31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Development of the EEG measurement method under exercising.

Noriyuki DOBASHI, Kazushige MAGATANI, Tokai Univercity, Japan

Abstract— **It is said that the result of the game of sports is controlled by player's mental state. Especially, player's concentration greatly controls the result of the game. Therefore, we think that if player's mental state under exercising can be evaluated, it becomes possible to guide the player appropriately. Our mental state can be understood from analyzing EEG (Electroencephalogram). Especially, it is said that the change of alpha and beta rhythm of EEG will indicate the change of human's mental state. Therefore, we think that if EEG of the athlete can be measured under exercising, it becomes possible to evaluate mental state of the athlete.**

However, EEG is measured in the state of the rest usually, and measuring EEG under exercising is difficult. Because, the amplitude of EEG is very small and high amplification is necessary to obtain observable EEG. A movement of the body causes vibration of electrodes, and these vibration cause artifact of EEG. So, our objective of this study is a development of the new measuring method of EEG under exercising.

In this paper, we will talk about our developed EEG measuring system for athletes. This system measures EEG and acceleration of the athlete's body. These measured data are sent to the receiver by a FM transmitter. Received data are analyzed with the personal computer, and the EEG and the noise are separated.

Some normal subjects were tested with our developed system. From these experiments, it was clarified that our system had some problems. However, EEG with little noise was able to be obtained in all cases. Therefore, we think that if these problems are improved, our developed system will become useful for the measurement of EEG under exercising.

I. Introduction

It is said that the result of the game of sports is controlled by player's mental state. Especially, player's concentration greatly controls the result of the game. Therefore, we think that if player's mental state under exercising can be evaluated, it becomes possible to guide the player appropriately. Many trainers want to evaluate player's mental state and to guide the player based on this result. In this study, we would like to evaluate athlete's mental state by using his/her bio-signals.

Some vital signs (for example, ECG, heart rate, blood presser and so on) indicate the physical condition of the athlete under exercising. However, we cannot evaluate mental condition of the athlete by these vital signs. If we want to evaluate mental condition using bio-signals, EEG will be a good signal for this purpose. Change of the power spectrum of EEG has relation to the change of psychological condition. For example, stress makes change the frequency band of EEG to high. For our purpose, alpha-rhythm and beta-rhythm of EEG (from 8 to 30Hz) are useful.

However, it is said that the measuring EEG under exercising is difficult. Because, the amplitude of EEG is very small and high amplification is necessary to obtain observable EEG. Therefore, electro-magnetic noise and motion of a subject (same as motion of electrodes) cause the EEG artifact. In case of the athlete under exercising, a movement of the body causes vibration of electrodes, and these vibrations cause artifact of EEG. If we can develop the method that makes measurement of EEG under exercising possible, this method will become useful for assessment of EEG under exercising. Our objective of this study is a development of the new measuring method of EEG under exercising.

In this study, we suppose that most of the artifact of EEG under exercising will be concerned with the motion of subject (especially, the motion of subject's head), and EEG will be independent of the motion of subject. In order to discriminate between EEG and noise from measured EEG under exercising, the EEG measurement system was experimentally developed and assessed. This system has the following features.

1. EEG and body motion of the subject are measured.
2. Measured data are sent to the receiver by telemetry.
3. From measured EEG under exercising, EEG without artifact is extracted by using a developed digital filter.

In this paper, we will talk about this EEG measurement system.

II. METHODOLOGY

A. System hardware

Fig.1 shows a block diagram of our system. Acceleration of subject's head and EEG are measured simultaneously, and these data are analyzed in a computer system. In our system, it is necessary not to disturb the motion of exercising to measure these data. So, a user of this system equips with electrodes for EEG, an acceleration sensor, amplifiers for EEG and acceleration and FM (frequency modulation) transmitter. Measured acceleration and EEG are amplified and multiplexed. This multiplexed data is sent to the receiver by FM transmitter. Carrier frequency of this transmitter is about 80MHz and this FM signal can be received by a FM receiver on the market in Japan. Received data is de-multiplexed and de-multiplexed data (EEG and acceleration of subject's head) are analog to digital converted. And then digitized data are analyzed in a personal computer.

Fig.2 shows the position of EEG electrodes. As shown in this figure, electrodes are set on vertex (+), midline frontal (-) and left auricular (common). An acceleration sensor is set on the left side of subject's head. Fig.3 shows a developed EEG amplifier (band width is from 0.1Hz to 40Hz) and an acceleration sensor (Star precision ACB302) is also shown in Fig.4. A block diagram of a multiplexing and a de-multiplexing unit are shown in Fig.5. As shown in this figure, frequency multiplex method is used. Acceleration and EEG data are frequency modulated in a multiplex unit. Carrier frequency of acceleration and EEG are 5kHz and 1kHz respectively. These modulated data are mixed and transmitted by a FM transmitter. In a de-multiplex unit, data from a FM receiver is discriminated between modulated acceleration data and modulated EEG data by a high pass filter and a low pass filter respectively. These data are frequency demodulated and noise reduced. Fig.6 also shows a multiplexing unit and a de-multiplexing unit. These data are analog to digital converted and these digitized data are analyzed in a personal computer. In the A/D conversion, resolution is 12bit and sampling frequency is 1kHz.

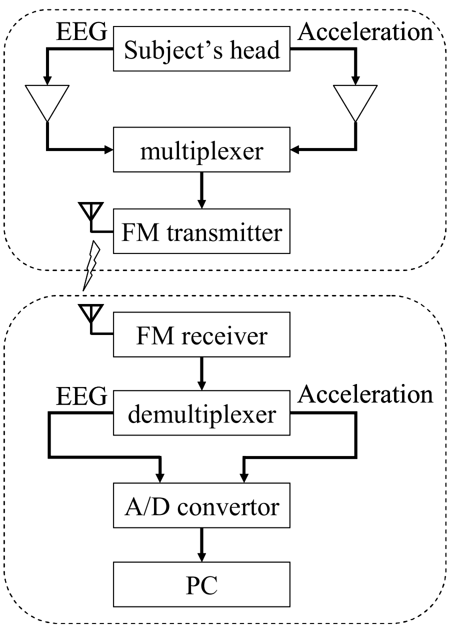


Fig.1 A block diagram of our system.

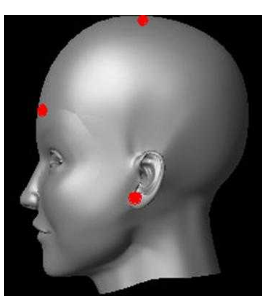
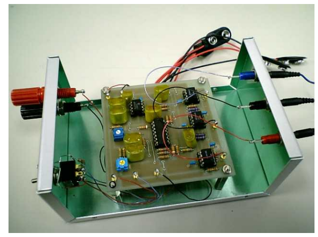


Fig.2 The position of the EEG electrodes.



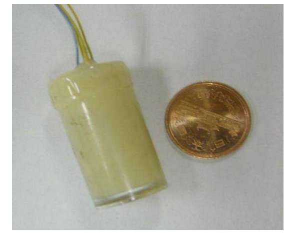


Fig.3 EEG amplifier. Fig.4 An acceleration sensor unit.

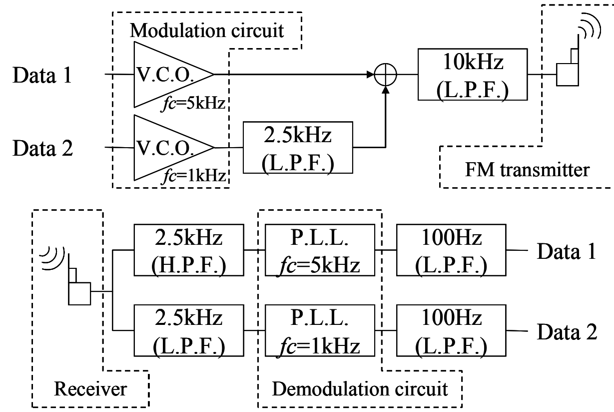


Fig.5 A block diagram of our telemetring.

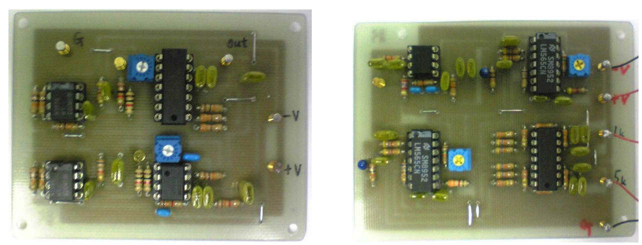


Fig.6 a) A multiplexer. b) A demultiplexer.

A. System software

It was confirmed that measured EEG under exercising and acceleration of a subject's head have the strong correlation from previous our study [1]. In our system, the adjustment noise canceller is used for the noise removal. This method removes the noise element from the signal that contains the noise. A principle of the adjustment noise canceller is shown in Fig.7. In this theory, the noise source is assumed $X(t)$, and the signal that we want to extract is assumed $S(t)$. We suppose that $S(t)$ and $X(t)$ have no correlation. Where, we define $D(t)$ that is the liner summation of $S(t)$ and $X(t)$. Therefore, $D(t)$ is expressed the following equation.

$$D(t) = aS(t) + bX(t)$$

And we suppose that $D(t)$ and $X(t)$ are observable. In our system, we have to discriminate between $S(t)$ that is real EEG signal under exercising and $X(t)$ that is artifact of EEG from $D(t)$ that is EEG with artifact.

Actually, there is some time delay between noise element in $S(t)$ and $X(t)$. Therefore, the former equation changes into the following equation.

$$D(t) = aS(t) + bX(t + t_1)$$

Where, t_1 is the delay between noise element in $S(t)$ and $X(t)$. In our system, t_1 is calculated first. Fig.8 shows the algorithm to obtain t_1. As shown in this figure, t_1 is obtained as the value that makes correlation between $D(t)$ and $X(t+t_1)$ maximum. After this time correction is done, "*a*" and "*b*" are calculated in our system. In order to obtain a coefficient "*b*", the variable "*b'* " is changed it's value step by step, and the correlation coefficient between $D(t)$ and $b'X(t)$ is calculated for each "b' ". From this procedure, we can obtain the "*b'* " that bring the highest value of correlation coefficient between $D(t)$ and $b'X(t)$. We regard this "*b'* " as the coefficient "*b*". And then interested signal $S(t)$ is obtained. A flow chart of this algorithm is also shown in Fig.9.

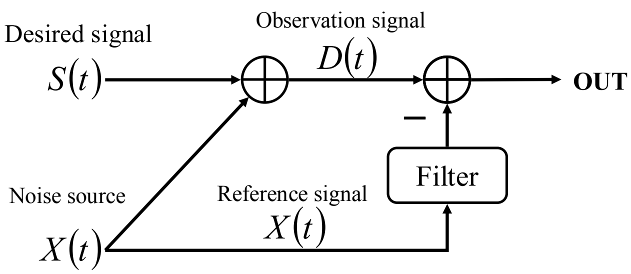


Fig.7 A principle of the adjustment noise cancellation.

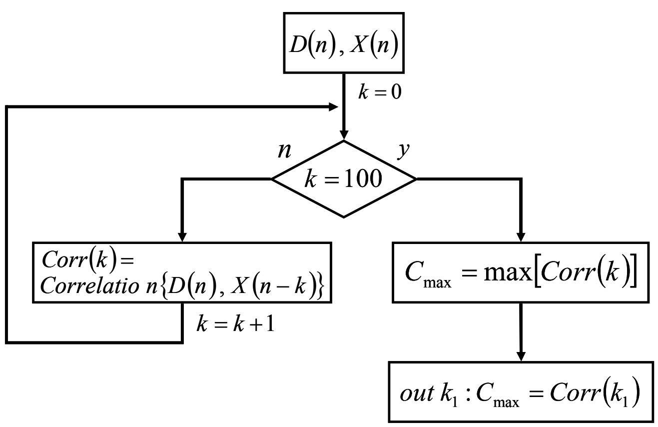


Fig.8 An algorithm to obtain delay time.

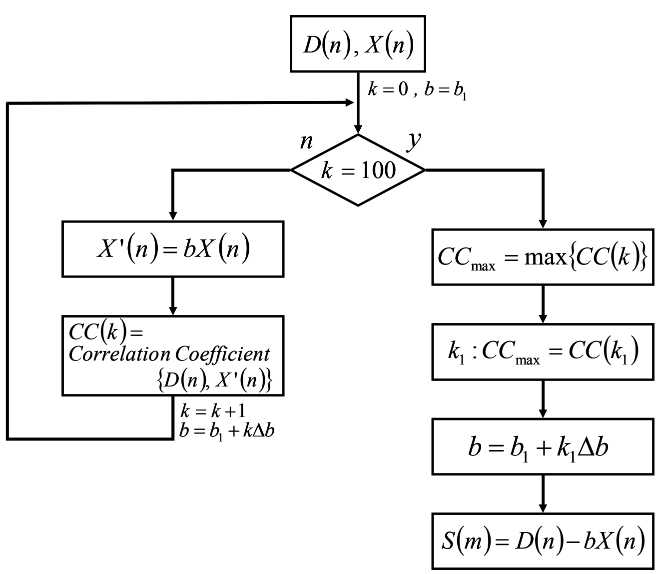


Fig.9 A flow chart of the adjustment noise canceller algorithm.

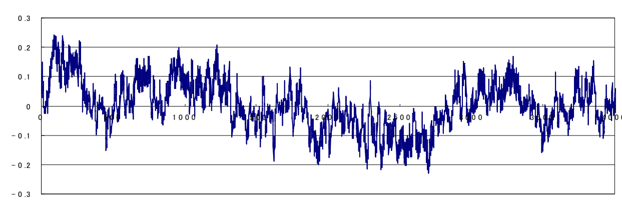
III. Experiment and Results

Some normal subjects were tested with our system. As mentioned earlier, electrodes are set on vertex (+), midline frontal (-) and left auricular (common). An acceleration sensor is set on the left side of subject's head.

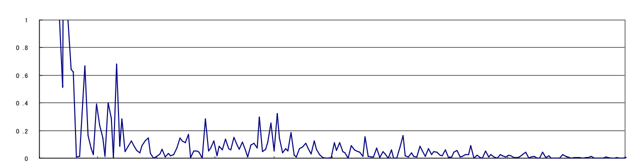
At first, EEG without exercising was measured. In this case, the measurement of EEG was done with a subject had sat on the chair. Fig.10 (a) shows an example of measured EEG in this experiment. Fig.10 (b) shows the power spectrum of this EEG.

Next, EEG under exercising was measured. In this case, a subject walked on the treadmill at usually speed, and subject's EEG and acceleration in the vertical direction was measured. Fig.11 (a) shows an example of measured EEG with artifact. Subject's acceleration is shown in Fig.11 (b). Calculated power spectrums of these data are also shown in Fig.11 (c) and Fig.11 (d) respectively.

Fig.12 (a) shows an example of the result of noise cancelation. The power spectrum of this result is shown in Fig.12 (b).

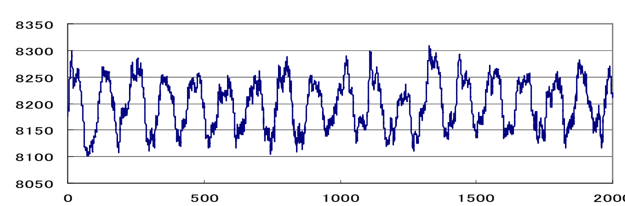


(a) Measured EEG.

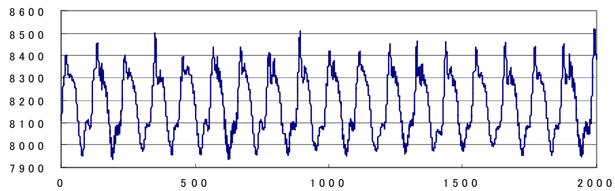


(b) The Power Spectrum of EEG.

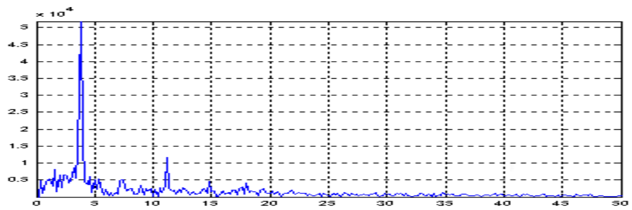
Fig.10 Data of Measured EEG without exercising.



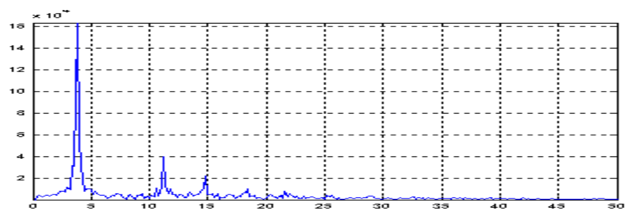
(a) The EEG with artifact.



(b) Subject's acceleration.

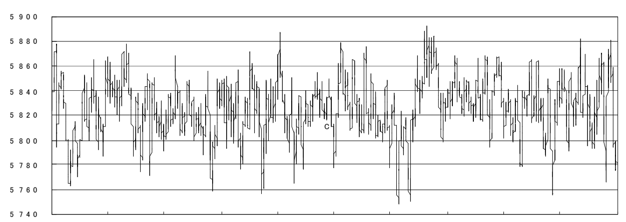


(c) The power spectrum. (EEG with noise)

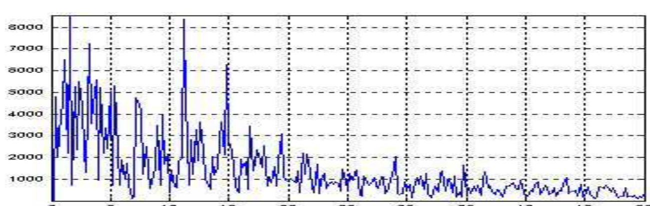


(d) The power spectrum. (Acceleration)

Fig.11 Measured EEG and Acceleration Data with exercising.



(a) Estimated EEG.



(b) Power spectrum. (Processed signal)

Fig.12 Output of our developed noise canceller.

IV. Discussion

First of all, we described about developed hardware. Our frequency multiplexing telemetry system worked perfect. Communicable distance of FM transmitter is about 100m. This distance is enough to measure EEG indoors. Developed frequency multiplexing system can correctly transmit signal whose bandwidth is from DC to 300Hz. And our system did not disturb the motion of exercising to measure subject's EEG. Therefore, we think that our developed hardware of the system is useful to measure EEG under exercising.

The developed software that cancels artifact of EEG is described as follows. As shown in Fig.11 (a) and (b), the waveform of measured EEG under exercising is similar to the waveform of subject's acceleration. Therefore, the power spectrum of EEG under exercising is also similar to the power spectrum of subject's acceleration as shown in Fig.11 (c) and (d). Both figures have a remarkable peak of 3.8Hz. We think that this peak depends on subject's step rate and the peak of about 12Hz is the 3rd harmonics of step rate. On the other hand, as shown in Fig.10 (b), most of the power spectrum of EEG measured in rest state was between from about 2 to 15 Hz and a remarkable peak is not found. As shown in Fig.12 (b), remarkable peak of 3.8Hz is not found in power spectrum of the result of noise cancelation. And waveform of the result is similar to the waveform of EEG without exercising. We think that our noise cancelation method works well from these results. However, as shown in Fig.12 (b), small peak of 12Hz that will be harmonics of subject's step rate is not cancelled. In other word, this harmonics has not cancelled completely though it became small by our noise cancelation method. We think that it will be necessary to solve this problem in the future.

V. Conclusion

In this paper, we talked about our developed EEG measuring system for athletes. A frequency multiplexing telemetry system was developed as hardware of the system. This system can measure subject's EEG and acceleration of subject's head, and can be communicated by the distance of 100m. From the results of experiment, it was confirmed that this system worked completely.

In general, if we want to measure EEG under exercising, the artifact of EEG that originates in movement of athlete's body becomes a problem. To cancel this artifact, the adjustment noise canceller was experimentally developed. From the results of experiment, it was confirmed that the noise did not cancel completely though it decreased greatly. Therefore, we've concluded that if this problem will be improved, our system will be useful for the EEG measurement system under exercising.

References

[1] Naoya HOSAKA, Junya TANAKA, Akira KOYAMA, Kazushige MAGATANI, "The EEG measurement technique under exercising" IEEE EMBS 2006

[2] Junya TANAKA, Mitsuhiro KIMURA, Naoya HOSAKA, Hiroyuki SAWAJI, Kenichi SAKAKURA, Kazushige MAGATANI "Development of the EEG measurement technique under exercising" proceeding of the International Federation for Medical & Biological Engineering VoL.12(2005)