Development and Evaluation of a Collaborative Virtual Environment Supporting Self Feedbacks of Electroencephalogram

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ABSTRACT

Currently, there are many occasions to communicate with each other in the collaborative virtual environment. However, it is more difficult to keep high-motivation for participating in communication in such virtual environment than in face-to-face environment. It is considered that the reasons are 1) the difficulty of understanding how their own motivations are and 2) the boring expression due to the fixed view point. To address this issue, we display electroencephalogram information to a virtual space by *forward-backward* model – zoom in/out of whole virtual space. According to the results of experiment, our system successfully provides an environment in which people can keep high-motivations for participating in communication.

Keywords: Collaborative Virtual Environment, Avatar, Conference, Communication, Electroencephalogram, Electroencephalography, Forward-backward model, Zoom

1 INTRODUCTION

Currently, there are a number of occasions to communicate with each other in the virtual space through the spread of collaborative virtual environments. We have developed e-MulCS (enhanced Multiparty Conference System) as the teleconference system using a virtual environment that enables users located in different places to share a seamless space and communicate smoothly [1]. The user of this system wears a video see-through head mounted display on which remote users are represented as computer graphics avatars, as if they are located in the local place.

However, users reported that keeping concentration and high-motivation is hard in the virtual environment provided by remote communication systems such as e-MulCS. According to the interview survey, there seemed to be two reasons for this problem. First, it is difficult to aware the spontaneous degradation of his/her own motivation though users seem to have a tendency to be in such state when they are communicating remotely. Second, the expression of environment is boring because the view point of user is almost fixed.

To address this issue, we have developed the collaborative virtual environment supporting self feedbacks of thinking states by *forward-backward* model (proposed in Chapter 4.2). In this environment, the thinking states derived from electroencephalogram are described with the zoom of the virtual space.

Section 2 reviews existing Multi-party conference system using collaborative virtual environment, and Section 3 mentions electroencephalogram and related works. Section 4 presents our approach, Section 5 describes the prototype system, and Section 6 presents an evaluation of the prototype. Section 7 concludes with a discussion and brief summary.

2 MULTI-PARTY CONFERENCE SYSTEM USING COLLABORATIVE VIRTUAL ENVIRONMENT

2.1 Existing Technologies

The multi-party conference system (video conference system), which is generally used by many people, has a window which is divided into several smaller windows according to the number of participants, and displays the video of each participant's front view in each divided-window (see Figure 1.) [2]. However, this system has some big problems. Because of the divided-window, it is hard to understand the positional relationships of participants and there is no way to figure out who is focusing on whom. Also, participants cannot get the feeling that they are together due to separation of display area. These facts become the obstacles for the participants to communicate smoothly, and make them feel inconvenient.

Several studies were made on how to enable the participants to be aware of "who is focusing on whom" and to get the sense of co-presence. In MAJIC [3][4], the participants are able to communicate with the others at a distant place, and they can be aware of on whom the other participants are focusing due to special allocation of screen and cameras. Likewise, cAR/Pe! also provides the shared virtual environment for remote collaboration [5]. In this system, live video streams of the participants are spatially

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arranged around a virtual table, so they can see where the other participants are looking at. Though not dedicated to conference purpose, systems such as PAW [6], Valentine [7], InterSpace [8] and SecondLife [9] construct a virtual space, and users can use the avatar (embodiment of a participant in the virtual space) to go around freely and communicate with one another.

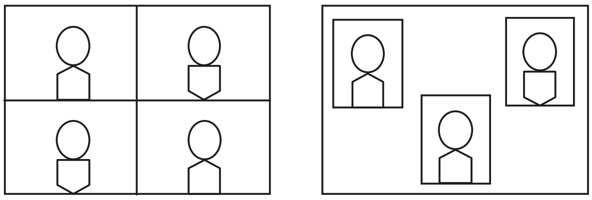

Figure 1: Windows of the general video conference systems.

We have developed e-MulCS (**e**nhanced **Mul**tiparty **C**onference **S**ystem) as the teleconference system that enables users located in different places to share a seamless space and communicate smoothly [1]. The user of this system wears a video see-through head mounted display on which remote users are represented as computer graphics avatars, as if they are located in the local place. The direction of face is detected using the motion sensor attached to the head mounted display and reflected in the direction of the avatar (see Figure. 2). It is confirmed that users are able to understand easily "who is focusing on whom" and make communication a success [1]. In this system, electroencephalogram information of participant is also reflected in postures of the avatar (see Section 3).

Figure 2: e-MulCS.

3 ELECTROENCEPHALOGRAM

3.1 Properties of Electroencephalogram

Electroencephalogram is biologic information observed constantly, and changes under the influence of thinking activity of the brain. Historically five major types of electroencephalogram activity are recognized: Delta wave (up to 4Hz), Theta wave (from 4Hz to 8Hz), Alpha wave (from 8Hz to 12Hz), Beta wave (from 12Hz to 30Hz) and Gamma wave (above 30Hz), though there is no precise agreement on the frequency ranges for each type. Especially, the zone of Beta wave appears frequently at a time when thinking process is required, and there is the feature of seldom appearing at the time when thinking is not required [10][11][12][13].

3.2 Existing Technologies

Information such as feelings and emotions are acquired by analyzing electroencephalogram, though those are hard to be obtained from appearances. There was a research of tutor assisting system using electroencephalography and mixed reality [14]. In this system, thinking states of students are estimated using electroencephalography, and the tutor can see their thinking states represented with computer graphics on each student's face by use of the head mounted display.

There were several researches on video editing using electroencephalography. In the research of Aizawa at el., movies captured by wearable cameras were edited using information obtained from electroencephalograms [15]. In the research of Nakamura at el., a digest of movie was generated using electroencephalograms of cameramen.

Musha at el. proposed Emotion Spectrum Analysis Method (ESAM), in which they tried to analyze human's emotions and feelings [17]. On the other hand, Robert at el. analyzed the pattern of electroencephalogram while users made the imagination of foot movement [18]. They were trying to develop a brain-computer interface by which users can walk through the virtual environment without any muscular activity but using only the imagination of foot movement.

In e-MulCS, electroencephalogram information of each participant is reflected in postures of the avatar, and whether the participant is thinking or not can be recognized intuitively [19]. For example, in Figure 2, it can be recognized that the avatar in the center and in the left side is thinking, and the one on the right side is in the state of not thinking.

4 PROPOSAL OF COLLABORATIVE VIRTUAL ENVIRONMENT SUPPORTING SELF FEEDBACKS OF ELECTROENCEPHALOGRAM

In remote communication, user motivations tend to be less than in case of face-to-face communication. It is considered that there are two reasons as follows.

1) It is difficult to aware the spontaneous degradation of his/her own motivation (becomes the state of not thinking), though users seem to have a tendency to be in such state when they are communicating remotely.

2) The view point of user is fixed in many cases. This static environment seems to be partially responsible for the degradation of commitment because it is boring.

To address these issues, it is considered that awareness of one's own thinking state and weariless interface are necessary. In consideration of these arguments, we propose a new approach to develop the collaborative virtual environment supporting self feedbacks of electroencephalogram with *forward-backward* model.

4.1 Extraction of Thinking Degree

We use electroencephalograms in order to extract a user's thinking condition. The reasons are as follows.

1) Electroencephalograms change under the influence of thinking activities of the brain as mentioned in Chapter 3.1. Especially, the zone of Beta wave appears frequently at a time when thinking process is required, and there is the feature of seldom appearing at the time when thinking is not required [10][11][12][13].

2) The electroencephalogram can be observed continuously, different from expression and attitude changes.

3) Internal changes of participants those cannot be observed from expressions and attitudes are detectable from electroencephalograms.

In this research, the information on whether the user is thinking or not thinking is extracted by analyzing the electroencephalogram.

4.2 Self-Feedbacks of Thinking Degree by Zooming

There are some means that can be used to give self feedback of electroencephalogram states. The simplest way is displaying electroencephalogram power of each moment on the meter (we call this the meter method). However, it can be a burden to the user to read a meter while concentrating on communication and conversation. Honda at el. proposed a virtual office system named VALENTINE in which user's view width changes according to the level of concentration [7]. In this system, the edges of view area become dim when users concentrate on their own works (we call this the dim method). However, considering that our goal is realizing smooth communication, this approach is not appropriate because dim expression makes it hard for users to see their partners. These arguments point a need for the natural, intuitive and easily viewable feedback method for smooth communication.

Here, we had observed our laboratories' students who are talking with each other for a long while, and noticed the specified pattern in their behaviors. Many students incline forward when they are immersed in conversation. On the other hand, they incline backward and lean over on the chair back when they seemed to be bored and thinking nothing. We have considered that intuitive feedback is accomplished by the model based on these ordinary forward and backward behaviors, and designed the ***forward-backward*** model for describing the state of electroencephalogram. In this model, the virtual space is zoomed in when the power of electroencephalogram is high (the brain activity is increased), and zoomed out when the power of electroencephalogram is low (the brain activity is decreased). Unlike in case of the meter method, the user does not have to take his/her eyes off the people in the virtual space for checking the meter, because the state of electroencephalogram is described with the zoom of the whole space. Differently from the dim method, the user can see his/her partners clearly if the zoom range is conducted within a certain definite range. In addition, the problem marked 2 at the beginning of Chapter 4 seems to be solved, because the view of user zooms in and out interactively according to continuous changes of electroencephalogram.

5 PROTOTYPE SYSTEM

5.1 EEG Measurement

We use the electroencephalograph IBVA of which shape looks like a headband, because this device is enough small and light for users to wear easily and move freely. This device sends data to the receiver linked to the computer on real time wirelessly. IBVA has three electrodes. One is placed on the center of forehead and the others are placed on Fp1 and Fp2 of International 10-20 System of Electrode Placement, which is a method used to describe the location of scalp electrodes for electroencephalogram recording [20]. The forehead one is the reference electrode, and electroencephalogram is measured using potential difference between Fp1 and Fp2. The range of frequency for measurement is 0 - 60 Hz, and this range is inflexible.

In order to treat the information sent from the transmitter of IBVA on real time, we have created the program (see Figure 3), which analyzes data sent from the receiver on real time. In this program, the function of Hanning window is applied to the data from the serial port, which is originally sent from the transmitter of IBVA. Then, Fast Fourier Transform (FFT) of the data is carried out and the spectrum of 0 - 60 Hz is obtained about every 1.15 seconds.

As to the frequency, first, bands in which there are many noises (0 - 4 Hz) or electroencephalogram is rarely detected (40 - 60 Hz) are removed. Then, 12 - 28 Hz (a part of Beta wave) is extracted and used for following calculation, because it is confirmed by our 60-subject-experiment that electroencephalogram of this band has a pronounced tendency to appear frequently at a time when thinking process is required, and not to appear at the time when thinking is not required [21][22].

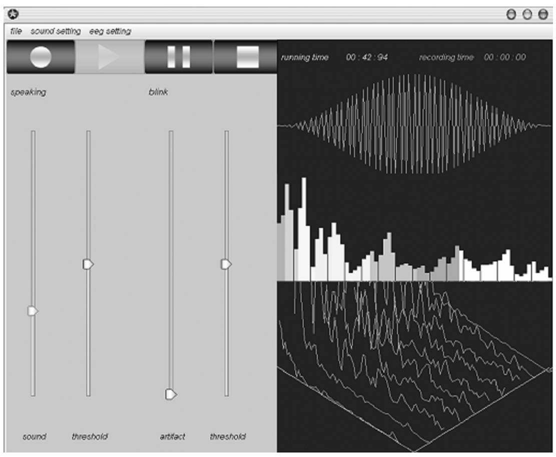

Figure 3: Electroencephalogram handling program.

5.2 Zoom Interface

Electroencephalogram is labile biologic information. It is susceptible to noises caused by body motions. For example, Figure 4 (top) shows the electroencephalogram changes of the subject who had been communicating with partners. The vertical axis is the power of electroencephalogram (normalized to make the maximum strength be 1 and minimum strength be 0) and the horizontal axis is the time-line. It shows that electroencephalogram fluctuates in a short time, and it may prevent the user from concentrating on communication if these frequent changes of electroencephalogram are reflected in the state of zoom directly. To avoid such a consequence, the zoom state of each moment is determined by not only the electroencephalogram data of the moment, but the data obtained during the past certain period from the moment. This is described as follows.

$$ZoomLevel(x) = \sum_{i=0}^{N-1} \{(N-i) \times EEGPower(x-i)\}$$

x is the ID of each moment and ***EEGPower(x)*** is the power of electroencephalogram at the moment ***x***. The sigma function means that the data of the past ***N*** moments are required for calculating the zoom level of each moment, and ***(N-i)*** is the weighting function by which weights of newer data are increased. In this implementation, we use 10 as ***N***. It takes about 11.5 seconds to obtain 10 sets of data. Here, ***ZoomLevel(x)*** is derived by this equation and scaled to 5 levels (1: zoom out most far – 5: zoom in most close). Figure 4 (bottom) shows the change of zoom level derived by use of the electroencephalogram data described in Figure 4 (top). For example, electroencephalogram power changes widely in a short time around 600 seconds. On the other hand, these changes are absorbed to some extent in case of zoom level. This enables to prevent zoom change from occurring frequently, and the burden of user may be reduced. Figure 5 (top) and Figure 5 (bottom) shows appearances of the user interface when zoom in and out is occurred, respectively. Both views are interpolated smoothly.

Note that the maximum and minimum strength values of electroencephalogram are required for calculating zoom levels, though those values are obtained not in real-time but after-the-fact. To address this issue, electroencephalograms of users are measured during a prior task conducted immediately before using the system and the maximum and minimum values are confirmed beforehand. Then these values are used as substitutes for true values.

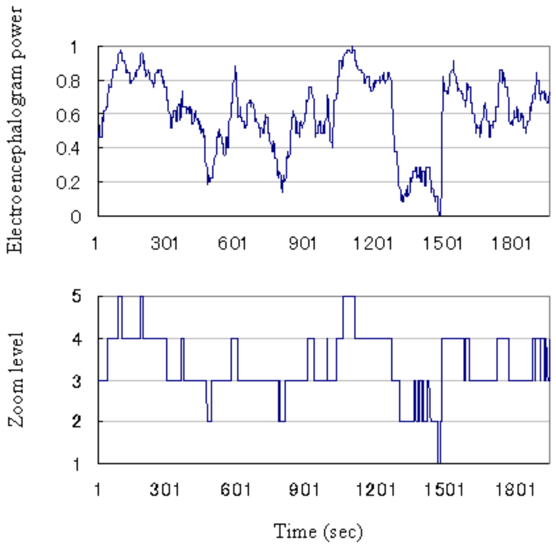

Figure 4: Electroencephalogram power (top) and zoom-level (bottom).

6 EXPERIMENT

6.1 Overview

We conducted one experiment to

1) Evaluate whether a high level of user commitment is maintained by self feedbacks of electroencephalogram.

2) Evaluate whether the *zoom method* based on the *forward-backward* model is adequate for self feedbacks of electroencephalogram.

As to 1), the environment with *no self feedback* and *self feedbacks by the meter method* (described later) are compared. The meter method is adopted for comparison way because this simple method may have few external causes. As to 2), the environment with *self feedbacks by the meter method* and *self feedbacks by the zoom method* (the proposal method) are compared.

6.2 Survey Method

As one example of remote communications, a meeting in which participants are required to take an active part and exercise their wits was applied to the experimental task. In this task, subjects (11 students in their twenties) were required to attend meetings one by one and argue with two experimenters who are located in distant places using e-MulCS.

Subjects received an instruction to make suggestions and remarks actively, though they also instructed not to speak more than is necessary to avoid unnaturalness of communication. Each subject attended three types of meetings of which lengths were five minutes respectively. Each pattern of meeting had one topic and one self feedback method of electroencephalogram. Topics and feedback methods were different in each meeting pattern. Three topics were prepared as follows.

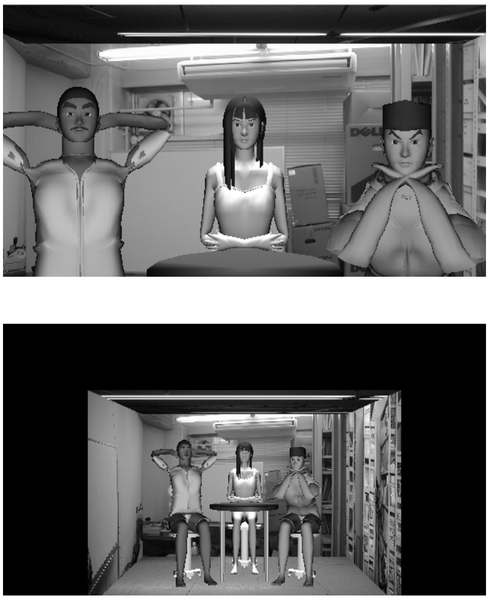

Figure 5: Zoom in (top) and zoom out (bottom).

1) What would you do if you won the 300 million yen in a lottery?

2) What is required to make sumo wrestling be included among Olympic events?

3) What would you do if you got a time machine?

All of them were required to make suggestions, and selected carefully so as not to depend on knowledge and experiment of each subject. It was confirmed beforehand that none of subjects had ever won a large amount of money in the lottery or played sumo wrestling.

As to self feedback methods, there were *no self feedback*, *self feedbacks by the meter* and *self feedbacks by the zoom* (the proposal method). In *no self feedbacks method*, there were no changes caused by electroencephalogram. In *meter method*, the state of electroencephalogram was indicated by the meter of which appearance was simple as much as possible to eliminate external causes (see Figure 6). *Zoom method* was the same method as described in Chapter 5.2. In case that the power of electroencephalogram was strong/weak, the meter moved upwards/downwards in *meter method* and zoomed in/out was occurred in *zoom method*. *Meter method* and *zoom method* had five levels of the same scale (1: electroencephalogram power is weak - 5: electroencephalogram is strong). In case the electroencephalogram power became more/less than the previously-defined thresholds, the level changed. Note that the conditions of changing level were same in both methods.

To reduce the influences of the combinations of topic and feedback method, those combinations were determined with lot drew by subjects themselves. Two experimenters who attended meetings were notified of the determined topic at the start of each meeting. On the other hand, the experimenters were not notified of which method was applied so as to take the same stance in all the case.

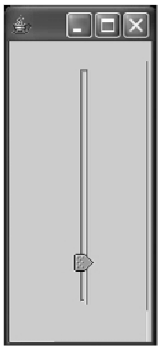

Figure 6: The appearance of meter.

It is important to mention here that *no self feedback method* was applied to the first meeting regardless of lot results, because the first meeting was not only experimental task but also *prior task* mentioned in Chapter 5.2. That is to say, the maximum and minimum values of electroencephalogram obtained during the first meeting (with no feedback of electroencephalogram) were applied in the second and third meeting (with feedbacks of electroencephalogram). The style of the first meeting and the later meetings were almost same except for feedback method, so the maximum and minimum values obtained the first one seemed to be the reasonable substitutes for true values in the later ones.

6.3 Quantitative Results

Quantitative results of the experiment are given in Table 1. Meter method shows lower average level and higher number of changes. Taking into account that the conditions of changing level were same in both methods as described in Chapter 6.1, this difference is referable to the difference of effects provided by electroencephalogram display method. It is considered that keeping their concentrations and motivations stable at a high level was difficult in meter method, because they had to drift their attention to the meter purposely each time. That is to say, they had to pay attention to both of communication partners and the meter located at the particular area in the view. In contrast, zoom method shows higher average level and lower number of changes. This might indicate that keeping high concentrations and motivations becomes easier by intuitive zoom method - the whole of view is zoomed in as if the user inclines forward when he/she is thinking, and zoomed out as if he/she inclines backward when not thinking.

Table 1: Quantitative results (N=11).

	Average level	Number of changes	Standard deviation
Meter method	2.6	40.1	1.19
Zoom method	3.8	31.7	0.81

For more detailed analysis, number of supportive response (such as "I see." and "Exactly.") and utterance length are applied as indicators of motivation during the tasks. The surveyed results are shown in Table 2.

Table 2: Number of supportive response and utterance length (N=11).

	Number of supportive response		Utterance length	
	Average (times)	Standard deviation	Average (sec)	Standard deviation
No feedback	20.27	9.06	56.18	23.62
Meter method	19.73	7.73	78.45	29.38
Zoom method	19.73	10.25	98.36	32.15

First, we conducted Wilcoxon's paired signed rank test between *no feedback method* and *meter method* to evaluate effects of the availability of feedback. As to the number of supportive response, we could not observe a significant difference because the P value for the number of supportive response was larger than 0.10. On the other hand, the P value existed between 0.01 and 0.05 for the utterance length. Then, we conducted Wilcoxon's paired signed rank test between *meter method* and *zoom method* to evaluate effects of the expression of feedback. As to the number of supportive response, we could not observe a significant difference because the P value for the number of supportive response was larger than 0.10. On the other hand, the P value is less than 0.01 for the utterance length. Based on these results, it is considered that subjects had spoken longer because a high level of motivations were maintained by self feedbacks of electroencephalogram, and the effect of self feedbacks were increased by *zoom method*.

Let us mention the result of utterance length in more detail. Compared meter method to zoom method, one subject's utterance length decreased of 23.4%, though those of the other ten subjects increased by an average of 114.0%. In the interview to the subjects, the subject whose utterance length decreased remarked that his concentration had been prevented by zooming in, though most of other subjects remarked that noticing their concentration levels had been high by zooming in, they had been motivated to speak more. It follows from these arguments that *zoom method* was effective for most of users, but there is still room for improvement.

6.4 Qualitative Results

Table 3 shows the results of questionnaires sent out to the subjects. The subjects were required to answer each question on a four-grade evaluation (0:I do not think so. - 3:I think so).

Table 3: Results of the questionnaire (N=11).

Question		No feedback	Meter method	Zoom method
Could you keep your motivation high?	Average	1.73	2.27	2.73
	Standard deviation	0.65	0.47	0.47
Could you concentrate on conversations?	Average	2.00	1.82	2.55
	Standard deviation	0.77	0.75	0.69
Could you have a feeling of being in the virtual environment?	Average	0.82	1.27	2.36
	Standard deviation	0.60	0.65	0.50
Did you feel the indicator (meter/zoom) described your thinking states?	Average	-	1.82	2.18
	Standard deviation	-	0.75	0.40

Asked "Could you keep your motivation high?", *zoom method* was scored the highest point, followed by *meter method* and *no feedback method*. The P value of Wilcoxon's paired signed rank test between *no feedback method* and *meter method* was less than 0.01, and between *meter method* and *zoom method* was less than 0.01 too. These data indicates that the availability of feedback was effective to keeping high motivations, and the effect was enhanced by zooming expression. The difference between the result of *meter method* and *zoom method* was attributed to the style of expression, that is, the expression style of *zoom method* is more intuitive than that of *meter method*. Many subjects remarked that they had been distracted by checking the meter and had difficulty concentrating on conversations. Asked "Could you concentrate on conversations?", *meter method* was scored the lowest point. As to *zoom method*, the subjects scored the highest point and remarked "Easy to understand" and "Not embarrassed".

In zoom method, the view point of user zooms in and out as if he/she inclines forward and backward, though he/she actually does not move at all. We had worried about that the mismatch between the virtual view point and the real body position might decrease the sense of immersion to the virtual environment. However, asked "Could you have a feeling of being in the virtual environment?", zoom method was scored the highest point, and the P value of Wilcoxon's paired signed rank test between zoom method and meter method (scored second highest) was less than 0.01. In the interview to the subjects, no one reported the virtual sickness. It follows from this result, the zoom expression based on the electroencephalogram have a certain positive effect on increasing the sense of immersion to the virtual environment.

7 DISCUSSION AND CONCLUSION

The purpose of this work is to construct the virtual environment in which users can keep high-motivations for participating in communication. In order to achieve this, it is considered that awareness of one's own thinking state and weariless interface are necessary, and we have developed the collaborative virtual environment supporting self feedbacks of electroencephalogram by *forward-backward* model. In this environment, the thinking state of user is described with the zoom of the virtual space, i.e., the whole of view is zoomed in as if the user inclines forward when he/she is thinking, and zoomed out as if he/she inclines backward when not thinking.

As to the analysis of relationship between electroencephalogram and motion in the virtual environment, one research group has proposed an interesting method – to detect the pattern of electroencephalogram while a user made the imagination of foot movement and change the view of virtual environment as if the user walk forward [18]. Though this may be useful as far as the purpose of user is movement, their approach is not appropriate for users whose purpose is not moving in the virtual world but communicating with others in the chair. For the same reason, *virtual motion* - the view point moves as if the user inclines forward or backward without actual motion - would not be a big problem. If functions to move in the virtual space just as the user intended were provided, *virtual motion* should be very confusing. However, our system is not designed to provide virtual environments in which users can move freely, but designed for communication in fixed situations.

The evaluation results show that keeping high concentrations and motivations becomes easier by the availability of electroencephalogram feedbacks, and the effect is enhanced by zooming method based on the *forward-backward* model. As to the aspect of quantity, the average utterance length of *zoom method* was approximately 1.75 and 1.25 times as long as that of *no feedback method* and *meter method*, respectively. As to the aspect of quality, *zoom method* marked the highest scores in all the points of the questionnaire, including questions about keeping concentration and immersive experience. On the other hand, though zoom expression was useful for most of the subjects, one subject remarked that his concentration had been prevented by zooming in. This indicates that there is still room for consideration of the style of feedback expression.

In the next step, the precision of motivation measurement is to be improved. The situation may be more complicated under present circumstances, though the motivation state is determined with only the strength of electroencephalogram in the current system. Consider the situation in which the user thinks something not related to the theme of meeting, in which case the motivation level is determined high incorrectly due to the highness of electroencephalogram level. To avoid such a consequence, factors such as the utterance frequency are to be used for determination of the motivation level, and the development is currently in progress.

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