Abstract — Human-robot communication is an important subject for housekeeping, elderly care and entertainment robots. To make a natural communication entrainment between human and robot, emotion plays a vital role. From this viewpoint we have developed a KANSEI communication system based on emotional synchronization [1]. The robotic emotion was entrained to human emotion by using a vector field of dynamics, and then the robot made a facial expression to express the robot emotion. In this paper we investigate the effect of the emotional synchronization in human-robot KANSEI communications. We conducted experiments to evaluate the effects of the proposed system based on emotional synchronization. In the experiments of human-robot interaction using the emotional synchronization, we found that human feeling became comfortable when the robot made the synchronized facial expression to human emotion. Then it was confirmed that emotional synchronization in human-robot interaction could be effective to keep a comfortable state.

I. INTRODUCTION

In an aging society it is necessary to consider using robots for housekeeping or for work with elderly care in homes or in hospitals. Such assisting robots have to communicate with humans. Then, robots purposely designed for communicating with humans have attracted our attention. These robots are indispensable for human-robot symbiosis in the near future and need to have not only intelligence but also KANSEI to make natural communication. KANSEI is cerebral activity without logical thinking such as emotion, feeling, impression, sensitivity, intuition. Although much research has been done in artificial intelligence, there has been little consideration about KANSEI in many scientific fields such as engineering, since KANSEI is a subjective process. It is important to consider KANSEI in the field of communication robots.

It is well known that facial expressions play a very important role in daily communication. In order to familiarize the robot with human society, it is essential to create affinity with facial expressions. From this perspective, we have developed a head robot called KAMIN (KAnsei MIND robot) [2] to enhance emotional communication with humans. The robot has a facial expression function using a curved surface display. This technique provides a facial expression easily compared with other methods of mechanical facial expression.

We may change the atmosphere of interaction by adjusting our emotion to the other accordingly. For example, the interaction field becomes lively, if a robot makes a pleased reaction when the partner is pleased. On the other hand, if we do not make any reaction, the size of the interaction field does not increase very much. Jonsson et al. [3] found that matching the car voice to the drivers’ emotions had enormous consequences. Drivers who interacted with voices that matched their own emotional state had less than half as many accidents on average as drivers who interacted with mismatched voices. In communications between human beings, it was found that happy facial expressions are promoted and anger and sadness expressions are weekend by the partner’s reactions with synchronized emotional expressions [4]. Therefore, the emotional synchronization in human-robot interaction is important to swell the interaction state. From this point of view, we have proposed a KANSEI communication system based on the emotional synchronization for human-robot interaction [1]. The concept of the emotional synchronization is shown in Fig.1. The emotional synchronization guides human and robot to sympathy through the interaction. We have developed a communication system using KAMIN to implement the proposed method. There is a study on a mirroring technique in human-agent communication that mimics human behavior [10]. Our approach is different from the mirroring technique, because the proposed technique is based on entrainment of emotions between human and robot, not merely behavioral mimicry.

The ultimate purpose of this study is to find the interaction technique which makes a comfortable state through adjusting the communication field. In this paper, we evaluate the effects of the emotional synchronization in human-robot KANSEI communications.

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In the next section, we address the outline of KANSEI communication system based on the emotional synchronization. In section III we conduct the experiment to evaluate the influence of emotional synchronization. In section IV, communication experiments using the proposed communication system with emotional synchronization are conducted to examine the effectiveness. Finally, in section V we conclude this paper.

II. OUTLINE OF KANSEI COMMUNICATION SYSTEM

A. Communication system based on emotional synchronization

The schematic drawing of the developed system is shown in Fig.2. The human emotion is recognized by KANSEI analysis of human voice. The robotic emotion was entrained to the human emotion by using a vector field of dynamics. The robotic facial expression using a communication robot “KAMIN” was realized dynamically based on the robotic emotion.

The block diagram of the KANSEI communication system is shown in Fig.3. The system consists of recognition, emotion generation and expression parts. In the recognition part we use the voice analysis software, “RobEsense” made by Nemesysco Ltd. [5], to recognize the emotions from human voice. In the emotion generation part, the robotic emotion is determined by the emotional entrainment using human emotion. The emotional entrainment is performed by a vector field of dynamics according to the strength of the synchronization. We use an online design method of dynamics to realize the synchronization between human and robotic emotions. The robotic emotion is mapped to an emotional symbol space, and then the vector field of an expression space is generated according to the state of the emotional symbol space. The expression space generates the facial expression of KAMIN based on the state of the characteristics quantity. These information processing systems are performed continuously by using the vector fields of dynamics, since the emotion and the expression of the robot is constantly changing.

The design of the information processing is performed as follows: Firstly, we design the expression space with robotic expressions (e.g. happy, angry) using the vector field of dynamics. Secondly, we symbolize the designed expression space as a symbol space using the singular value decomposition method. Thirdly, we map the symbolized space to the emotion generation space (designed by using vector field) using the nonlinear mapping function which is using the polynomial expression approximation.

B. Emotional recognition and generation

The voice analysis software “RobEsense” [5] in the recognition part is a tool for judging the emotional state of human voices. It is used in a call center and for the diagnosis of depression mainly. It analyses the emotion of human voice using 18 parameters which are obtained from data using high speed sampling. The result of voice analysis does not depend on language or gender [5].

We chose two parameters, “Excited” and “Atmosphere”, from the 18 parameters of related emotions through the experiments. “Atmosphere” identifies speaker’s atmosphere such as seems happy or trivial. Russell’s circumplex model of emotion [6] is utilized to express human and robotic emotions in the recognition part. This model can represent the emotions based on a two dimensional space as shown in Fig.4. One of the axes in the space expresses “comfort-discomfort,” and the other is “rouse-sleep”. Using the numerical values of the parameters “Excited” and “Atmosphere” in “RobEsense” we express the emotional state based on Russell’s model. In addition, we form a vector field of dynamics on the two dimensional

Fig.2 Schematic drawing of human-KAMIN interaction system

Fig.3 Block diagram of the KANSEI communication system

Fig.4 Russell's circumplex model of affect
space to realize the entrainment between the human and robotic emotions. In the vector field we make a basin of attractor near the position of human emotion to entrain the robotic emotion. We call it the emotional generation space for the robot as shown in Fig.5. The human emotion obtained by “RobEsense” is plotted in the vector field, and an attractor is constructed in the vector field using the online-design method of dynamics. The attractor is updated continuously according to the result of the recognition part. In the on-line design method, the oblivion and weighted parameters explained below, as determined by the strength of the entrainment in the emotional generation space.

We conducted an evaluation experiment of emotional recognition using voice analysis. 16 voice samples which are obtained in every day life are utilized to evaluate the emotion. We compared the emotional state which was declared by the speaker with the atmosphere and excited parameters of RobEsense in the Russell’s model plane. Figure 6 shows the result of the evaluation experiment. The numbers are sample numbers of the voice data. The speaker’s emotions and RobEsense parameters of the same sample number are located in the same area in the plane except area (B) in Fig.4. The area(B) shows the state where awake level is high and unpleasant, it is considered that the speaker had not reached in such a state. Therefore, we can evaluate the speaker’s emotion using the atmosphere and excited parameters of RobEsense.

C. KAMIN and Facial expression

Yamada [8] found the relationship between the basic emotional category and the structural variables of facial expression based on the displacement structure of the characteristics points in the facial expression. Yamada reported that there are two kinds of the facial structural variables called “Inclination” and “Bend”. “Inclination” means the displacement of the characteristic points concerning the degree of the slant of eyes and eyebrows. In the case of the mouth, it means the strength forming the shape of V and reverse V characters. “Bend” means the curvature of eyebrows, or the strength of the opening of the eyes and the mouth. In this study, we referred to this facial expression model in order to make the robotic facial expression of KAMIN.

We make a two dimensional space whose axes indicate “Inclination” and “Bend” to express the facial image. And then we build a vector field of dynamics on the two dimensional space to make the facial expression dynamically. In this study we assume that the facial expression is not static, it is a dynamic process. The facial expression is modeled by an attractor on this vector field. We designed the attractors of the basic six emotions based on Yamada’s facial expression model.

We symbolized the facial expression space and make a symbol space. In the symbol space a point expresses an emotional state and a vector field of the facial expression space. Therefore, we can change the vector field of the facial expression by the state of the symbol space.

We used the head robot KAMIN [3] as shown in Fig.7. The head mechanism is a facial image display, and it consists of a dome screen, a fish-eye lens, and a projector. The face image is projected to the dome screen from the inside. The fish-eye lens is installed on the front of the projector, and it projects the picture on the dome screen.

The facial image is made up of the line drawing, and it is determined numerically. The facial image consists of
straight lines, bezier curves, and circles. A straight line can be created from specifying two points. Similarly a bezier curve is four points, and a circle is the center point and a radius. That is, the state of facial expression is specified with the parameter vector of the points and the radiuses.

An emotional state is expressed within the parameters of six basic emotions: happy, sad, anger, fear, surprise, and disgust. The parameter vector of the facial image is computed from this emotional state. The state of the face model in six emotions is set up beforehand.

Using this method, the subtle expression between emotional states is possible by using the parameter vector. We modeled the parameter vector based on “Inclination” and “Bend”. Then we can determine the parameter vector by the coordinate in the facial expression space. Figure 8 shows an example of facial expressions which express from normal to happy emotion.

III. INFLUENCE OF EMOTIONAL SYNCHRONIZATION

A. Experimental design

In order to examine the influence of the emotional synchronization to human emotional state, we conducted an experiment. It was necessary to have the subjects be a comfortable or uncomfortable state at the time of experiment. Therefore, either a comfortable or uncomfortable state was induced in each subject at the beginning of the experiment. This was accomplished by showing the subjects six slides of picture. Each subject observed two kinds of the pictures to induce comfortable and uncomfortable states. In a comfortable state, all of the pictures reflected happy themes; for uncomfortable state, all of the pictures reflected disturbing themes. We checked if slides can change the psychological status by using “RobEsense”.

After the subjects were led to comfortable and uncomfortable state, the subjects communicated with KAMIN. The robot expressed the emotional state of comfort or discomfort for each subject with each emotional state. The overview of the communication experiment is shown in Fig.9. The subject sat on the position where was 100 [cm] away from KAMIN and talked to the robot. The subject talked while watching a face of KAMIN. In addition, we did not address the contents of communication to the subjects, they talked freely and at their own pace. Each subject took the communication experiment four times; two times in the synchronization case and two times in the non-synchronization case. We assumed that if the subject’s emotion is comfortable or uncomfortable, then the robot’s emotion is comfortable or uncomfortable, respectively, in the case of synchronization. In the non-synchronization case, if the subject’s emotion is comfortable or uncomfortable, then the robot’s emotion is uncomfortable or comfortable, respectively. The subjects filled in a questionnaire based on a semantic differential (SD) method [9] after the communication to examine the impression of the subject to KAMIN. Subjects answered in 7-point scoring scale. In addition, the subjects were asked which communication case you liked better to evaluate change of subject’s emotion by the communication.

B. Results of voice analysis and subject’s feeling

We compared the change of the subject’s emotion with the strength of synchronization of robot using atmosphere parameter of voice analysis “RobEsense”. The value of the atmosphere parameter indicates the strength of comfortable state. Figure 10 shows the average values of the atmosphere parameter for each communication method, synchronization or non-synchronization case. In the case of synchronization, the average value of the atmosphere parameter is larger than that of the non-synchronization case. Therefore, the subjects feel better in the emotional synchronization of KAMIN.
The results of the question about the human feeling in each communication case are as follows. When the subject’s emotion was comfort, all subjects answered that the comfortable response of KAMIN was better than uncomfortable one. On the other hand, when the subject’s emotion was identified as discomfort, 6 subjects answered that the uncomfortable response of KAMIN was better than comfortable one. Consequently, the synchronized response of KAMIN induced the human comfortable state than the unsynchronized response. That is, the human emotional state becomes more comfortable in the case of high synchronization.

C. Evaluation of impression to KAMIN

We examined the difference of the impression to KAMIN by the SD method, when KAMIN expresses both synchronized and non-synchronized responses. The subjects filled in a questionnaire, with a 7-point scoring scale. The average values answered in the questionnaires are shown in Fig.11. It was found that in the case of comfortable response of KAMIN the subjects had positive impressions in terms of active, happy, friendly and so on comparing with the discomfort case.

IV. COMMUNICATION EXPERIMENT

A. Experimental Design

In order to examine the effectiveness of the proposed KANSEI communication system, we conducted some experiments using the communication system of KAMIN. The number of subjects was ten. The subject talked while watching the face of KAMIN. In addition, we did not address the contents of communication to the subjects, they talked freely and at their own pace. Each subject took the communication experiment four times. One of the experiments was conducted by using the emotional synchronization, the others were the non-synchronization cases. In the case of non-synchronization, we utilized three.

![Fig.10 Result of atmosphere parameters in voice analysis](image1)

![Fig.11 Impression of KAMIN with synchronized and non-synchronized expressions. Subject’s emotion: (a) Comfort, (b) Discomfort.](image2)

![Fig.12 Example of synchronization reaction](image3)
different conditions in facial expression of KAMIN. The robotic emotion in the non-synchronization case is located on a constant state in the emotional generation space. We selected the three kinds of robotic emotions as normal, comfort and discomfort. In the case of the synchronization, the facial expression of KAMIN changed much by reacting the subject’s emotional state. Figures 12 and 13 show the examples of synchronized and non-synchronized responses, respectively. In the case of non-synchronization, the facial expression did not change so much, since the emotion is fixed in a constant state. In addition, the subjects filled in a questionnaire based on the SD method after the communication to examine the impression of the subject. Subjects answered in 7-point scoring scale.

B. Results

The average values answered in the questionnaires are shown in Fig.14. Four kinds of average values are shown in the figure, a synchronization case and non-synchronization cases, normal, comfort, discomfort. The value of the synchronization case is larger than that of the non-synchronization case. It was found that in the case of synchronization case the subjects felt better comparing with all the non-synchronization cases.

V. CONCLUSIONS

In this paper we investigated the effect of the emotional synchronization in human-robot KANSEI communications. We conducted experiments to evaluate the effects of the proposed system based on emotional synchronization. In the experiments of human-robot interaction using the emotional synchronization, we found that human feeling became comfortable when the robot made the synchronized facial expression to human emotion. Then it was confirmed that emotional synchronization in human-robot interaction could be effective to keep a comfortable state.

As the future work, we are planning to investigate the effect of the emotional synchronization in long-term experiments.

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REFERENCES


