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Expressions of Emotion in Smart-doll Eyes using a Micro Display

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** Regular Paper*

***Abstract*:** Recently, technologies for expressing or recognizing emotion from facial expressions in digital displays, such as those found on smart dolls and robots, have been advancing. Among such facial expressions, the eyes can express detailed emotions through fine movements and reactions. The purpose of this study is to extract the elements for expressions of emotion via digital media used for smart-dolls' eyes, and to develop guidelines for creating such expressions of emotion. Extraction of factors for the expression of emotion along with a suitability verification process were conducted to develop suitable eye content for smart dolls through expert focus group interviews, surveys, and statistical analysis. As a result, four elements for the expression emotion with the eyes (eye shape, gaze, iris size, and effect) were derived, and 13 emotional expression guidelines were developed accordingly. The findings of this study are expected to play an important role as an effective technology tool for communication of emotions when developing facial expression systems using the digital displays that continuously appear.

***Keywords*:** Digital image processing, Emotional expression, Digital eyes, Micro display, Smart doll

1. Introduction

As smart dolls and humanoid robots utilizing cutting-edge technology emerge in the field of entertainment, technology for expressing facial emotions through digital displays is advancing [1-4]. In particular, in the case of smart dolls, the demand is for natural emotional communication based on human technology, emphasizing increasing humanity and not simply emphasizing cutting-edge technology or mechanical capabilities combined with information technology (IT) [5-7]. In addition to the general expression of emotional gestures and facial expressions, which are non-verbal, fine understanding of emotions and accurate expressions of emotion based on sophisticated technology are required [8, 9]. Since human emotions are complex, it is not easy to accurately apply them to digital devices [10]. In general, emotional facial expressions use more than 40 muscles in the face, which repeatedly relax and contract [11]. This type of flexible realistic expression is difficult to reproduce on hard-material hardware, such as smart dolls or humanoid robots. Therefore, this paper suggests a method to express emotion using a combination of robotic hardware and computer graphics software, and focuses on the eyes to enable the maximum emotional expression in a digital display on robotic hardware.

In facial expressions, the eyes (sometimes called the window to the mind) are a very important factor in expressions of emotion, and are a key part of the face [12-15]. The eyes can express an emotional reaction to information presented for human–machine interaction. In previous studies, eyes were applied to present the emotion and mentality of a robotic system for human–machine interaction. Yamazaki et al. proposed an eye robot focused on eye expressions, and proposed a mascot robot system as a casual communication robot [16]. The eye robot can express eye motion, which consists of eyelid motion and ocular motion based on the mechanisms of the human eye. Reyes et al. analyzed the influence on humans of angry robotic facial expressions with an electro-mechanic minimalist robotic face that can produce six universal expressions [17]. Breazeal studied the role of emotion and expressive behavior in regulating social interactions between humans and expressive anthropomorphic robots [18]. A humanoid robot, Kismet, is able to express emotive states using an electronic hardware head system that consists of the eyes, eyebrows, ears, and neck. These researchers suggested emotional expressions for the eye and face based on robotic hardware. The eyes of robotic hardware can particularly make moves like tilts and pans, and other elements of the face can help the eyes present emotion. These studies presented ways for the eyes to

independently express emotion, and eye elements help improve social communication between user and machine. However, there were limitations to showing emotional communication using only hardware systems. Therefore, this proposal is a fusion of robotic hardware and a graphical display, which can be an effective way to overcome some of the limitations on such emotional communications.

The digital eyes applied to smart dolls or humanoid robots can be represented as digital content on a display for communication with humans [19]. For the eyes of conventional smart dolls or entertainment robots, the methods to express emotion are mechanical and unrealistic, with a flat design [20, 21]. They have limited emotional expressions, using simple forms and color, with many unnatural movements. They consist mainly of functional interactions for information delivery and execution, and are based on information input and response-oriented communications. However, the study presented here was conducted to express emotions with accurate and realistic movements. In previous research, specific eye elements, such as eye contact, eye gaze, and eye movement, were treated as important parts of expressions of emotion. These eye elements increase affective arousal, and more importantly, eye contact automatically evokes a positively affective reaction [22]. The eyes imply sources, such as the gaze direction and tears, and autonomic responses, such as pupil dilation, eye blinks, and blushing, are subtle yet visible to observers [23]. The point of this study is to focus on the eyes from among all the elements expressing facial emotions and to suggest a method to maximize the expression of emotion with the eyes when the other elements of facial expressions are limited. This will be an important technology that can be applied to smart dolls as it leads to further understanding of natural facial expressions and accurate emotions from expressions with the eyes.

The purpose of this study is to find the elements for expressions of emotion in human eyes that can be used in digital media, such as smart dolls, and to propose guidelines by developing a method for the expression of each emotion. Equipped with the smart-doll's eyes as a miniature display, this study derived objective emotional factors for six emotions that can be used with smart dolls. Then, digital graphic contents that applied this method were developed. Based on the results of experiment verification, guidelines for the expression of emotions with the eyes are proposed. The research results are expected to serve as guidelines for expressing emotions and for completing facial expressions in digital content areas, such as robots and animations, as well as smart dolls.

2. Materials and Methods

2.1 Smart-doll hardware

The smart doll to which the eye contents were applied for development in this study was a ball-jointed doll. Unlike ordinary dolls, ball-jointed dolls can be decorated with lively facial expressions, exquisitely designed joints,

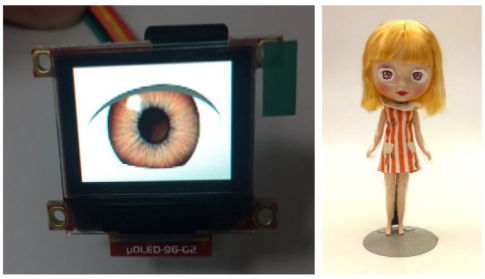


Fig. 1. The LED micro display module for the eyes of the smart doll.

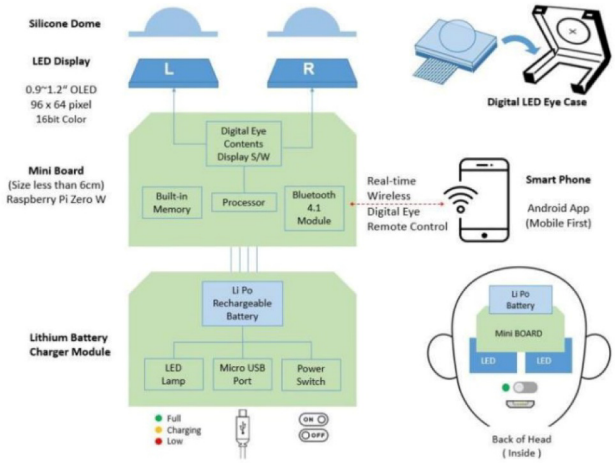


Fig. 2. The hardware configuration with a silicone dome, LED display, mini-board, smartphone, battery, and the head of the smart doll.

and various eyeballs, wigs, makeup, and costumes according to the user's sensitivity and preference [24]. For this reason, people do not say they *buy* a ball-jointed doll; instead, they say they *adopt* one [25]. This implies the concept of a pseudo-person or companion. Therefore, by incorporating IT into ball-jointed dolls, or combining them with smartphones, they are pursuing various play styles and entertainment values that respond to people's words or actions.

Focusing on the eyes of the smart doll, the original eye structure was removed, and a display mounted so it could be adjusted and implemented in a smartphone application. By using the Lila Doll ball-jointed doll, a miniature LED display was mounted for the eyes in order to implement digital content. A miniature LED was mounted inside the doll's eyeball sockets in the shape of a transparent silicone dome similar to the human eye structure. The microprocessor driver was designed to display various eye shapes and movements. The contents of the eyes, such as iris size, color, and eye blink rate, can be adjusted through an application on a smartphone. Animations for six emotions developed in this study are displayed.

The parts for the hardware of the LED eyeballs were selected based on being light in weight, and on their miniaturization, intelligence, and generalization, and they were tested before assembly, considering the conditions required to insert them into the head of the ball-jointed doll. A compact LED module with a size of less than one inch

was selected, which can be mounted on the doll's face. It was selected as a structure that can interface with the Raspberry Pi mainboard. In particular, detailed shape changes for the eyes and a resolution for color reproduction were considered. In addition, rather than directly exposing the display, it was designed to be covered with dome-shaped silicon on top to show the actual three-dimensional structure of the eye.

2.2 Deduction of Emotional Expression Elements for Eyes

There were focus group interviews (FGI) with designers and users of ball-jointed dolls to determine the target emotions. First, Paul Ekman's six basic emotions [26] – Happiness, Sadness, Anger, Fear, Disgust, and Surprise – were suggested for consideration as target emotions of the smart doll. Focus group participants needed only Happiness, Sadness, and Anger for communication with the smart doll, because they thought the other emotions are not suitable for emotional communion with the doll. Secondly, the three target emotions were examined, and three other emotions were added based on Russell's circumplex model of emotion [27, 28], which consists of two axes, Arousal–Sleepiness and Pleasure–Displeasure, with 28 emotional words distributed. Also, four domain emotions were defined as Distress, Depression, Excitement, and Contentment based on the two axes [27, 28]. The first three chosen target emotions could match vocabularies of the circumplex model. All emotions and domains of the circumplex model considered, the interviewees suggested three more emotions to apply to the smart doll (Relaxed, Tense, and Glad) from among the vocabularies that express emotions. Third, after adopting four emotion domains, user interviews were conducted to redefine a vocabulary to fit the smart doll. From this process, six target emotions – Happy, Angry, Sad, Relaxed, Sexy, and Pure – were derived through discussion. For Sexy and Pure, consideration was given to the words that people use and intuitively understand, as shown in Table 1.

Table 1. The definition of each emotion.

Emotion	Meaning	Note	Russell's emotion vocabulary
Happy	feeling delight and pleasant	-	Happy
Sad	Angry: feeling bad and anger	-	Sad
Angry	Sad: depressed and sick	-	Angry
Relaxed	stable and drowsy	-	Relaxed
Sexy	charming and fascinating	Similar to Charming but Sexy has intuitive understanding	Tense
Pure	nice and clear	*Innocent* is distinguished from *Pure*	Glad

2.3 Developing Eye Content based on Elements for Expression of Emotion

Digital eyes were made by extracting elements for expression of emotion and the features of the eyes according to the extracted emotions. Content with expressive eyes corresponding to each emotion (animations, cartoons, etc.) were collected into 75 images and classified by emotion through expert FGIs. It was difficult to judge an emotion by seeing a lot of images at once because the images excluded everything but the eyes. Therefore, in order to objectively evaluate the emotions, each image was presented one by one to determine which of the six emotions it corresponded to. Then, the classified images were listed in order, placing the images with the most expressiveness first. There was a discussion about the differences between the elements of a specific emotion and other emotions. The characteristics of the eyes were based on the factors that influence the expression of emotions in the eyes, such as eye movement [29], eye shape [30], gaze direction [31], eye contact, eye blink rate, and pupil dilation [32]. According to the experts, there is a limit to abundantly and independently expressing emotions with only the eyes; however, they could find common expressions from the eyes. They thought that eye shape, gaze, and iris or pupil size are elements of eye expression in graphical images and animation. In particular, in the case of animation with movement, the experts could easily build a consensus on the kind of emotion from only the eyes. In addition, emotional expression with the eyes was proposed to include special effects by taking advantage of digital expressions to overcome any limitations. For example, tears are a visual signal of sadness by contrasting the perceived sadness of human facial images with tears against copies of those images that had the tears digitally removed [33]. The sclera of the eye can be evaluated as a cue to the emotion of individuals. A red sclera was rated as showing more anger, fear, disgust, and sadness, and less happiness, than the usual uncolored sclera [34]. Therefore, tears, a reddened sclera, and a shiny eye (which can be created with computer graphics) can make a strongly appealing emotion.

Through this discussion, the basic elements for expression of emotion with the eyes can be classified, while common expressions for the six emotions were extracted. As a result, the experts established elements for the expression of emotion – eye shape, gaze, iris size, and special effects – and defined the characteristics of each emotion. Based on this, six examples of emotional eye content were developed for digital animation. For eye content expressing emotions, 12 kinds of animations emerged. Each emotion concept was made by applying the emotion without effects and with special effects for the elements of expressing emotion with the eyes. One more piece of content for the smart doll was produced: Neutral (no emotion). It is presented with the eyes staring forward without movement. The Neutral eyes became the basic set and were the standard for applying different eye elements. For example, when applying Angry eyes, the eye tails of the eye shape were designed higher than with Neutral, and

the iris size was adjusted to be larger than Neutral. The content of each emotion was produced as an image that repeatedly presents motion for up to six seconds (except for Neutral). Animations are at 374x100 pixels so they can fit in the miniature display of the smart doll's eyes.

2.4 Suitability Testing and Guidelines Suggestions

Guidelines were suggested through suitability testing and analysis of the 13 pieces of emotion expression content. Suitability was verified through a survey and statistical analysis in order to determine whether the developed content properly expressed the intended emotion. First, the definitions from the emotion vocabulary were given to the subjects so they understood the meaning of each emotion. After presenting each image as a stimulus, a survey was conducted with 232 subjects (114 males, 118 females), who selected only one out of seven vocabulary definitions (the six emotions and Neutral). A chi-square test (χ^2 test) was conducted to verify the suitability of the eye contents. After objective verification, expression guidelines for each emotion were suggested. The guidelines were developed in the frame method based on the elements of emotion expression with the eyes as designed for each emotion.

3. Results

3.1 Definitions of Elements

As a result of the developed elements of emotion expression, the eye contents for digital media are expressed and recognized via eye shape, gaze direction, iris size (and pupil size), and special effects. The definitions that can be applied to the eyes of the smart doll for these four elements are shown in Table 2.

Table 2. Defined emotion expression elements.

No.	Expression Elements	Definition
1	Eye Shape	This element of emotional expression manifests itself in the form of the overall eye shape, and the direction and length of the corners of the eyes, rather than characteristics of biological elements.
2	Gaze	The movement of the gaze may be generated based on the motion for the direction in which the eyes stare. Emotions are felt depending on how the pupils change while staring forward, rather than the initial value for staring in the first screen.
3	Pupil Size	In biological theory, the size of the pupil changes as the iris contracts and relaxes, rather than actually changing in size. However, in digital content, the expression of emotion is sensitive to changes in the size of the iris (including the pupils) compared to the whites of the eyes, rather than from changing the size of the pupil itself.
4	Effect	Elements that appear in human expressions of emotion but that are not expressed in reality. They are exaggerated in digital content (like sparkles in tears or from reflections). Graphical representation is dominant.

3.2 Emotion Expression Content with Eyes in a Micro Display

The production images and suitability verification results for the 13 expressions of emotion are shown in Table 3. A questionnaire was designed to provide a chi-square goodness of fit test. The results presented show that the significance suitability is satisfied by all the emotions ($P<0.05$). The digital eye images and chi-square test results verify that all 13 pieces of content meet the criteria. However, for Happy and Sad, the word *relaxed* was selected more than the intended original word. For Happy with Effect and Sad with Effect, the frequency of the originally intended word was the highest. Therefore, Emotion with Effect was shown to be better at expressing emotion. Based on these results, explanations of the elements for expressing each emotion are in Table 3.

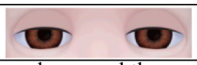
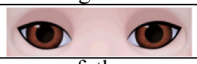
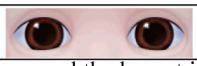
3.3 Guidelines for Emotional Expression Content with Digital Eyes

The contents are composed of four layers: eyelids, shadows, highlights plus effects, and pupils plus irises. The duration for, and expressions of, the elements are presented in units of frames containing the playing time. Each emotion is designed to have the eyes blink once every 3~6 sec., which is the human eyes' blink rate, and which is also applied when the eyes are in motion. The position of the gaze is expressed in pixels relative to the upper left corner of the set standard, 960x640 pixels, and reduction and enlargement are indicated based on 100% of the pupil and iris sizes for the Neutral emotion. Layers that overlap in the guidelines are marked in gray. Based on this system, six emotional expression guidelines – Happy, Angry, Sad, Relaxed, Sexy, and Pure – and the Neutral guideline (which is a normal, fixed eye without expression) were developed. The effect of each emotion is presented by a layer on the guideline. The basic guideline of each piece of content presents Emotion with Effect, including the layer of highlights plus effects. If content does not take an effects layer, it can be an emotion guideline.

4. Discussion

In this study, elements for expressing emotion with the eyes were extracted and can be applied to smart dolls; emotional expression guidelines were developed to display the results on digital media. The emotions of the smart doll were deduced as six types, which are Happy, Angry, Sad, Relaxed, Sexy, and Pure. This study is meaningful in that

Table 3. The descriptions of digital eye contents and the suitability of each.

Emotion	Digital Eye	Decription	X^2
Neutral	Emotion		292.698
	Identical to the existing smart doll.		
Happy	Emotion		160.241
	Eyes are gently rounded and smiling. The gaze is centered and the size of the iris is the same as the basic form.		
	Emotion with Effect		705.138
	It is expressed as a heart symbol that conveys happy and loving in the same form as the basic version, and the eye blinks upward from the center.		
Angry	Emotion		989.319
	The corners of the eyes are up and the gaze moves upward as if staring at the center. The iris moves upwards and shrinks to make the area of white stand out more.		
	Emotion with Effect		440.310
	It has the same shape as the basic version. The flame symbol, an expression of anger, is shimmering in the iris.		
Sad	Emotion		437.103
	The corners of the eyes are down, and the gaze is downward with the eyelid in the center. The size of the iris is the same as the basic form.		
	Emotion with Effect		1054.690
	It has the same form as Sad and expresses the effect of tearing eyes, similar to real humans when they feel sad. Gaze is downward.		
Relaxed	Emotion		756.914
	The eyes are facing down and the upper parts of the eyes are covered, expressing sleepy and drowsy. The size of the iris is the same, and the gaze looks toward the center.		
	Emotion with Effect		945.966
	It has the same shape as Relaxed with motion of the eyes closing added.		
Sexy	Emotion		321.121
	Although the corners of the eyes are up, it is gentler than when expressing Anger. The gaze is centered, and the size of the pupil is large. Makeup is used to convey the meaning charming and sexy.		
	Emotion with Effect		656.336
	It has the same shape as Sexy, with a wink motion added to convey charming and sexy.		
Pure	Emotion		224.448
	It uses rounded eyes and the largest iris and pupil size. The gaze is centered.		
	Emotion with Effect		293.828
	It has the same shape as Pure and uses the twinkling effect and blinking of the eyes, like those of curious children.		

it derives the target emotions for application to digital eyes in smart dolls. There is a limit to expressing human emotions with digital eyes using a display. Therefore, it is important to find a characteristic for a clear distinction when expressing an emotion by defining the emotions required for emotional communications between the user and the smart doll.

In the general facial expression research, most of the emotion guidelines present ways to distinguish emotions by recognizing points of a whole-face image [35, 36]. Those guidelines suggest emotions and key points of facial muscles that can be recognized through a camera sensor. In the fields of graphics and robotics, the expression of emotion with the eyes has been suggested as being part of the facial expression. Ochs et al. mentioned the importance of social context in virtual facial expressions of emotions with digital characters [37]. Humanoid robots also provide guidance on facial expressions including the expression of emotion; however, they mainly focus on eye movements and eye gaze on hardware platforms [38, 39]. Compared with those studies, the guidelines for emotional expression presented in this study are able to express the delicate emotions of the eyes with a digital display, which is effective for a system that needs to express emotional communications between human and machine. Therefore, these guidelines for emotional expressions can be usefully applied to interactive display systems on which it is difficult to express facial muscles and with hardware having limited movement.

The four elements representing the emotions are eye shape, gaze, iris size, and effect. There are various kinds of elements to express emotions with eyes, such as pupil size, eyelid movements, blinking speed, gaze direction, and the muscles around the eyes [40-42]. However, eye shape, gaze, and iris size were adopted in this study because not all the elements of the eyes are suitable for expressing emotions with a smart doll that consists of hardware and a display medium. In addition, this study revealed that an effect acts as the content expressed with a digital display. In particular, the human eye not only expresses emotions with the eyeball, but also with movement of the eyelids and the 44 muscles of the face [43, 44], such as the muscles around the eyebrows. However, there are costs and technical limitations to implementing in smart dolls the natural movement of facial skin, like a real person. Therefore, this study supplemented this limitation in expressing emotion by using digital effects. In fact, in interviews with experts, the effects were defined as important factors in expressing emotions with digital eyes. Also, in the suitability test, the content with an effect showed a higher suitability score.

This study suggests expression guidelines for these factors with the following emotions: Happy, Sad, Angry, Relaxed, Pure, and Sexy. By applying the four elements, the criteria for expressing emotion, and by adding motion, this study helped develop detailed guidelines for each frame of animation based on emotions that can express real feelings. Guidelines for expressing emotion with digital eyes can play an important role in the development of emotion recognition and expression skills, facial animation, and emotional communication content. However, these

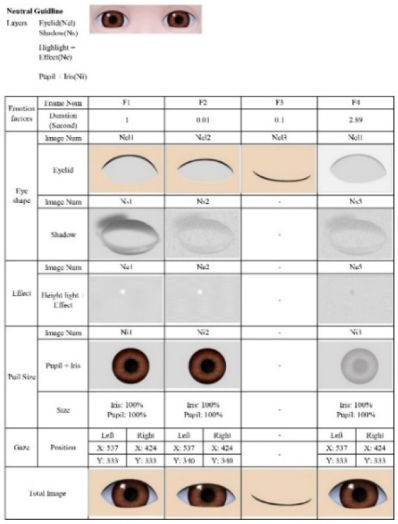


Fig. 3. Guideline for Neutral.

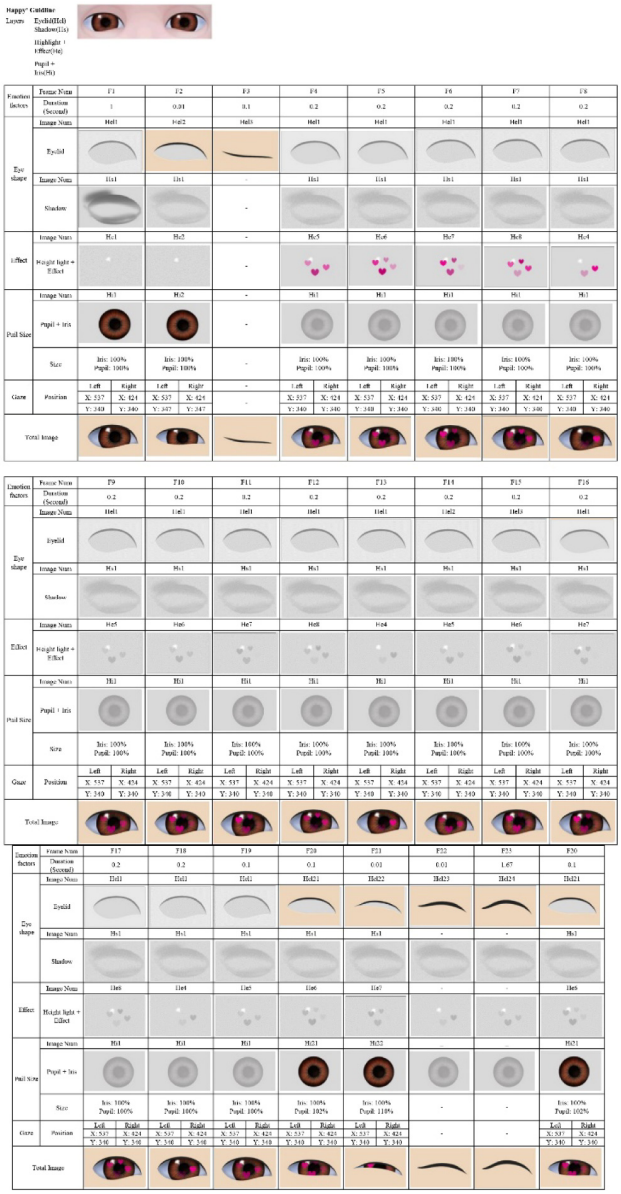


Fig. 4. Guideline for Happy.

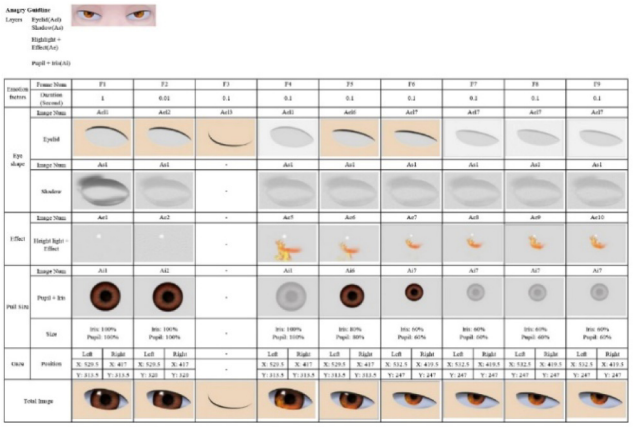


Fig. 5. Guideline for Angry.

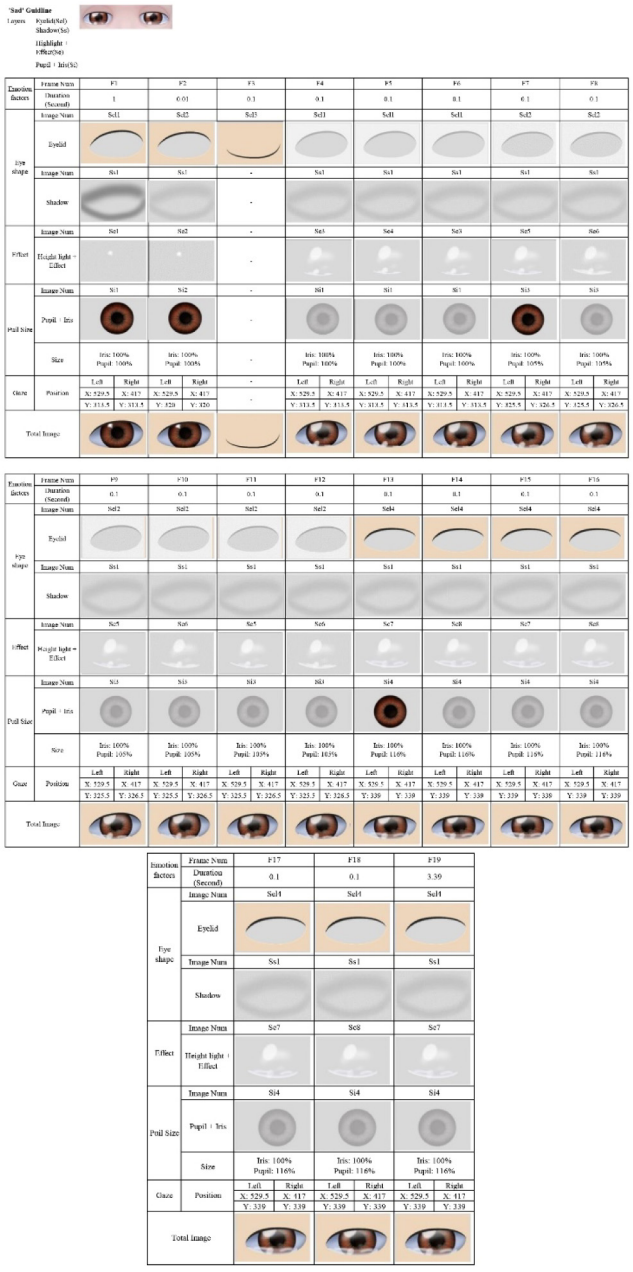


Fig. 6. Guideline for Sad.

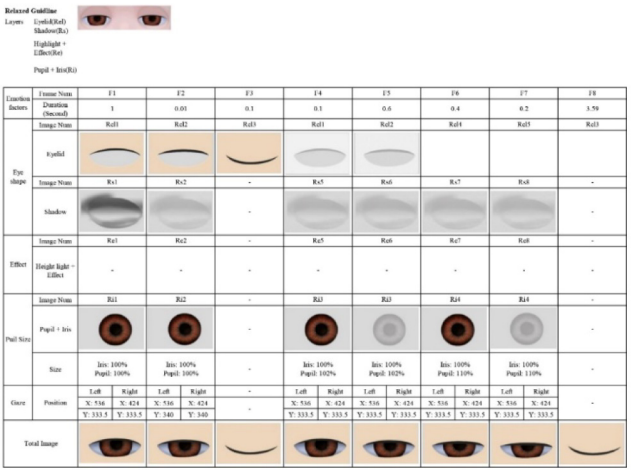


Fig. 7. Guideline for Relaxed.

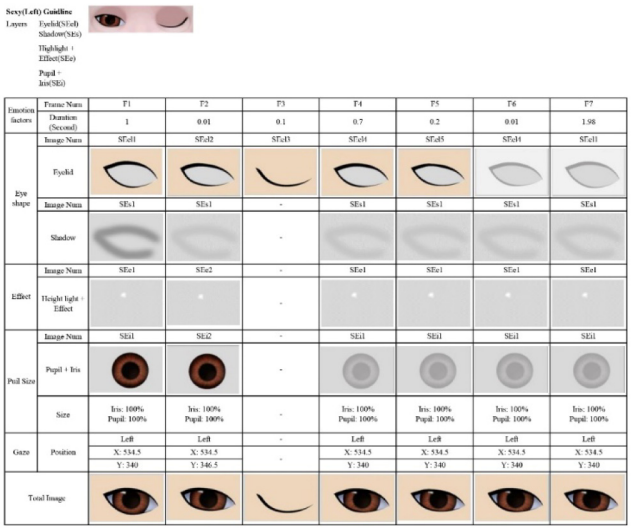


Fig. 8. Guideline for Sexy – left eye.

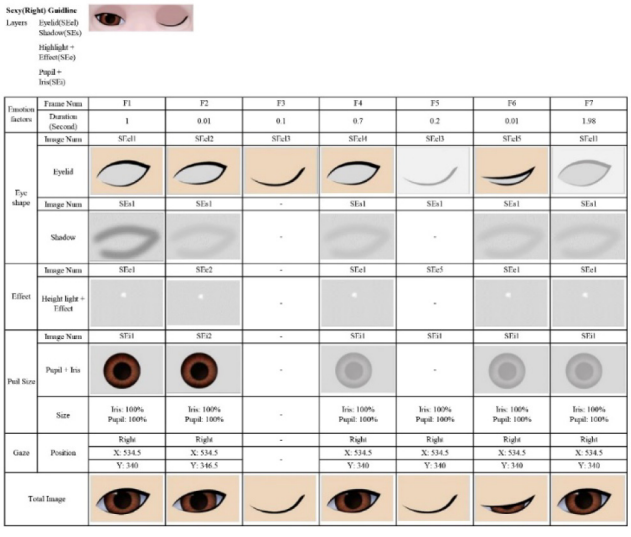


Fig. 9. Guideline for Sexy – right eye.

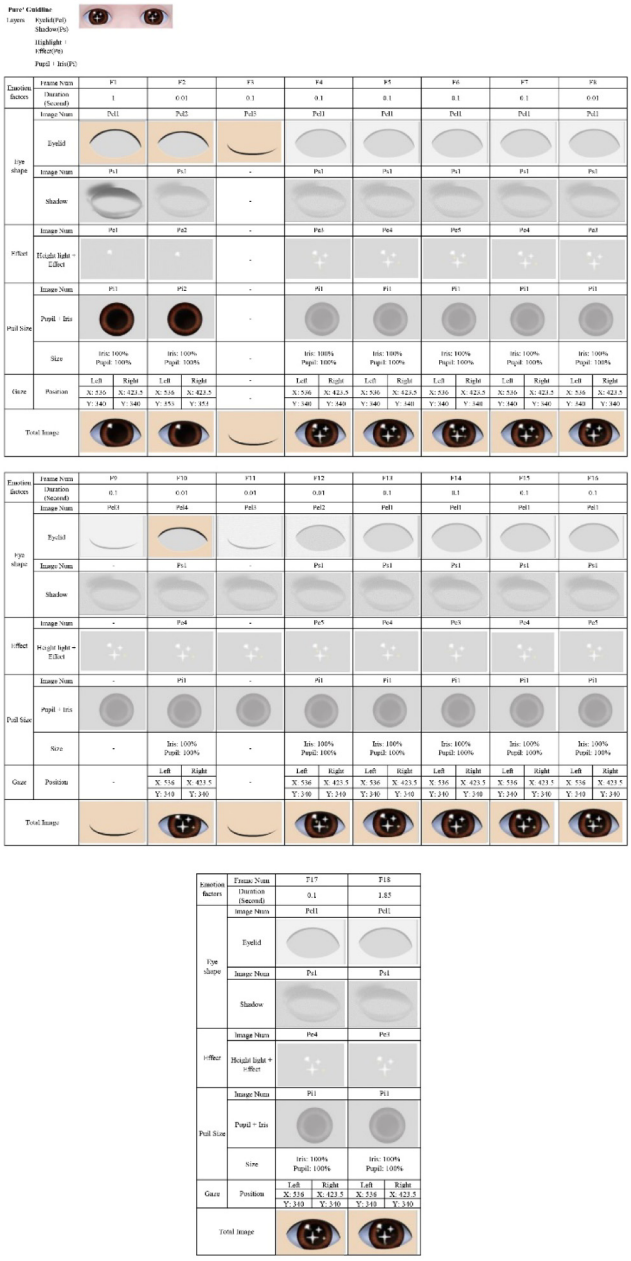


Fig. 10. Guideline for Pure.

guidelines are centered on the eyeball and eyelids. There is a limitation to expressing emotions when focusing on the eyeballs alone and not including other factors around the eyes, such as eyebrows. Movement by muscles around the eyes, by the eyebrows, and by wrinkles in the skin can provide real and strong expressions of emotion. Although there is a limitation when using only the eyeballs, the research value of detailed and delicate emotional expression with the eyes was achieved. In particular, Happiness, Sadness, and the Relaxed emotion were not clearly expressed without special effects, based on the goodness of fit test. Further research is needed on how this affects other surrounding elements and how to make these emotions clear. However, the results of this study will provide useful guidelines that can be applied to humanoid robots or chat-bots, as well as smart dolls, that express emotion with the face.

In addition, the digital LED eyeball used in this study will enable the natural expression of emotion not only by dolls but by other artificial intelligence service robots. This will give robots a sense of vitality, and the demand for robots will expand to human-friendly services in the future. Therefore, research on this should be expanded.

5. Conclusion

This study drew on four elements for expression of emotion with digital eyes, as applicable to digital media, and developed animation content for six emotions. Also, by proposing specific animation guidelines through verification of suitability, this study can be the basis of technology that enables effective expression and recognition of emotion via the eyes that will play an important role in facial expression technology for digital content, increasing the number of robots, smart toys, artificial intelligence systems, and emotional intelligence systems. This study showed the possibility of producing next-generation, emotional, intelligent dolls in a market environment. The boundary between the existing doll industry and the personal entertainment robot industry is breaking down by combining robot technology and emotional intelligence technology. It is hoped that this study will be the foundation of development for emotional intelligence technology that understands and expresses human emotion and that can be utilized in combination with digital media.

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