A Method of Supporting Personal Activities in Virtual Reality Space Utilizing Physiological Data

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Abstract

In virtual reality space, we get a highly immersive sense, which allows us to concentrate well on work activities. In such space, there is, however, a general problem associated with desk work; continuously working decreases concentration due to fatigue and other factors, and work efficiency is in turn decreased. To have some sense of feeling refreshed, workers need to take a break. In real space, workers can leave their work area to relax, so we hypothesized that we could help workers in virtual reality space to feel refreshed by changing their virtual environment. However, it is the timing of when the user needs refreshing that is problematic.

We propose here a method of supporting personal work activities in virtual reality space utilizing physiological data obtained from the user. We evaluate whether the user's physiological data as a measure of the extent of concentration can be used to determine when to switch the work space to a virtual conversation space for relaxation. As it is reported that previous the 60 seconds of brain activity level can indicate a worker's mental state, when concentration is determined to have decreased to below the reference threshold by monitoring brain waves, the work space is automatically switched to a conversation space in which users can relax.

The experimental results reveal that human error was decreased by the proposed method, resulting in improved work efficiency. These findings suggest the utility of the proposed technique in improving work efficiency in virtual reality space.

1. Introduction

A universal problem related to desk work is that during continuous work activities concentration is decreased through fatigue and other factors, which in turn decreases work efficiency. At such times of tiredness, workers need to feel refreshed in order to continue working efficiently. Such refreshment comes through conversation or taking a rest or smoking break. To do this, the worker usually needs to leave the work space and move to another space.

In virtual reality space too, this move to a different environment or space can be easily done. Therefore, we hypothesized that a moderate feeling of refreshment could be achieved while working in virtual reality space just as if the user had actually moved in real space, since a high sense of immersion and presence can be achieved in virtual reality space.

However, it is the timing of when the user needs refreshing that is problematic. In this research, we focused on evaluating whether the user's physiological data as a measure of the extent of concentration could be utilized to determine when to switch the work space to a new relaxation space.

Physiological data which is unconsciously generated, such as brain waves, pulse rate, and breath cycles, show relations to the state of the mind and body, including levels of awakeness and stress. The monitoring of brain waves in particular is a good index of a worker's state.

We propose here a method of supporting personal work activities in virtual reality space utilizing the worker's physiological data. In this research, to create a virtual reality work environment that through visual and auditory stimuli is highly immersive and can be used portably in individual work spaces, we developed a light-weight helmet-type device that integrates a head-mount display and an electroencephalograph. In evaluation experiments, we evaluate whether human error is decreased by the usage of our proposed method and consider its utility.

The paper is organized as follows. The background to the research and problems to be solved are explained in section 2, and a review of previous work and the background to physiological (vital sign) data are given in section 3. The proposed method of supporting personal work in virtual reality space using physiological data and its implementation are explained in section 4, and experiments to evaluate its effectiveness are described in section 5. Finally, we draw conclusions from our work and discuss future study and applications in section 6.

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2. Background and Problems

2.1. Virtual reality space

Virtual reality that can in real time transmit a true feeling of realism and presence via a network interface device has become an important research topic in recent times. Virtual reality technology involves knowledge of computer science, communication studies, the arts and so on, and it has been applied in diverse fields such as software production and development, security, and simulations of medical treatment and military training.

When working in virtual reality space, because the technology affords the user a strong sense of presence and is highly immersive, it is easy for the user to concentrate, which is very useful when working privately. In fact, the richness of media that can be used to create such a highly immersive virtual reality space for a worker can be afforded on the basis of understanding physiological data that reflects the worker's state. Such data includes brain waves, pulse rate, and breath cycles.

VPL Research, Inc published the firstest business Virtual Reality system called "RB2" in the world[1]. Users that wear goggles and Data gloves can go into the space computer made.

Cruz of Illinois University in work on virtual reality space in 1992 constructed a virtual environment called CAVE which projects an image onto a total of four screens, one at the front of the user, one each on the right and left sides, and one on the floor[2]. CAVE creates a sense of being immersed in a virtual three-dimensional environment, projecting the image wherever the user looks. Hirose of Tokyo University modified the concept of CAVE by adding a fifth screen to the ceiling to construct CABIN[3], making it possible for the user to see the sky when looking up.

By utilizing these technologies, we can go into virtual environment with highly immersive sense[4][5][6].

2.2. Concentration and efficiency of work

Concentration decreases after about 30 minutes of continuously working, and accuracy of work performance then tends to decrease. Moreover, it is assumed that tired eyes and mental fatigue are the main causes of lowered concentration. In these circumstances, extended work activity leads to decreased work efficiency[7]. Therefore, some form of moderate relaxation such as having a conversation is needed to refresh the worker.

Though various factors are thought to influence work efficiency, individual work activity is strongly influenced by the factor of concentration. Concentration can be classified into two types : inner concentration that focuses only on one's own internal thoughts and feelings.; and external concentration that focuses on the use of one's senses to handle activities, thoughts and feelings external to oneself[8]. Mental activity of an individual involves inner concentration.

Environmental factors as well as physiologic factors can disturb concentration[9]. External environmental conditions such as brightness in a room, sounds, and smells all have an impact on concentration. The sound environment especially influences concentration; tiredness level increases and concentration decreases when a sound of 60-70 dB or more is heard continuously[9, 10], where 60dB is the sound of normal conversation. Moreover, as mentioned earlier, the level of concentration is reflected in physiological data including brain waves, breath cycles, pulse rate, where increased excitement of the central nervous system is reflected in changes in electrical resistance of the pulse, brain waves, and skin[9].

If we continue to work disregarding feeling tired, our work efficiency drops. Generally, it is said that efficiency of work and study tends to decrease after 50-60 minutes[9]. Taken all of the above-mentioned factors into consideration, in efforts to improve work efficiency in virtual reality space, it is necessary to consider not only the impact of the environment on the worker but also his or her concentration and tiredness levels.

3. Physiological data

3.1. Characteristics of physiological data

In this research, we define physiological data as that data which originates unconsciously from activity of the autonomic nervous system. This includes brain waves measured by electroencephalography (EEG), heart muscle activity measured by electrocardiography, and blood pressure. Physiological data is an index of autonomic nervous system activity, and much research has determined its relations to the state of the mind and body, such level of awakeness, biorhythm, stress, cognitive load, and tiredness level[11].

3.2. Brain wave

EEG measures electrical potentials on the scalp and generates a record of the electrical activity of the brain [12]. EEGs are classified into δ-waves ($f < 4$ Hz), θ-waves (4 Hz $\leqq f <$ 8 Hz), α-waves (8 Hz $\leqq f <$ 12 Hz), β-waves (13 Hz $\leqq f <$ 30 Hz), and γ-waves (30 Hz $\leqq f$). The α-wave becomes dominant in the occipital and parietal lobes of the brain when we close our eyes or relax. β- and γ-waves are called fast waves, which can be found in states of high consciousness, such as excitement, stress, and concentration. β-waves are also conspicuously recorded on the frontal lobe [12][13]. Brain activity data recorded on EEG has already been successfully utilized to control work activity in previous studies [14][15][16][22][23][24][25].

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3.3. Utilization of physiological data

Many researchers have already attempted to use the characteristics of these vital signs to influence work behavior. A system to prompt relaxation and refreshment by reflecting vital signs was proposed by Fukushima [17]. Other studies have utilized breath cycle data collected by determining chest expansion to control the movement of an avatar in virtual space [18] and brain waves collected by EEG into changing the expression of an avatar [19]. Research to reflect thinking states derived from EEG data into the behavior of an avatar was also studied by Fukui [20]. These studies were attempts to reflect vital signs in the control of the workspace or an avatar, and their aim was not to improve work efficiency. Friedman has, however, tried to apply vital sign measurement with high accuracy to control work activities such as operations [21]. However, the daily use of such a system is difficult due to its heavy load on the worker and high cost of the device.

4. Proposed Method and Implementation

4.1. A method of supporting personal work

In the virtual reality space, a high immersive sense and a sense of realism and presence can be achieved. This makes it easy to concentrate from a real space, which is very helpful to aid concentration and work performance in individual work. If we can recognize a worker's state by utilizing physiological data, it should be possible to recognize a decrease in concentration and achieve the following work improvements.

- Temporarily interrupt work activities in order to instigate taking a break
- Work more quickly and accurately by working efficiently, by optimizing the time we work when fully concentrating.

Our proposed method supports personal work in virtual reality space by measuring the brain wave data described in section 3.2 and presuming the active state of the worker's brain from such data.

4.2. Index derivation from EEGs

In this study, we determine the worker's state based on EEG findings. These reasons are as follows.

- Brain waves can be constantly measured by EEG when working.
- The worker's state can be accurately determined since brain waves are difficult to control consciously.
- Brain waves are measured by inexpensive simple electroencephalographs, which also have a low load on users.
- β-waves measured by the simple electroencephalograph are clearly observed in the frontal lobe at a high level of consciousness.

Hayashi *et al*. previously proposed the "Brain Activity Level (BA-Level)" to indicate brain activity measured by the simple electroencephalograph[26][27], and Miyata *et al.* used the recorded data as an index of automatic creation of animation digests [28]. We adopt the BA-Level as the index of worker state in this study.

The derivation procedure of the BA-Level is as follows.

1. Measure brain activity on EEG.
2. Perform fast Fourier transform (FFT) and frequency decomposition.
3. Remove instant noise derived from the myoelectric potential.
4. Average data of the frequency band area from 14 to 27 Hz, which accurately indicates brain activity, and define this as EEG data of one sample.
5. Automatically detect the scope of EEG data strength in order to deal with individual differences.
6. At each moment, multiply EEG data of the latest N samples by weighting function and sum these. Define the obtained value as the BA-Level of that moment.

We therefore detect brain activity accurately in real time using the simple electroencephalograph and quantify it as the BA-Level.

4.3. Virtual reality work space

In this research, the work space is switched to a conversation space by utilizing brain wave data, and then back to the work space on a timed basis. The virtual reality work space is shown in Figure 1. Here, a painting task is the individual work activity performed in the virtual reality work space. This task was chosen because the error rate can be easily measured and subjects understand the present state intuitively. The details of the work activity are as follows.

1. The block shape comprised of individual tiles that is to be painted by the worker is displayed in the center of the screen. Five kinds of block shape and 12 colors are used.

2. On the block on the left of the screen the worker paints the same color as shown in the sample block displayed on the right of the screen. The worker selects the paint color by clicking the palette on the left of the screen, and painting is done by clicking the work object.

3. Both the work objects and the sample objects can be rotated by dragging the mouse, and therefore the worker can view and paint all parts of the three-dimensional blocks.

4. Two bars on the left of the screen show the remaining number of preset working hours and (the number of tiles that have been painted correctly) /(total number of all tiles for painting). The worker aims to correctly paint all the tiles of a block before the time remaining reaches zero.

5. When the time reaches zero, a new work object is displayed even if the previous work object was unfinished.

The interface that operates this system is shown in Figure 2. The task is operated using the lower panel as follows.

(1)Start of calibration task

The calibration task of deriving the BA-Level based on brain waves recorded in the past 60-seconds is performed. The content of the task is the same as that used in the experimental block painting task.

(2) Cessation of calibration task

The calibration task is stopped. The highest value and the lowest value of BA-Level are recorded.

(3) Start of block painting experimental task

This work activity of block painting is started and the brain wave data obtained during the task and the accomplishment rate of the task are recorded.

(4) Cessation of block painting experimental task

This experimental task is stopped. The brain wave data obtained during the task and the accomplishment rate of the task is recorded in a file.

4.4. Virtual reality conversation space

The virtual reality conversation space was created as shown in figure 3. In this system, it is possible to talk with people in a remote location using this conversation space.

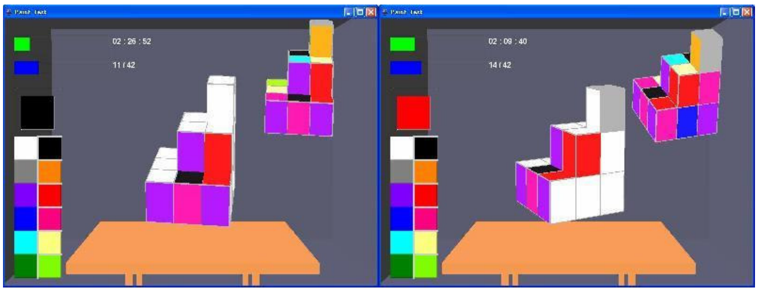

Figure 1. Virtual reality work space and work object rotation

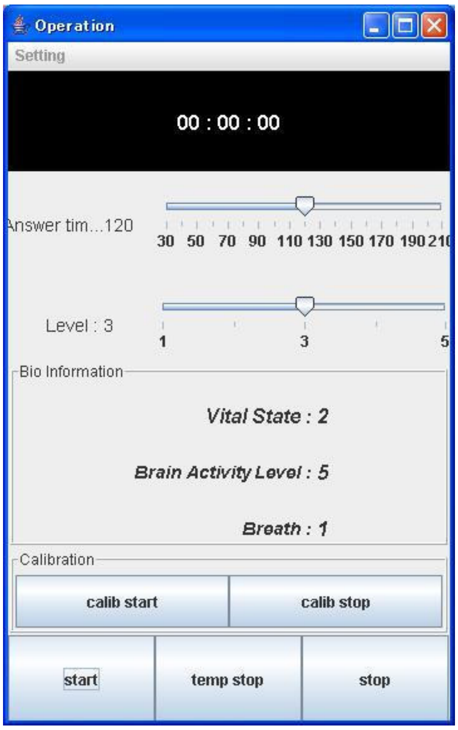

Figure 2. Control panel of the proposed system

4.5. Switching the virtual reality spaces

The system switches from the work space to the conversation space on the basis of the BA-Level derived from the brain wave data obtained during the work activity; when the worker's concentration level falls below the reference value, the work space is automatically switched to the conversation space.

Physiological data is not used to switch back to the work space from the conversation space. This switch is instead made on a fixed time basis. The worker converses with people remotely as a period of relaxation and when the fixed time of the conversation has passed, regardless of physiological data, the conversation space is automatically switched back to the former work space.

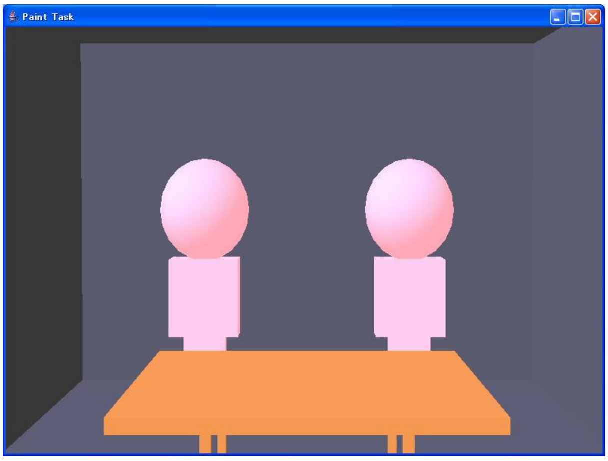

Figure 3. Virtual reality conversation space

4.6. Obtaining EEG data

We used as the recording device a helmet-type device (Figure 6) which integrates a head-mounted display and a headband-type electroencephalograph, the IBVA of IBVA Technologies, Inc. [29] (Figure 5).
The IBVA measures brain waves by measuring the potential of the frontal lobe with three electrodes. This device has the advantage that the load on the worker is low because it is wireless and lightweight; only a small sensor is attached to the frontal part of the headband and transmits EEG data wirelessly to a PC. Users can therefore feel free to move about.
The frequency band is from 0 to 60 Hz during the estimation. We apply FFT with 128 points to the data from the electroencephalograph. Then, we obtain the data at a speed of 0.87 samples per second. We developed the program in JAVA, which measures brain activity as BA-Level(Figure 4). This application displays the BA-Level and EEG waveforms in real time.

5. Experimental evaluation and discussion

This section describes the experimental evaluation of the proposed system, and discusses the effectiveness of the system on the basis of the results.

5.1. Experimental

5.1.1 Purpose

The purpose of this experiment is to verify whether human error decreases to improve work efficiency in virtual reality space by using the proposed technique. We make comparative study of the error rate using the proposed technique with two other techniques to determine which method is most effective for minimizing human error in the work task.

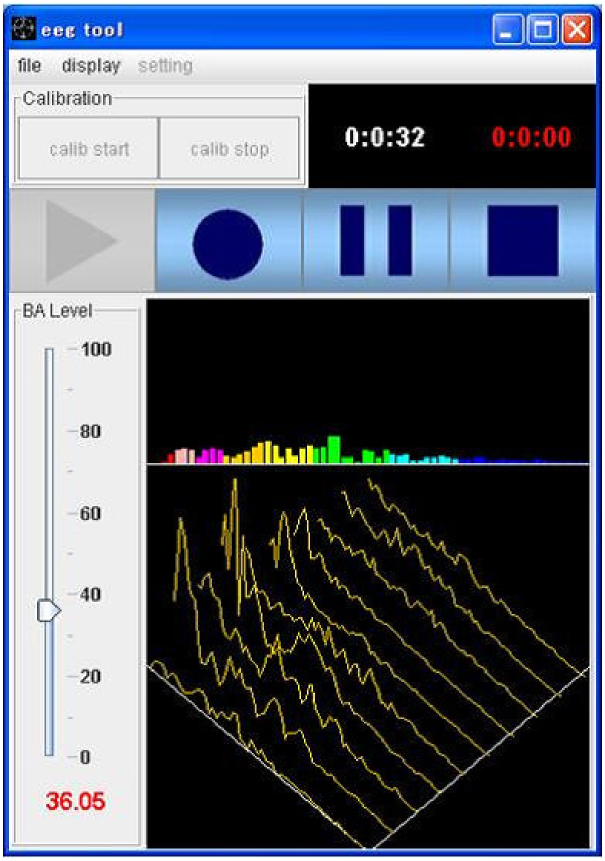

Figure 4. The application of BA-Level derivation

Figure 5. IBVA device

Figure 6. Helmet type device

5.1.2 Method

The experiment was conducted from 17 January 2007 to 25 January 2007 with 10 students (9 men and 1 woman) aged 21-23 years.

The experiment proceeded as follows.

1 The subject puts on the helmet-type device and confirms the screen can be viewed through the head-mounted display. (figure6)

2 In the virtual reality space, the painting task is performed using one of the following three methods (A-C) presented at random:

Method A: the work space is switched to the conversation space by using physiological data (the proposed method)

Method B: the work space is switched to the conversation space on a time basis and without utilizing physiological i data

Method C: The worker continues working only in the work space; there is no switch to a conversation space.

The evaluation experiment involved the same painting task as described in section 4.3. The time limit for working at each task was set at 6 minutes in total. In the proposed Method A and in Method B, we set the time lint for talking in the conversation space to 45 seconds.
The 45-second period of relaxation in the conversation space is not included in the 6 minutes working in the work space. For example, in Method A, when the BA-Level showed a decrease below the reference value after working for, say, 3 minutes, the work space was switched to the conversation space, the subject could then talk for 45 seconds before being automatically being returned to the work space to work for a maximum of another 3 minutes.
The error rate while working using each of the three methods was measured and a questionnaire was administered to subjects after using each method. We asked subjects questions such as, "Did the VR space change according to the time that you feel you were not concentrating so well?", "Did you concentrate more when you came back from the conversation space?" and, "Were you used to painting slowly?"

5.1.3 Results

Table 1 shows the experiment results with regard to the error rate for each of the three methods used. The evaluation of the error rate was defined by the following expression:

$$error\ rate = \frac{Total\ number\ of\ wrong\ answers}{Total\ tile\ clicks\}} \times 100 \quad (1)$$

Table 1. Error rate for each experimental method

Subject	A. TEC(%)	B. TEC(%)	C. TEC(%)
1	21.0	29.4	43.4
2	28.6	41.7	35.2
3	33.3	43.4	43.6
4	28.8	39.2	37.3
5	20.7	22.2	25.5
6	17.4	24.6	26.5
7	31.5	40.9	29.9
8	17.2	26.2	47.4
9	14.4	14.3	6.1
10	12.7	9.2	14.8
Mean value	23.2	29.1	31.0

5.2. Discussion

As can be seen from Table 1, the proposed Method A had the lowest mean error rate. Moreover, the proposed method showed the lowest error rate, and this error rate was lower than that for Method B in 8 out of 10 subjects. It is thought that the higher degree of work efficiency in Method A derived from accurately determining the decrease in worker concentration and making a timely switch to the conversation area, forcing the worker to have a short period of refreshment. The error rate was the highest for Method C where the worker experienced no break.
To determine whether the differences between the groups was significant, multiple authorization was carried out between the error rate of Method C and that for each of Methods A and B using the method of Steel. As a result, we6

found a significant difference between Methods A and C, but no difference between Methods B and C at a significance level of 5 percent.
Therefore, the utility of the proposed method was experimentally confirmed on the basis that error rate was reduced by utilizing physiological data to switch the work space to a conversation space at timing appropriate to the worker's current state. In addition, on the questionnaire, some subjects answered that for the proposed Method A, "it switched just when I was becoming tired", "It offered a little diversion", and "I thought the time that I can concentrate on work was long".
This time, we used a conversation space as the space in which the worker could relax; however, a larger error reduction effect may be produced if other stimuli such as odors and music were to be presented and this remains a task for future study.

6. Conclusion

We have proposed a method utilizing the user's physiological data to address a problem of the degradation of concentration and work efficiency during continuous personal work in a virtual reality space. Our experimental results revealed that changing the virtual reality working space to one that stimulates relaxation and increases concentration was effective for improving work efficiency during a painting task. Our proposed method decreased the rate of human error compared with other methods that either changed the work space to a relaxation space purely on a time basis or offered no such change of space.
In the future, we will examine other spaces besides conversation space to stimulate relaxation and investigate further the most suitable timing of the measurement method to change the work space.

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