Intelligent Environments 2018
I. Chatzigiannakis et al. (Eds.)

doi:10.3233/978-1-61499-874-7-157

Human-Robot Personal Space Evaluated with Biological Information Emotion Estimation Method

Yiriko Someya [a,1], Yoshito Tobe [b,2], Reiji Yoshida [a],
Nobuto Matsuhira [a], Midori Sugaya [a]

[a] *Shibaura Institute of Technology*
[b] *Aoyama Gakuin University*

Abstract. Recently, interactive robots have been widely used around the world. In the field of this research, nonverbal communication is expected to play an important role in interactions between humans and robots. We hypothesized that if a robot maintains a comfortable distance to humans they will be more readily accepted. Generally, the idea of personal space (PS) is defined as the invisible boundary between humans, modifiable by intimacy. If violated the lack of personal space creates a feeling of discomfort. Human-robot personal space is not necessarily the same as human-human personal space. We focus on the human-robot personal space and seek to understand how people experience violation of personal space by robots. Previous studies investigated how people feel when a robot violated their personal space by observing their heart rate. However, specific feelings are difficult to determine just by using heart rate. This paper investigates the emotions generated when a robot moves into someone's personal space by using an emotion estimation method, which maps values obtained from heartbeat and brain waves to Russell's circumplex model of affect. A significant difference in the feeling of high valence and low arousal found between inside the personal space and outside the personal space. Further, a significant difference in the feeling of high arousal five seconds before and after the robot stopped was found between groups with different degrees of the person's interest level for robots. These results show the effectiveness of using biological signal based emotion estimation to evaluate the impression of a robot at the boundary of personal space.

Keywords. Human-robot interaction, Russell's circumplex model

1. Introduction

In recent years communication robots are widely used for the purpose of application to new services and intelligent entertainment. In the area of human-robot interaction research, the design of a robot takes into consideration that the robots behavior will

[1]Someya Uriko, Reiji Yoshida, Nobuto Matsuhira, Midori Sugaya, College of Engineering, Shibaura Institute of Technology. Toyosu, Koto City, Tokyo, Japan; E-mail: doly@shibaura-it.ac.jp.

[2]Yoshito Tobe, Department of Integrated Information Technlogy, Aoyama Gakuin University, 5-10-1, Fuchinobe, Chuo-ku, Sagamihara, 252-5258, Japan3; E-mail: yoshito-tobe@rcl-aoyama.jp.

affect the user experience. Nakata et al. showed that the user has a favorable impression of the robot when performing an interpersonal accepting action in robot contact [1]. Okada et al. improved user experience metrics such as activity, pleasure, affinity, intentionality, and continuity by actively performing greeting actions [2], showing the usefulness of active behavior. The basic idea in these methods is to investigate the subjective impression of a person when a robot displays basic patterns of human communication.

Personal space (PS) is an important part of human communication [3]. Interestingly, although the notion of personal space is associated with humans, it was first discovered in animals [18]. Computer Vision bases PS research in Non-verbal communication on estimation of PS as described by Amaoka et al. [4]. Against a virtual opponent in Second Life, which is used as one of the modalities [3] and which is an important research subject pertaining to nonverbal communication. However, PS for a human's robot has not been fully investigated. We think that the idea of PS is important in robot-human interaction. Robots that are physically present provide different experience to humans depending on their distance. For example, when a robot enters the personal space without considering human emotions, the experience of the robot may deteriorate. Considering PS is important to improve human experience of robots. We look to improve human experience of robots by deducing optimal PS interactions.

As a method of evaluating user experience, Nakajima et al. focused on the PS for the robot and investigated peoples PS with a heart rate monitor [13]. They found that when the robot intruded into the personal space at a speed of 0.8 [m / sec] or more, the heart rate became faster. However, it is difficult to identify emotions with heart rate. Specifically it has no resolution pertaining to the emotions “tense”, “excited” or “surprised”. Moreover, heart rate will change with breathing and exercise and is genetically variable between humans. It is important to estimate PS with the emotion more properly by discriminating detailed emotions with a more robust approach [7].

Ikeda et al. used physiological information such as brain waves and heart rates to estimate human emotion by Russell's circumplex model of affect and evaluate the method [8,16]. In the method, biological information is associated with Russell's two-dimensional coordinates [13], the emotions are estimated with the orthogonal x and y axes and adjectives of emotion are arranged in a circular pattern. Heart rate is measured by pNN50 and mapped to the x axes and the brain waves are mapped to the y axes. Using the four quadrants and the arranged adjectives of emotions in a circular pattern, they estimate the approximate emotion successfully. In the method, the pNN50 is used for measuring the fluctuation of heartbeat to classify the status of low valence state such as "tense", and high valence state such as “pleased”. The classification of the arousal is measured with the electroencephalography (EEG) [6,12]. Several studies have been done[14] to classify emotions using EEG and recent studies used machine learning to classify emotions[11].In this study, we aim at estimating emotion when a robot intrudes into someone’s PS and analyzing it by using the biological emotion estimation method based on the Russell classification model. We assume that the emotional reaction for the robot in the PS would be useful to determine the best location for the robot.

Based on this idea, we have developed a robot and evaluated its effect on PS at different approaching speeds of 0.2 and 0.4 m/s. The experiment results show that there is a significant difference both in whether or not the user is interested in the robot and in the approaching speed of the robot. They also show that there is a significant difference between inside and outside of PS for low arousal and the high valence emotion “calm”. Furthermore, the high arousal and neutral valence emotional state "surprised" has a significant difference in whether or not the user is interested in the robot when the robot stops. Therefore, evaluating the experience of robots would be possible with biological-information-based emotion estimation at the boundary of PS. The structure of this paper is as follows. Section 2 shows the evaluation method by emotion estimation, which is the proposal, the experiment and its consideration in Section 3 and the summary and future tasks in Section 4.

2. Emotion evaluation of robot approaching to PS

2.1. Emotion Estimation for Robot-Human PS

We first define PS as an invisible boundary surrounding a person's body, and its size varies depending on the intimacy with the partner [5]. This distance is said to have four distinct classifications: close distance (- 0.45 m), individual distance (0.45 m to 1.20 m), social distance (1.20 m to 3.60 m), and public distance (3.60 m) [5]. Within this boundary, people feel uncomfortable when the person or robot is approaching, and are also physiologically affected, such as increase of heart rate [18]. In this study, we aim at evaluating the person's detailed emotion when a robot moves to the PS boundary. In order to do this we use an emotion evaluation method based on biometric information. The method of estimating emotion based on biometric information is a method proposed by Ikeda et al. [8]. Ikeda et al. correlated the brain waves to the arousal of the y-axis of the two-dimensional coordinates called Russell's circular model and pNN50 of the x-axis as the indicator of comfortable, and identified the various emotions with the two parameters. Based on this proposal, our group has improved the accuracy by classifying emotions by adding vector decomposition analysis, and making it possible to estimate the emotion more than the validation of heart rate. It is possible to classify the emotions such as "tense" in high arousal and low valence state, "bored" in low arousal and low valence, etc. In addition, in emotion analysis of biological information, when comparing with the emotion estimation result by facial image analysis, they found that it is possible to estimate the emotion more reliably not depends on the features of the expression of the face [8]. Based on this understanding, we consider that it is possible to investigate the difference of individual emotions of robot-human PS.

2.2. Emotion Estimation Method with Biological Information

As described in the previous subsection, we apply [8] as a classification method of emotions. As we described in the introduction, two values of the measured brain wave and heart rate (pNN50) are treated as coordinates on the XY plane, and the angle with respect to the X axis is calculated from the origin of this coordinate. The angle is discriminated by applying the Russell annulus model to a classification model simplified to eight emotions. Also, in order to judge the magnitude of emotion, not only angle but also distance from the origin is calculated, and this distance is evaluated as the magnitude of emotion in this research. This method classifies emotions into eight categories using Russel's circular model to be simplified and approximated (Figure 1).

The measured values obtained with EEG are associated with a point in the two-dimensional plane. Subsequently, the calculated angle of the point from the x axis and the distance between the point and the origin correspond to the type and the approximate strength of emotion, respectively.

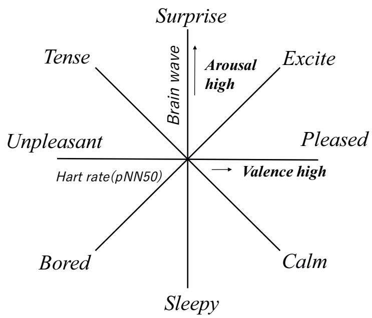


Figure 1 8 emotional classifications of Russell's circular model

3. Evaluation

3.1. Experiment Method

In this study we prepared the two evaluations for emotion estimation, one was emotion estimation by measurement of biological information that was described above and the other was statistical analysis by subjective questionnaire for the collaborators.

(1) Emotion estimation method by measurement of biological information: The value of the x axis is calculated using the pulse sensor [17]. This sensor measures the heart rate by the photoelectric volume pulse wave recording method, the evaluation index uses pNN50, which indicates the proportion of the heart rate at which the difference between the RR interval of the peak value of the heart beat and the adjacent RR interval exceeds 50ms from the continuous heart rate. In general, the RR interval is the ratio of the respiration and blood pressure, since it is assumed that there is constant fluctuation due to the influence, the higher the ratio of the RR interval, the more valent (comfortable) state is estimated. Therefore, to calculate the value of this ratio, it is said that the comfortable state can be judged by associating with the x-axis. The y-axis value was used for the measurement of brain waves by NeuroSky's MindWave Mobile [15]. The brain wave sensor provides the two metrics that are Attention and Meditation. Attention is associated with β wave, and Meditation is associated with α wave. The β states are associated with normal waking consciousness. The α waves originate from the occipital lobe during wakeful relaxation with closed eyes. Attention and Meditation are the values that remove noise from α and β waves, respectively. We use the two metrics' difference as to correspond to the y axis. In this study, we considered that it is possible to judge arousal level by this difference value.

(2) Subjective assessment questionnaire was conducted to answer the subjective feelings of the participant in the questionnaire selection formulas. It is a subjective questionnaire evaluation. In the subjective questionnaire, the eight axes of emotional classification model are "surprised", "excited", "pleased", "calm", "sleepy", "bored", "unpleasant" and "tense". The size of the emotions and the size of each emotion was

evaluated in six stages. In addition, as an attribute evaluation questionnaire of experiment collaborators, we asked questions about interests and interests to robots [9] and asked questions about interpersonal behaviors and the surrounding environment [1], respectively.

3.2. Experiment with a Robot

The purpose of this evaluation is to firstly measure the emotional change from biological information when changing the distance between the robot and the person. Next, we analyze the relationship between recalled emotions and attributes of experiment participants. There were 10 experimental collaborators (9 men in their twenties and 1 female in her twenties). The room temperature was set to 25 degrees. For the electroencephalograph, Mindwave Mobile [2] which is EEG of Neuro Sky [2] was used, and the heart rate meter was Pulse Sensor [17]. We use the robot "Concierge Robot" (Figure 2), that has an area sensor (URG - 04LX - UG 01) for measuring the distance data, a tablet for displaying the face and emitting voice. The Software architecture that we are developed was shown in the Figure 3.

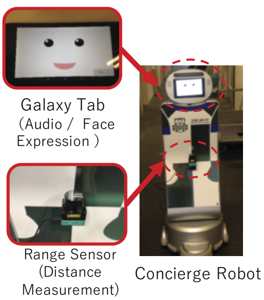


Figure 2. Concierge Robot

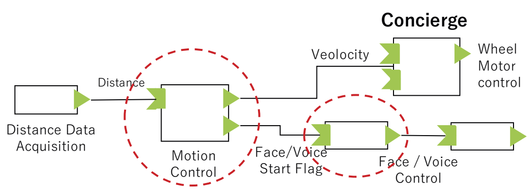


Figure 3. Software Architecture (RT-Middleware)

In order to measure the PS for the experimental collaborators' robots, the experiment collaborators were instructed to use the stopwatch function of the smartphone. This robot is developed by the Shibaura Institute of Technology.

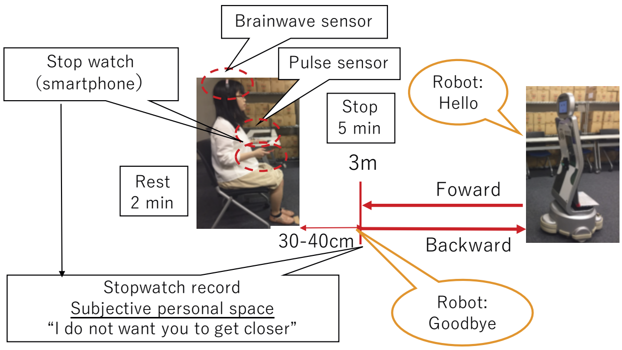
3.3. Experiment Procedure

In the Figure 4, we illustrate the experiment situation. In front of the experiment collaborator, there is a robot. The experimental procedure is described as follows.

1. The robot waits at the position 3 m ahead from the collaborator
2. EEG and pulse sensor attached to the collaborator, rest for 2 minutes
3. Robot: After hearing "Hello", approaching linearly at a speed of 0.2 [m/sec]
4. The experiment collaborator starts a stopwatch as the approach starts
5. During approach, the collaborator gets lap at the point where the robot thinks "I do not want you to come any closer"
6. Robot stops for 5 seconds at 30 - 40 cm position with the collaborator
7. Robot: After saying "Good-bye", linearly retreat at a speed of 0.2 [m / sec]
8. During retreat, the collaborator stop the smartphone timer at the point where the robot thinks "I do not want you to separate any more"

9. After retracting to the movement start position, the robot stops
10. Fill out the questionnaire after robot operation finished
11. Repeat steps 3 to 9 at a speed of 0.4 [m/sec]

Considering the counterbalance, the order of the moving speed of the robot was 0.4 m/sec after five experimental collaborators at a speed of 0.2 [m/sec] and the remaining five experimental collaborators at a speed of 0.4 [m/sec] and then 0.2 [m / sec].



Motion of the robot within the range of close distance (to 0.45 m), Individual distance (0.45 to 1.20 m), Social distance (1.20 to 3.60 m) [1]

Figure 4. Experimental Situation

4. Evaluation

4.1. Experiment Result

Based on the biological information gathered through experiments, we try to analyze the emotion analysis results by the method. As shown in Figure 5, when the robot approaches at 0.2 m / sec, it can be confirmed that the emotions of high arousal and low valence emotions such as being "tense" and "unpleasant" have increased after the robot has entered the PS of the experiment collaborator A.

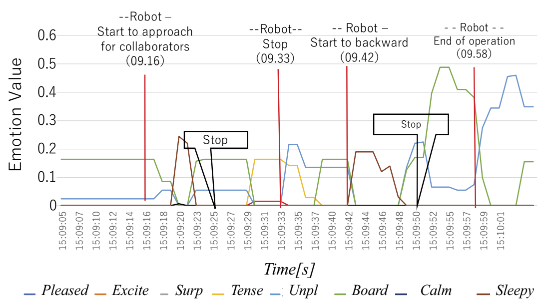


Figure 5. Emotion Transition of Experiment with Collaborator A (0.2[m/sec])
stop: is the pushed time that the collaborator selects.

When the robot approached experiment collaborator B under similar conditions, the emotion of "surprise" became large after the robot entered the PS of experiment collaborator B from Figure 6. Next, when the robot approaches at 0.4 m/sec, as shown in Figure. 7, when the robot enters into the PS, the experiment collaborators A does not show the feeling of "surprise" or "tense", the emotion of “sleepy” rose a little. When the robot approached experiment collaborator B under similar conditions, the emotion of "tense" and "unpleasant" became large after the robot entered the PS of experiment collaborator B from the figure.

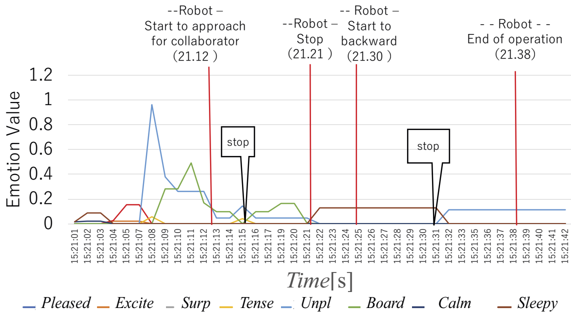


Figure 6. Emotion Transition of Experiment Collaborator B（0.2[m/sec]）

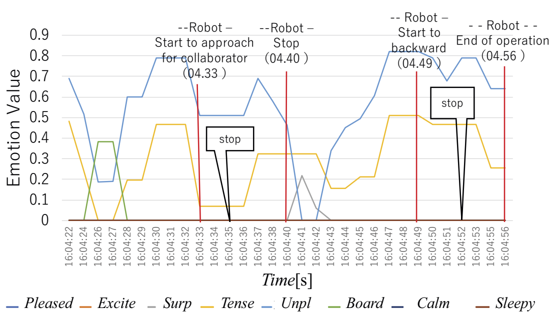


Figure 7. Emotion Transition of Experiment Collaborator A（0.4[m/sec]）

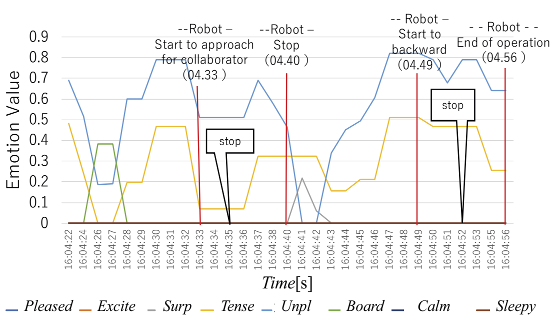


Figure 8. Emotion Transition of Experiment Collaborator B（0.4[m/sec]）

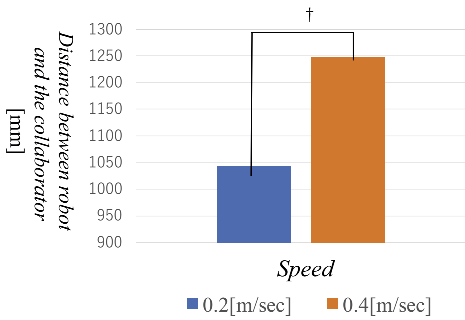


Figure 9. Difference of "unpleasant" in a group with high interest in the robot and a group with low interest.

4.2. Discussion

From the experimental results shown in Figures. 5 to 8, when the robot intrudes into the subjective PS when approaching, the emotions of "tense", "surprise", and "unpleasant" are high in both experimental collaborators. The feeling of A and B are considered that the psychological distance of subjective assessment with questionnaire results would be influences the emotion of "tense", "surprise", and "unpleasant".

Furthermore, in Figure 9, the emotion of "unpleasant" that is neutral in arousal and low valence in 5 seconds before and after stopping when the robot approached at 0.2 [m / sec] from the group with high interest in robot was lower than that in low group. We consider the result that the people who are interested in robots prefer robots that appear in science fiction movies etc. We have speculated the reason for this. The people who are interested in robots often prefer robots that appear in science fiction movies. Therefore, the expectation for the expecting image of the robot is high. In the experiment, when they saw the actual robot which came near, they would be feel the gap with the robot they expected (since our robot would not be so exciting compared with the SF robot characters). Therefore, we think that they felt uncomfortable with the robot.

4.3. Extended Experiment and Results

We increased the number of experiment collaborators by six and conducted experiments again. We had 16 collaborators in total. This is because the result of the experiments shown in Section 3.1, there are no significant difference at the statistical results of proximity distance and speed. Even if an increase in emotion of being "tense", "surprised", and "unpleasant" was observed at the time of approaching the robot.

The additional experiment was carried out in exactly the same way as the experiment that was described in previous section. In addition, as the analysis method, using the result of having the robot question whether interest in the robot is answered by the subjective questionnaire, the group in the reaction of the biological information is divided. As a result, it was possible to obtain results with significant differences that could not be obtained with 10 collaborators within the 16 collaborators. Figure 10-13 describes the experiment results and discussion, respectively.

The analysis results are obtained from the twelve people excluding cases where the data could not be acquired sufficiently. Figure 10 shows the difference in distance between the experimental collaborators and the robot for each speed of 0.2 [m/sec] and 0.4 [m/sec], while the average of 0.2 [m/sec] was 1,043 [mm], the average of 0.4

[m/sec] was 1,246 [mm], depending on the speed, the robot and the experimental collaborator. A significant trend was seen in the distance evaluation (p <0.09).

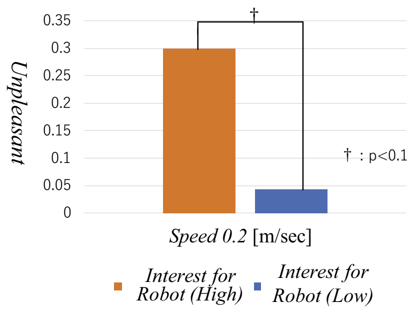


Figure 10. Personal space at robot approach speed 0.2[m/sec] and 0.4[m/sec]

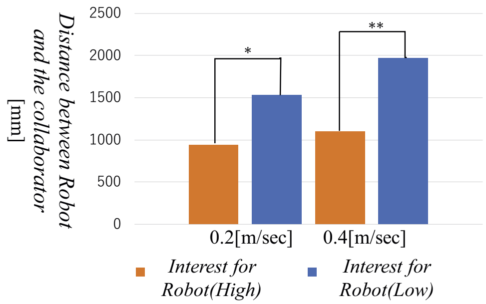


Figure 11. Personal space at robot approaching robot interest

With this result, it became clear that not only the distance but also the speed affects the response to the robot as it approaches the PS. In particular, the robot has the aspect of machine and object, therefore it is thought that there is a tendency to be perceived as dangerous, this would affect the psychological distance of subjective evaluation. Generally, a personal distance is to be observed also between animals and people, other than between humans. In the future, it is necessary to survey and compare the robot as a new target as well.

Figure 11 shows two different approaching speeds 0.2 and 0.4 [m/sec] and the difference of robot interest in subjective assessment questionnaire. As for the robot interest with questionnaire, we divided the group with high interest in the robot and the group with low interest to the robot by the subjective questionnaire calculated the average of each group and tested. As the result, the robot approaching speed 0.2 [m/sec], there was a significant difference in the psychological distance which is the subjective distance that is decided by the collaborators in the experiment, in any of the cases of 0.2 [m/sec] (p <.05), and 0.4 [m/sec] (p <.01). In any case, a robot interested person that is classified with the allowed a robot to approach closer, the distance of around one questionnaire, the meter observed on average can recognize the expression of the approaching opponent, and generally defined as the individual distance in PS to communicate (0.45 m - 1.20 m) with the people personally. On the other hand, those who are not interested in robots that are classified with the questionnaire chose to stop at a longer distance than those who are interested, both at high speed and at low speed. At 0.4 m / sec, the average distance is around 2 m, it is defined as the common social distance (1.20 m - 3.60 m) in PS as an unknown human communication space.

4.4. Additional Experiment: emotion analysis Result

We performed an additional experiment and analyzed the result with more statistical data. Figure 12 shows the result of the "calm" emotional state when the robot is inside / outside the PS.

In the Figure12, a significant tendency was seen in the value of "calm" emotions in and out of the PS. "Calm" is a classified in the comfortable state, which is a reaction of the autonomic nerve, and at the same time it is a value indicating a state of relaxation with a low degree of arousal level measured by brain waves. Ten people considering the counter balance of the experiment as a result of analyzing the results. From this, it is conceivable that it can be used as an index for autonomous control considering PS by analysis focusing on "calm" emotion and construction of prediction model.

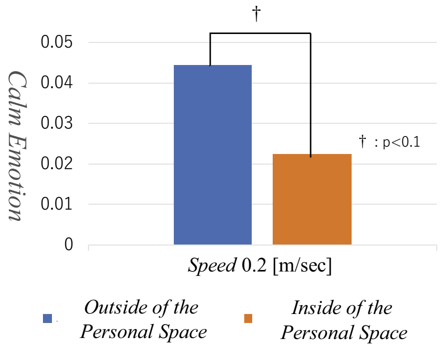


Figure 12. "Calm" emotion when the robot is inside / outside of the personal space

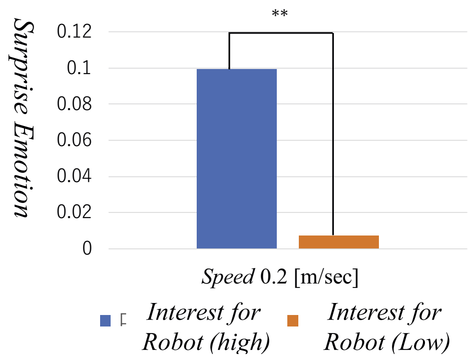


Figure 13. Robot against Robot Interest

Figure 13 shows the results of comparing the differences in the magnitude of emotions of "surprise" for 5 seconds before and after stopping the robot for each of the two groups with different robot interest levels by the questionnaire method. The result shows that the robot is 0.2 [m/sec]. There was a significant difference in the feeling of "surprise" when approaching the robot at 0.2 [m/sec]. ($p < .01$). Specifically, it was found that the group of people with less robot interest had a stronger emotion of "surprise". From those who are not interested in robots, they are not familiar with the autonomous robots, therefore the biological reaction is aroused in emotion of being "surprised". From this, it is conceivable that it can be used as a judgment index of the presence or absence of interest, whether or not a person is familiar with the robot, by analyzing people's "surprise" and constructing a prediction model.

5. Conclusion

In this study, we aimed to analyze the human emotional response when a robot moved across their PS boundary, based on biological information. The results of the experiment show a significant difference or a significant tendency in the difference in height of the robot interest degree and the speed of the robot's approach. The results show that it is effective to evaluate the experience of the robot at the PS boundary by emotion estimation using biological information. In the future, we aim to improve the user experience of the robot by maintaining the optimum distance deduced from the result obtained by the biometric information emotion estimation method.

References

[1] Okada Akiho, Midori Sugaya, Impression Evaluation for Active Behavior of Robot in Human Robot Interaction, Human Computer Interaction International 2016 (HCII 2016), Toronto, Canada, Jul 17-22, Lecture Notes in Computer Science book series (LNCS), Universal Access in Human-Computer Interaction, Novel User Experiences, vol.9733, pp.83-95, 2016.
[2] Soraia M. Alarcao, Manuel J. Fonseca, "Emotions Recognition Using EEG Signals: A Survey", IEEE Transactions on Affective Computing, vol. PP, issue 99, pp. 1-20, 2017.
[3] Amaoka T., Laga H., Saito S., Nakajima M. (2009) Personal Space Modeling for Human-Computer Interaction. Entertainment Computing ICEC 2009. ICEC 2009. Lecture Notes in Computer Science, vol 5709.
[4] M. Gillies and M. Slater, "Non-verbal communication for correlational characters," the 8th Annual International Workshop on Presence, London, September 2005.
[5] Hall, E. : Hidden Dimension. Doubleday Publishing, pp.57-71, 1966.
[6] H. Hinrichs and W. Machleidt, "Basic emotions reflected in EEG-coherences," Int. Journal of Physophysiology, 13(3), pp. 225 - 232, Dec. 1992.
[7] Yuhei Ikeda, Ryota Horie, Midori Sugaya, Estimate Emotion with Biological Information for Robot Interaction, 21st International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES-2017), Marseille, France, 6-8, Sep, Procedia Computer Science, Vol.112, pp.1589-1600, 2017.
[8] Yuhei Ikeda, Yoshiko Okada, Midori Sugaya, Estimate Emotion Method to Use Biological, Symbolic Information Preliminary Experiment, Human Computer Interaction International 2016 (HCII 2016), Toronto, Canada, Jul 17-22, Lecture Notes in Computer Science book series (LNCS), Universal Access in Human-Computer Interaction, Foundations of Augmented Cognition: Neuroergonomics and Operational Neuroscience (AC 2016), vol.9743, pp 332-340, Year 2016.
[9] Takayuki Kanda, Hiroshi Ishiguro, and Toru Ishida, "Psychological analysis on human-robot interaction," IEEE International Conference on Robotics and Automation (ICRA 2001), pp. 4166 - 4173, 2001.
[10] David Katz "Animals and Men: Studies in Comparative Psychology," Longmans Green. 1937.
[11] Yuan-Pin Lin and Tzyy-Ping Jung, "Improving EEG-Based Emotion Classification Using Conditional Transfer Learning," Frontiers in Human Neuroscience, Vol.11, 2017.
[12] Toshimitsu Musha, Yuniko Terasaki, Hasnine A. Haque, and George A. Ivamitsky, " Feature extraction from EEGs associated with emotions," Artificial Life and Robotics, Vol.1, Issue 1, pp. 15 - 19, March 1997.
[13] Koji Nakashima and Haruhiko Sato, "Personal distance against mobile robot," Proc. of Japan Ergonomics Society, 38, pp.454-455 , 1997. (Japanese)
[14] Toru Nakata, Tomomasa Sato, and Taketoshi Mori, "Expression of Emotion and Intension by Robot Body Movement, Intelligent Autonomous Systems 5 (IAS-5), pp.352 - 359, June 1998.
[15] NeuroSky . http://neurosky.com/
[16] Russell, J.: A circumplex model of affect. it Journal of Personality and Social Psychology; Vol.39, No.6, pp.1161-1178 1980.
[17] Switch Science, https://www.switch-science.com/catalog/1135/
[18] Fujio Yoshida and Masahiro Kodama, "Physiological and self-rated affective/cognitive responses of neurotic personality to an interpersonal stress situation," The Japanese Journal of Psychology, Vol. 58 No.1, pp.35-41, 1981. (Japanese)