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Multi-user Robot Impression with a Virtual Agent and Features Modification According to Real-time Emotion from Physiological Signals

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Abstract— **Communication robots are now getting popular. In particular, partner robots, which can perform personal services, are in high demand. However, they can be prohibitively expensive. Therefore, we considered a multi-user robot with a virtual agent service which could satisfy user demands. But, several issues need to be solved in order to achieve this purpose. Firstly, there is no general service platform for such robots. Secondly, even if we use the multi-user robot by executing the virtual agent service, the physical shape, and other characteristics of the multi-user robot sometimes creates a strong impression on users. Therefore, we proposed a virtual agent service platform, and the robot features modification for a multi-user robot. The robot can autonomously adjust its position according to each user's physiological signals, which based on emotion in real-time. We presented a preliminary evaluation to determine whether the proposed method could improve users' robot experience even for the users who are not familiar with the robot at all.**

I. Introduction

As we move towards a human-robot symbiotic society, communication robots and services mainly aimed at interaction with humans are becoming widely popular. It is estimated that more than 50% of the robot industry will be constituted for the services sector by 2035 [1]. The number of partner robots that provide personal services for individual users is on the rise [2]. Such robots provide user support, such as livelihood support, rehabilitation, and social activities. Many countries struggle with an aging population, particularly Japan. In Japan, many senior citizens are found to be living alone [3]. Improving the quality of life (QOL) of this specific group is one of the main goals of personal robots, or sometimes called partner robots.

The installation and maintenance cost of a partner robot is rather high and, therefore, not practical for individual usage. On the other hand, general-purpose communication robots installed in shared spaces are purchased by corporations and public institutions. Those general-purpose robots are becoming widespread as they are publicly available, and they could contribute to the shortage of human workers. It is important to build a mechanism to achieve personalized services in these robots by classifying multiple users using a virtual agent. A virtual agent is an animated computerized character that interacts with humans [4]. Research on virtual agents has been hindered by issues such as low versatility and lack of a common platform. In this research, we aim to develop a platform for virtual agents. Also, we will analyze the impression that users have toward personalized robots in different situations. The impression evaluation is essential when providing personal service. This study shows that it is possible to provide better user experience of robots by estimating emotions using individual physiological signals and autonomously adjusting the appropriate position of the robots when interacting with the user. We designed and implemented a robot with the proposed functions, and the evaluation showed it significantly improved user experience.

II. Literature Review

In human-robot interaction (HRI), an interaction through an agent is called human-agent interaction (HAI) [5]. Komatsu et al. conducted a comparative experiment with a robot and a virtual agent displayed on a monitor that looked identical to the robot. The result suggested that having a physical entity as a partner agent for interaction may enable smoother interaction [6]. Several studies have been conducted on virtual agents. However, many of the studies on virtual agents remain restricted to specific conditions due to costs, such as only using a virtual robot inside a monitor or a single dedicated robot. In Matsuda et al. study, common appliances such as general home appliances and information and communication technology (ICT) devices were changed into an agent by the attachment of humanoid parts like arms and eyes [7]. However, no viable common virtual agent to operate multiple devices has been described. Furthermore, there is insufficient information on a generalized method for building personal service using robots shared by multiple users.

As for the robot features, it plays an important role in achieving a better experience for a different group of users. Leite et al. reviewed the social robot features for long-term reactions. They stated that robots in shared space need to consider usability and adaptation to treat different kinds of users [8]. In human communication, body language during social interaction can affect communication. For a robot, the movement speed element of the body language can be pointed out that it could affect people's arousal level [9]. However, this

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may be speculative because the study of the human physiological signals effect of the robot features is still poor.

III. Proposed Method

In this study on HRI, robots with various appearances are designed with virtual agents to enable smooth communication between robots and humans. However, there are not many studies on a virtual agent platform that could support any robots. Also, methods for enabling personal service have not been sufficiently discussed. The features of the robot itself also affect the smoothness of the communication. Therefore, in the first half of this study, we aim to provide a personal service using a virtual agent on the multi-user robot. Then, the modification of the robot features based on physiological signals will be discussed in the latter part of this paper.

A. *Virtual Agent for Multi-user Robot*

To create a virtual agent, it is necessary to consider important items in human-human communication. According to Yamada, non-verbal information such as facial expressions, gaze, and gestures, which are called subtle expressions, are important in human communication [5]. Moreover, Tsuruda et al. pointed out that in the group of visual elements such as face and expressions have a high correlation with anthropomorphism, animacy, likability, perceived intelligence, and the correlation of face and expressions with virtual elements is particularly high [10]. We propose an easy-to-understand common agent by implementing a virtual agent with a face for any multi-user robot.

In this study, we assumed that the same user would use two different robots with different types and shapes at different locations but sharing the same features of the virtual agent. As shown in Fig. 1, agents are being implemented on the robots that have different conditions for communication. Even if the robot differs in shape, a user can use a multi-user robot as their personalized robot by communicating in the same way through an agent. Even though the robots are different in shape, it is desirable to minimize the impression difference in communication. Therefore, in this study, we evaluated the difference in user experience when a virtual agent that has the same face was implemented on robots that have different shapes and designed in order to eliminate the differences. To achieve this, we used the emotion estimation method based on physiological signals to evaluate the impression in real-time. Someya et al. and Kagawa et al. focused on the changes of an impression based on the position and motion of the mobile robot in real-time instead of based on the post-implementation questionnaires observation [11] [12]. By using our emotion evaluation method, the actual emotional response to the robot could be measured.

B. *Robot Features Modification*

To achieve a better impression of the user towards a robot, we could alter the robot's characteristics according to the user's emotion. In this study, we modified the features of the robot according to the users' preference which was based on the emotion classification. For the modification of the features, we proposed an autonomous position adjustment method that set the robot's position according to the physiological signals of the user. Here, with the pleasure level of the emotion measured, the robot approaching and retreating speed and position will be decided.

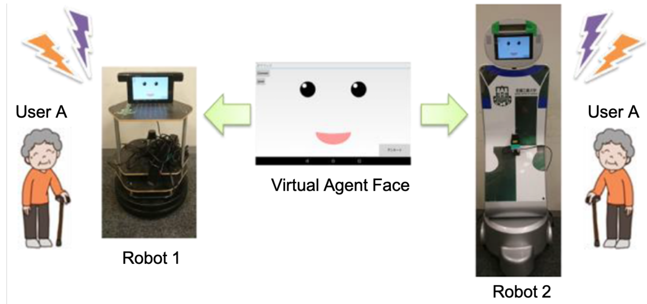

Figure 1. The idea of a virtual agent in multi-user robot

IV. Virtual Agent Platform Development and Preliminary Experiment

A. *Virtual Agent Platform*

The aim is to achieve a consistent level of personal interaction, even with different shapes of the robot that are not familiar. However, there is still no platform that has been built to be used for the virtual agent system. Therefore, we designed the virtual agent platform mechanism, and the design is illustrated in Fig. 2. In this platform, we set up the database that stores the information of each user (Personal Info DB). The users can execute their personal information from a server that stores the personal data in file units and enable personal settings on any machine at different locations. In this system, we built a server-client architecture and enabled file sharing where a client can easily use the files on a server.

As a basic system configuration, multi-user robots are the clients, and the sharing data mechanism by connecting to the clients is the server. The personal information database that maintains the executable files and individual registration information is recorded and located on the server. Executable files on the server are mounted on each client using the Network File System (NFS), and multiple files are made available collectively. With this, we built a mechanism where a virtual agent based on individual registration information can be executed and used from any client.

By preparing a configuration file based on individual differences of the multi-user robot condition such as the size and running speed of each robot, we implemented a unified virtual agent that is independent for any individual. In this study, we registered the face data of the virtual agent for each user and implemented the file sharing and executing.

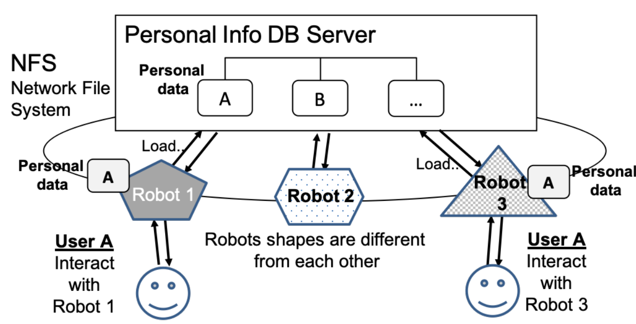

Figure 2. Virtual agent platform mechanism

B. Impression Evaluation of Robot Using Physiological Signals

To evaluate different responses to the approach of different robots, we estimated the users' emotions based on their physiological signals. These signals such as brain waves and heart rate are uncontrollable and keep changing according to the situation. Here, we conducted heart rate analysis and the brain wave measurement at the frontal-location of the brain, namely AF4, with the 10-20% method. This method has been used to evaluate human emotions and state of mind based on the fact that people react unconsciously to external stimuli in a way different from body sensations [13]. Ikeda et al. classified and estimated emotions by associating the brain waves and heart rate with the two axes of arousal and valence, respectively, on a coordinate system [14]. In this study, we used a similar method by Someya et al., since they produced desirable results in effective emotion evaluation on their robot [11].

In this study, the arousal level is obtained by the brain wave measurement using NeuroSky's MindWave, and the valence value is measured using Switch Science's heart rate sensor. The following frequency bands: 1-3 [Hz] (delta band), 4-7 [Hz] (theta band), 8-12 [Hz] (alpha band), 13-30 [Hz] (beta band, and 31-50 [Hz] (gamma band), were captured by the EEG and a notch filter set to 50/60 [Hz] was also applied [15]. From the points plotted based on the brain waves and heart rate values, the two-dimensional coordinate position (XY) is determined based on the emotion classification model. From that, the emotions have been classified into eight, "Happy", "Excited", "Alarmed", "Angry", "Sad", "Bored", "Sleepy" and "Calm" as shown in Fig. 3 [13] [14]. Then, we used vector classifying analysis for identifying the emotion expressed during the experiment by determining the magnitude of the emotion [13].

C. Experiment Outline

Following the example of the evaluation experiment by Ikeda et al., we analyzed the emotions with values obtained from the sensors when two different appearances of robots (Concierge robot and Kobuki robot) approach to and retreat from the user [14] [16] [17]. A male subject in the twenties participated in this experiment.

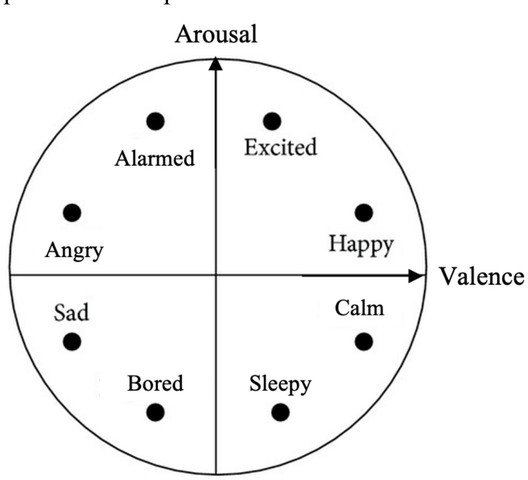

Figure 3. Emotion classification model

Figure 4. Concierge robot (left) and Kobuki robot (right) [13] [14]

D. Robot Design and Installation

Two robots were used for the experiment. "Concierge" of SOCIAL ROBOTICS and "Kobuki" of Yujin Robot, as shown in Fig. 4 [16] [17]. The face of the robot was equipped with the Galaxy tablet to indicate the face of the virtual agent. The Robot Operating System (ROS) was used to control the robots for the experiment. In this study, we used ROS Indigo, which is running on Ubuntu 14.04. The implementation of ROS supported by C++ and Python, and we used C++ in this study for robot control. A range sensor (URG-04LX-UG01) from Hokuyo was set up at the front and center of the robot to measure the distance data for the robot controlling.

F. Experiment Procedure

External factors such as noise could influence the measurement of physiological signals. Thus the experiment was carried out in a quiet room to eliminate the external variables with only the tester and subject. The subject was sitting on a chair with the electroencephalogram (EEG) and heart rate sensor attached to the body. A personal computer for estimating and recording physiological signals was set on the desk next to the subject. Then, the robot was placed at a distance of 3.00 [m] in front of the subject.

The distance moved by the robot was determined according to the distance of the personal space between individuals as follows [18].

- Close-range distance : ~ 0.45 [m]
- Individual distance : 0.45 [m] ~ 1.20 [m]
- Social distance : 1.20 [m] ~ 3.60 [m]
- Public distance : 3.60 [m] ~

The experiment mechanism is shown in Fig. 5. The moving distance of the robot in this study was set from 3.00 [m] to 0.40 [m] comprising close-range distance, individual distance, and social distance. The experimental step was carried out two times with each type of the robot, Concierge and Kobuki as follows [16] [17]:

(1) The robot is positioned at a distance of 3.00 [m] in front of the subject

(2) An EEG and a heart rate sensor are attached to the subject, then the subject rests for 2 [min] for the baseline measurement

(3) The robot approaches the subject at a speed of 0.2 [m/s] to a distance of 0.30 [m] ~ 0.40 [m] from the subject

(4) The robot stops just in front of the subject for 5 [s]

(5) The robot retreats from the subject at a speed of 0.2 [m/s] to a position 3.00 [m] in front of the subject

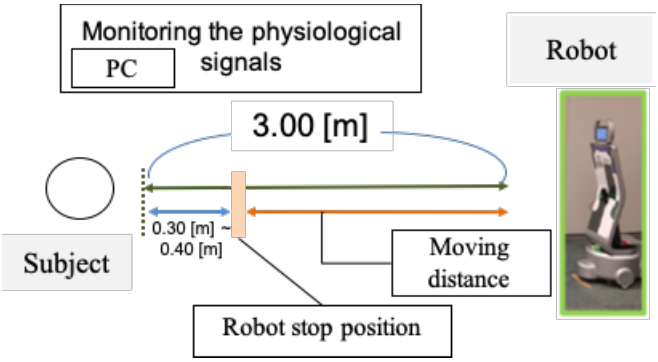

Figure 5. Experiment situation

G. *Experiment Results*

The transition of the estimated emotions results using the physiological signals for the two types of robots, Concierge and Kobuki are shown in Fig. 6 and Fig. 7 respectively. The changes have been observed for arousal and valence from both figures. Fig. 6 suggests that as the Concierge robot approaches, the subject felt "Excited".

Then, when comparing the value of emotion transition between Concierge and Kobuki robots, it was found that the Concierge robot was more likely to have higher arousal levels during the approach and retreat movement compared to the Kobuki robot. One of the reasons is the size of the Concierge robot is comparatively bigger than the Kobuki robot that makes the arousal level higher. By carrying out this experiment, it can be understood that the communication could be achieved by measuring the user's emotional response level from the robots that have differences in the characteristics.

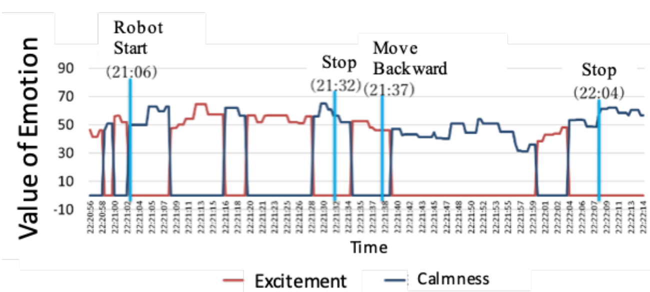

Figure 6. The measurement result of the movement of a Concierge robot.

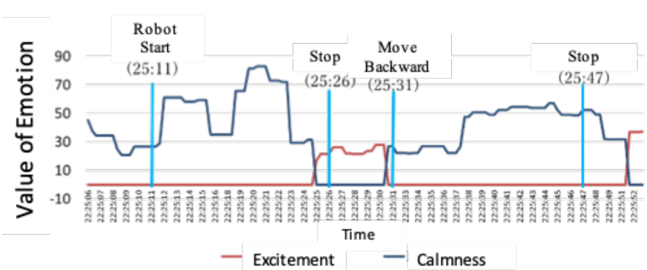

Figure 7. The measurement result of the movement of a Kobuki robot.

V. Improvement From Prior Experiment

From the previous experiment, we found that it is possible to use physiological signals to indicate the changes in the user's emotions as the robot approaches and retreats from the user. The aim is to achieve an optimum level of personal interaction by modifying robot features based on physiological measurements. The impression of the user towards a robot could be improved by altering the robot's characteristics according to the user's emotion. However, the previous experiment only investigated emotions toward different characteristics of the robots which leading to difficulty in general discussion.

Table 1. Robots' features. In the table header, FV is abbreviated for Feature Value, EOM is abbreviated for Ease of Modification.

Features	FV	Results of emotion studies	EOM
(1) Size	Big	High arousal level [Section 4]	Low
	Small	Low arousal level [Section 4]	Low
(2) Approach speed	Fast	Sad, angry [10]	High
	Slow	Happy, calm [10]	High
(3) Approach method	Linear	Happy, calm [10]	High
	Nonlinear	Sad, alarmed, angry [10]	High
(4) Position	Near	Angry, alarmed [9]	High
	Far	Angry [9]	High
(5) User's robot interest	High	Happy [9]	Low
	Low	Sad [9]	Low

We compared the characteristic features of the robots by referring to the robots' impression results of past studies by Someya et al. and Kagawa et al., and analyzed the ease of modification of each feature [11] [12]. A summary of the comparison result is shown in Table 1. From the table, the "(1) Size" of the robot could result in the changes of the arousal level, but the ease of modification for this feature was not easy. In this study, the adaptability to individuals needs to be considered for the features that are easy to modify.

The virtual agent platform designed in this study was intended to be used by many users such as in nursing homes. It is not necessarily limited to be utilized by users with a high level of interest in the robot. By modifying the "(2) Approach speed" and "(4) Position" of the robot according to the users' preference, it is possible to achieve "Calm" or "Happy", which was the emotion based on high valence level. With this modification, the robot could be used by many users including users with a low level of interest in the robot.

A. *Approach Speed and Position Control*

According to Table 1., when the approach speed is fast, the users tend to show "Sad" or "Angry" emotions. On the other hand, when the approach speed is slow, the users' emotions tend to be in "Happy" or "Calm" [12]. From these findings, it is considered that by a slight adjust in the approach speed, the users can maintain "Calm" or "Happy" emotions which were based on high valence level. Therefore, the approach speed of the robot was set to a low speed of 0.2 [m/s] in this study.

For the position, we proposed an autonomous position adjustment method that set the robot's position according to the physiological signals of the user. Based on the user's level of interest in the robot, the robot is set to move differently. User with a high level of interest in the robot is predicted to have an increased valence level when the robot approaches, whereas users with a low interest in the robot would have a decreased valence level when the robot approaches. Therefore, we decided to create a method where the robot approaches the user when their physiological signals change to the high level of valence, meanwhile, the robot retreats from the user when their physiological signals change to the low level of valence. With this position adjustment method, we consider that the emotions of "Calm", which were based on high valence and low arousal level, can be maintained.

For the autonomous position adjustment, we used the same emotion estimation method based on physiological signals similar to the one used in Someya et al. and Kagawa et al. [11] [12] [13] [14]. The behavior of the robot is determined by mapping the valence obtained from the pulse rate, and arousal obtained from the brain waves on a two-dimensional coordinate ranging from -100 to 100 on the horizontal and vertical axes. The emotion of "Calm" is observed when a positive value of valence (0 to 100) and a negative value of arousal (-100 to 0). When the "Calm" is observed from the user, the robot will approach. On the contrary, the emotion of "Alarmed" is interpreted when the valence in the negative range (-100 to 0) and arousal is in the positive range (0 to 100). When the "Alarmed" is detected, the robot will retreat. Meanwhile, in the case of any other combinations of valence and arousal levels, the robot will stop.

VI. Autonomous Position Adjustment Method

In order to group the participant based on their interest in the robot, we performed a preliminary experiment with 10 subjects to measure valence and arousal value when the robot approached and retreated. With the assumption that the user with high interest in the robot would feel more pleasure when the robot approach, while the user with low interest in the robot would feel more pleasure when the robot retreat. Therefore, two types of positioning were tested for all users: *approach* and *retreat*. For *approach*, the robot is designed that it would approach if the user's valence increase, and stop if the user's valence decrease. For the *retreat*, the robot is designed that it would retreat if the user's valence decrease, and stop if the user's valence increase. The number of users with high valence or arousal when the robot approaches and retreats are shown in Table 2. From the table, it can be implied that valence varies among individuals depending on the robot approach or retreat (5 versus 5). However, arousal seems to be similarly high (8 versus 2) when the robot approach, which could be misinterpreted if used to judge the robot interest level. Therefore, it is reasonable to use the valence level to determine the user's robot-interest level.

Table 2: The number of users with high valence or high arousal when the robot approaches and retreats

	No. of users with high valence	**No. of users with high arousal**
Approach	5	8
Retreat	5	2

In the following experiment, the subjects are divided into groups based on the valence result shown in Table 2, which implies the level of interest in the robot. The autonomous position adjustment method for each group is designed differently to achieve a better comfort feeling.

A. Design and Implementation

We designed two types of autonomous position adjustment methods: (1) position adjustment by approaching (*approach*) and (2) position adjustment by retreating (*retreat*). With position adjustment by approaching, the robot will approach the user when the user's valence level is positive, and then the robot will stop when valence is negative. With position adjustment by retreating, the robot will retreat from the user when the user's valence is negative, and then the robot will stop when the valence is positive. Fig. 8 shows the position adjustment map for *retreat* (upper) and *approach* (lower).

Here, we implemented the system for autonomous position adjustment and emotion estimation based on physiological signals with ROS and C++.

B. Experiment Procedure

Based on the previous experiment, we decided to use the Concierge robot in the experiment. This is because the Concierge robot had higher arousal levels during the approach and retreat movement compared to the Kobuki robot in the previous experiment. We believed that the stimulus which has magnificent reactions on the physiological signals, may come up with more significant results. Ten subjects (8 males and 2 females, aged 18-25) participated in the experiment with consent. The experiment is carried out to investigate the subjects' valence and arousal levels when the robot approaches and retreats. The subjects are divided into two groups according to their interest level in the robot: a high level of interest in the robot and a low level of interest in the robot. The classification of subjects is done based on their answers on the classification survey [12]. There were five subjects in each group.

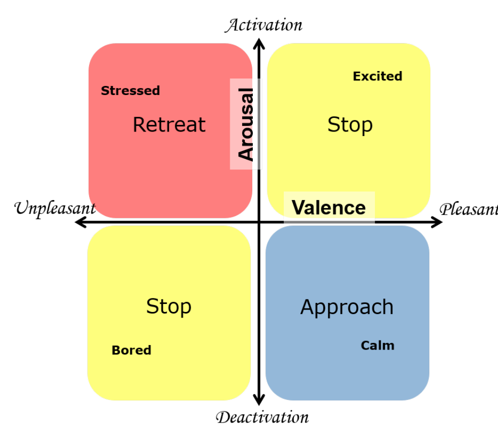

Figure 8. Position adjustment based on valence level.

The subjects' heart rate during the approaching and retreating of the robot was recorded and analyzed. The experimental step was a little bit different from the preliminary experiment. The experimental step was carried out as follows [16]:

(1) The robot is positioned at a distance of 3.00 [m] in front of the subject

(2) An EEG and a heart rate sensor are attached to the subject, then the subject rests for 2 [min] for the baseline measurement

(3) The robot approaches the subject at a speed of 0.2 [m/s] to a distance of 0.30 [m] ~ 0.40 [m] from the subject as ① in Fig. 8

(4) The robot stops just in front of the subject for 5 [s]

(5) The robot retreats from the subject at a speed of 0.2 [m/s] to a position 1.50 [m] in front of the subject as ② in Fig. 8

(6) The position of the robot will be adjusted using the autonomous position adjustment method for 30 [s] as ③ in Fig. 9, and then the robot will finally come to a complete stop

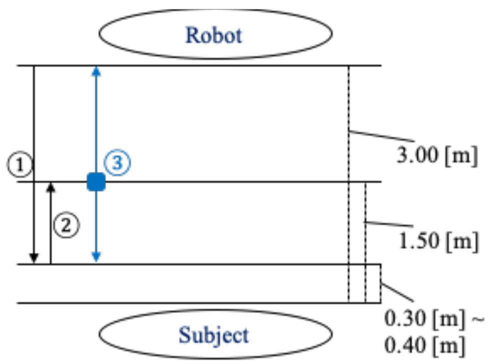

Figure 9. Experiment method with autonomous position adjustment

We compared the physiological signals (valence level) obtained when the robot was approaching and when the robot was retreating for both groups with high and low interest in the robot. Also, the arousal and valence levels recorded during the experiment will be compared between without autonomous position adjustment and with autonomous position adjustment.

C. Experiment Results

Fig. 10 and 11 shows time series analysis for arousal, valence and position for two different subjects; each belong to high level of interest in robot and low level of interest in robot group. Fig. 12 shows the average valence level during the approaching and retreating of the robot when there is an autonomous position adjustment and without the autonomous position adjustment. We observed the significant differences between the valence level during autonomous position adjustment and without the autonomous position adjustment for a high level of interest in the robot group $t(4)=-1.946$, $p=0.095$, and a low level of interest in the robot group $t(4)=-3.39$, $p=0.041$. From the results of the experiment, it could be implied that the subjects felt more pleasure when the robot's behavior is controlled by the autonomous position adjustment method. Therefore, we could imply from the results, such as when the subjects' valence level is low (unpleasant), stopping the robot by using an autonomous position adjustment method could suppress the decrease of valence level.

We also compared the average arousal level for approaching and retreating of the robot when there is an autonomous position adjustment and without autonomous

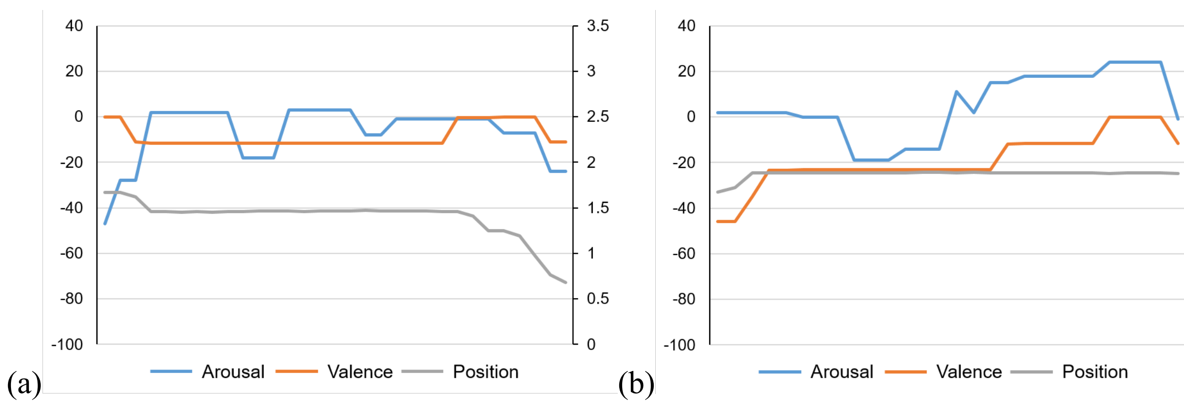

Figure 10. Time series analysis for arousal, valence (left Y-axis) and position (right Y-axis, in [m]) for subject A during approach (a) and retreat (b). Subject A is in high-level of interest in robot group.

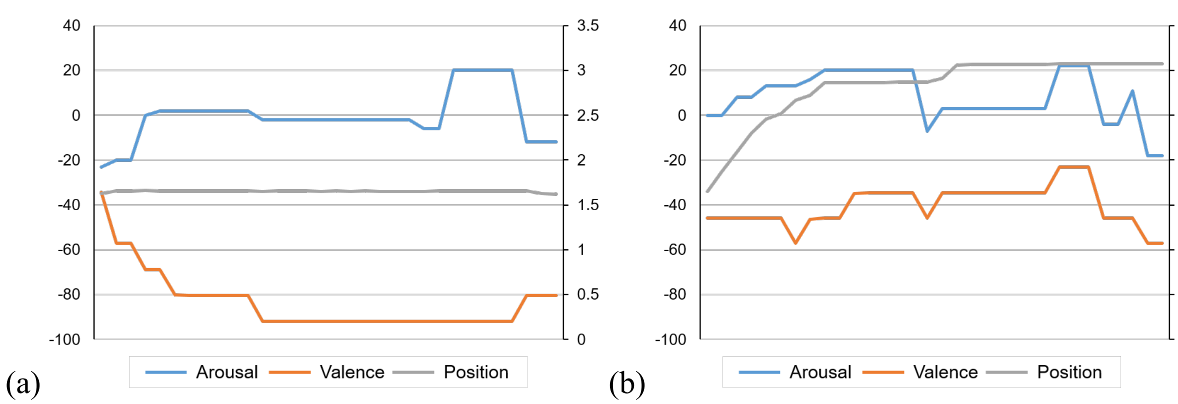

Figure 11. Time series analysis for arousal, valence (left Y-axis) and position (right Y-axis, in [m]) for subject B during approach (a) and retreat (b). Subject B is in low-level of interest in robot group.

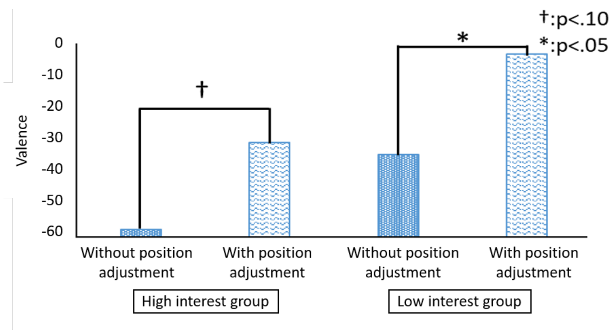

Figure 12. Average valence level during approach and retreat.

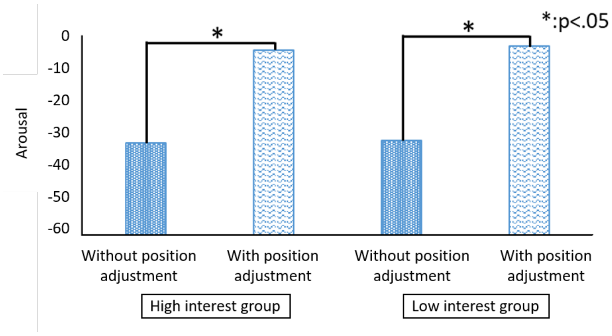

Figure 13. Average arousal level during approach and retreat.

position adjustment, as shown in Fig. 13. The average arousal level was higher when the autonomous position adjustment method was used for both robot approaching and retreating. Furthermore, we observed significant differences $t(4)=-2.866$, $p=0.023$, $t(4)=-5.362$, $p=0.01$ for both high and low levels of interest in the robot groups respectively between the arousal level during autonomous position adjustment and without the autonomous position adjustment.

From the results, it could be observed that the arousal level is higher even for subjects with low interest in robot during the autonomous position adjustment. This phenomenon is also mentioned in Kagawa et al., where the unpredictable movement of approaching, stopping, or retreating of the robot could make the subjects felt aroused; hence the arousal level increased [11].

VII. CONCLUSION

In this study, we proposed the implementation of personal communication services using a multi-user robot that could communicate with users based on their personal information. The proposed method could be used to solve the problem of the high cost of partner robots. A platform was designed and implemented using a virtual agent to achieve personal communication service using a multi-user robot. Using the developed platform, we conducted evaluation experiments for the difference in experiences due to the different features of the robots. Then, the autonomous position adjustment method is carried out based on the valence level measured from the physiological signals of the heart rate. The results from the autonomous position adjustment method showed that the arousal level increased due to irregular movements. Therefore, we can consider a method that has a constant movement to travel to an appropriate position in order to suppress the arousal level. In addition, in order to acquire physiological information from the users in real-time, it is important to examine the ways for recording communication data from the past study. It is also important to investigate the appropriate positioning through machine learning and suppressing an increase in arousal levels by decreasing the irregular movements. Last but not least, it is important to increase the number of subjects since the physiological signals may vary among individuals.

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