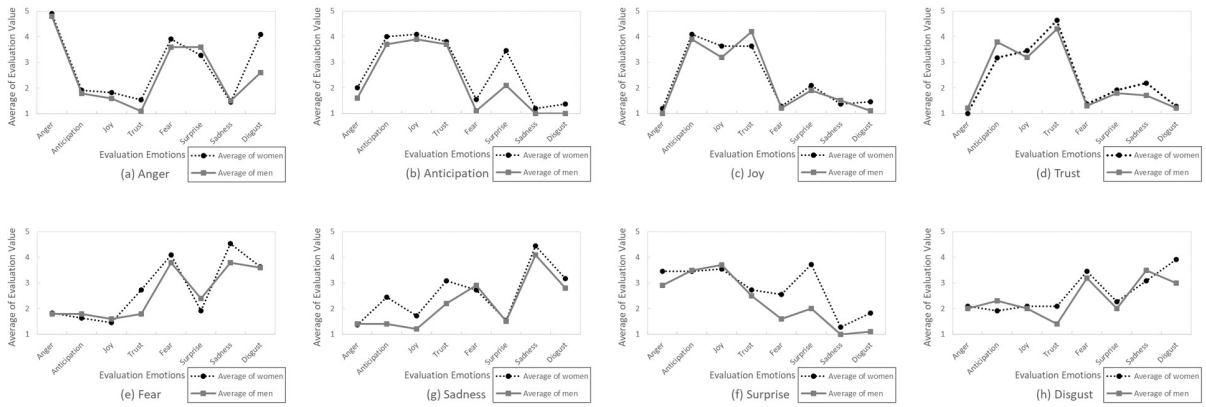

FIGURE 5. The result of experiment 1 (Gender difference)

5.2. **Experiment 2.** In this subsection, experimental results of experiment 2 are explained.

Figure 6 shows the result of experiment 2. The abscissa of the graph is the basic emotions to belong of the presentment emotions, and the ordinate represents the percentage of people who choose fast pattern. As anger, anticipation, and joy, many people felt that fast pattern expresses the strong emotions. Conversely, approximately 80% people chose a slow pattern as strong emotion about sadness. Therefore, the faster periods express the stronger emotions for anger, anticipation, and joy; the slower periods express the stronger emotions for sadness. However, the percentage of trust, fear, disgust is about 60%. It does not clear which speed of blink expresses strong emotions for these emotions.

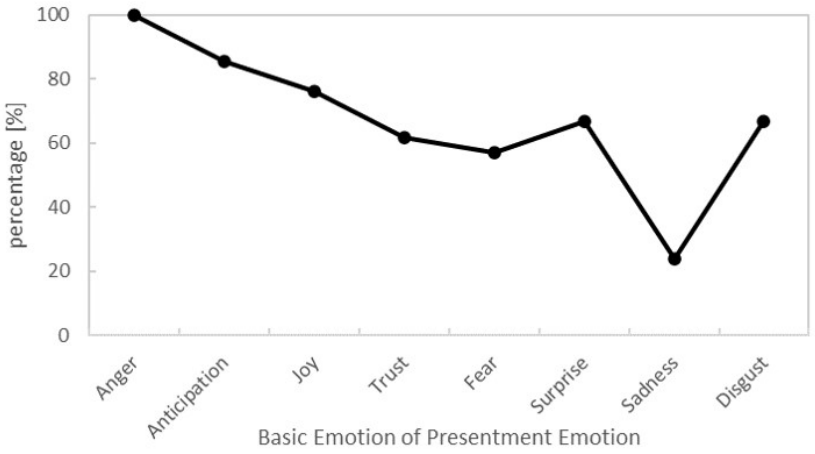

FIGURE 6. The percentage of the people who chose fast pattern for strong emotions

6. **Discussion.** Firstly, we discuss about 8 basic emotions.

Anger, trust, sadness, and disgust can express in this model. Anticipation and joy is likely to be confused. However, according to Plutchik, anticipation and joy are placed next to each other in a circle and are similar emotions [11]. Therefore, it is not such a serious problem. Fear and sadness are also placed next to each other with surprise in between, and since they are similar emotions and have similar patterns, this is also not a serious issue. From the above, the patterns of anger, anticipation, joy, trust, fear, sadness and disgust seem appropriate. By and large, it can be said that patterns with different

colors can be distinguished in this experiment. Conversely, patterns with similar colors but different blinking periods are not very distinguishable. Confusion of surprise with anger, anticipation and joy seems to have occurred due to the above. Conversely, these results suggest that easily confused emotions are emotions that participants feel as similar. In other words, they feel anticipation, joy, and trust are similar. They also feel fear and sadness are similar. This result also allows verification of Plutchik's wheel of emotions. Anticipation, joy, and trust are neighboring emotions in Plutchik's wheel of emotions. This is appropriate as it fits with this study. However, there is a surprise between fear and sadness. This order is not correct. However, this is the case of the young Japanese who conducted the experiment this time, and it does not mean that Plutchik's wheel of emotions is inappropriate.

Additionally, this experiment is adjusted to include approximately equal numbers of men and women to examine gender differences. Although there is no gender difference for the most part, there is a large difference in surprise and disgust. Women feel that expressed surprise in YR (Yellow Red), and feel that expressed disgust in R (Red) and RP (Red Purple) compared with men. Regarding disgust, different from Yamauchi et al.'s experiment, the result is that expression is possible. Therefore, we focused on the number of men and women in their study. In the experiment of them, there are many men than women at the experiment to evaluate model although there are men same number of women at the experiment to create model. The reason why disgust cannot express exactly is considered to be as above. The pattern that men feel that expressed disgust is not clear, but it may be different from that of women. Other papers do not mention differences between men and women. However, women tend to be more sensitive to color than men [7, 8]. Therefore, this result may have occurred. However, the detailed mechanism has not been clarified. Further experiments are required.

Secondly, we discuss about the relation between intensity of emotions and blink periods. The emotions that a fast pattern is chosen as strong emotions are anger, anticipation and joy. On the other hand, approximately 80% people chose a slow pattern as the sadness. As the result, it turns out that fast patterns are not always expressing the strong emotions. This conclusion is different from the conclusion by Yamauchi et al. [12]. As a tendency, fast patterns express the strong emotions in positive emotions. Conversely, slow patterns express the strong emotions in negative emotions. On the other hand, about the fast patterns of the basic emotions, the faster patterns express the stronger emotions. Conversely, the slower patterns express the stronger emotions about the slow patterns of the basic emotions. In this study, the percentage of trust, fear, surprise and disgust are about 60%, so these emotions are not asserted which speed of blink expresses strong emotions. It is almost blink speeds of these emotions exclusive of surprise. The speed of basic emotions of three these emotions is around 2000 [ms]. In the case of these periods, there is a possibility that it is difficult to express the intensity of emotions with the speed of the blink. As for surprise, it is thought that the result is obtained because the color could not express surprise. On balance, the pattern of fast or slow blink speed could express intensity of emotions by blink. However, relation between intensity of emotions and speed of blink should change by emotions.

In the end, two expressions are proved in this paper. The first expression is that there are differences by gender, and that women feel that expressed disgust in RP (Red Purple) more than men. The second expression is that it is not always that the fast patterns express strong emotions. These may be useful for creating the better model of expressing emotions for robots. On the other hand, new problem came up. First, there is whether the presence or absence of a waveform gives influence to emotions. Next, the differences

by gender. Finally, the method to express the intensity of trust, fear and disgust. By research of these, it is thought that even better model can be created.

7. **Conclusion.** In this paper, a new model that expresses 24 emotions that is proposed by Plutchik was created and evaluated. The proposed model expresses 8 basic emotions by 8 colors and intensity of emotions by speed of blink. First, the patterns that express 8 basic emotions were presented, and evaluated. As a result, it was found to be able to express anger with R (Red), trust with G (Green), sadness with B (Blue), and disgust with RP (Red Purple). Three emotions anticipation, joy and surprise are expressed by Y (Yellow) or YR (Yellow Red), but they are likely to be confused. Fear is expressed by PB (Purple Blue), but some people feel sadness. To distinguish these emotions, other methods of expressing emotions are also used or change the model. According to gap of gender, there are few differences for the most part, but surprise and disgust have differences. Because group differences may occur as well as gender differences, it is necessary to examine the validity of the model again when people whose age or nationality and suchlike are different from participants of the experiment were targets.

Secondly, the patterns that have the same colors and different blink speeds are presented to participants, examining the relation between intensity of emotions and speed of blink. Anger, anticipation and joy are the emotions that fast patterns express strong emotions, but sadness is the emotion that slow pattern expresses strong emotion. To express emotion with color and blink, change the relation between intensity of emotions and speed of blink by emotions.

This research shows the possibility that simple models using color and blink were usable as one of the methods of expressing emotions for the robots. In this way, it is possible that the robot that does not have shape of creatures or cannot speak can express emotions, and it is thought that there is a possibility that friendly robots will be created. Using this research result, it may be possible to create a robot that snuggles up to people. As a result, communication robots will be able to provide better care for patients with depression and others. Furthermore, the model can express 24 primary emotions that are proposed by Plutchik. It may be possible to express various emotions by using method such as using two or more colors.

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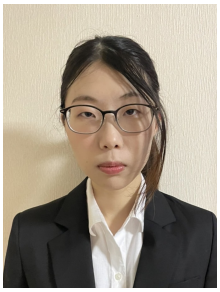
Author Biography



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