Examination and it's evaluation of preprocessing method for individual identification in EEG

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Abstract: In recent years, techniques of Brain Machine Interface (BMI) which conducts human communication and robot manipulation using human brain activity are widely researched. This is the result of a noninvasive electroencephalograph device that can measure Electroencephalogram (EEG) in real time. However, there is a present condition that the authentication method when BMI is not much researched. In our research, we propose a biometric authentication method of electroencephalogram using image stimulation. In this research, we propose a biometric authentication method of electroencephalogram using image stimulation. In this paper, we construct and then evaluate a system that performs biometric authentication using EEG at image stimulus. We perform feature extraction using cross-correlation coefficient, and Support Vector Machine (SVM) for classification / authentication. And We considered the method for preprocessing (digital filter, artifact countermeasure, epoch), we verify more appropriate preprocessing method. We verified the proposed method. In our proposed system , Equal Error Rate(EER): 2.0% was obtained when artifact countermeasure, digital filter (IIR filter), and epoch method were used. From the result of False Acceptance Rate(FAR) and False Rejection Rate(FRR), our system was suggested that accuracy is improved by taking artifact countermeasure.

1. Introduction

In recent years, the technology of Brain Machine Interface (BMI) which conducts communication, robot operation etc using human brain activity is widely spreaded.

The background is that non invasive electroencephalography devices capable of measuring electroencephalography (EEG) raw data in real time without embedding electrodes in the brain are on sale as products. Researches on BMI have been studied to support disabled and intractable patients using by autonomously moving wheelchairs[1]. In addition, authentication systems using IDs and passwords are mainstream as authentication methods currently in widespread use. Authentication using biometric information has the advantage that spoofing is difficult, better than conventional authentication using ID and password. However, biometric information such as fingerprints and faces recognition is always exposed to the outside, so there is a possibility of being stolen by the camera. Fingerprints and faces recognition can not be changed by their own intention. Electroencephalogram are internal information, and the possibility of being stolen is very low because it can't be measured unless a special device is attached. In addition, since the Electroencephalogram change by stimulation from the outside, it is possible to change the registration data if after the theft. Considering that BMI is used by people with incurable diseases, authentication and operation can be performed on the same device by using EEG brain wave authentication. Therefore, we don't need to use other devices, we believe that the burden on users can be reduced. In this research, we implement a biometric authentication system that uses EEG at presentation of image stimulus as an authentication system which is used when using BMI and is hard to be stolen. In this paper, we propose a proposal system and preprocessing (digital filter, artifact countermeasure, epoch) in order to improve the authentication rate.

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2. Related research

Performance index of biometric authentication is evaluated by Equal Error Rate (EER). EER is the point where the false rejection rate (FRR) and the false acceptance rate (FAR) are equal. An example of FRR and FAR curves is shown in Fig.1

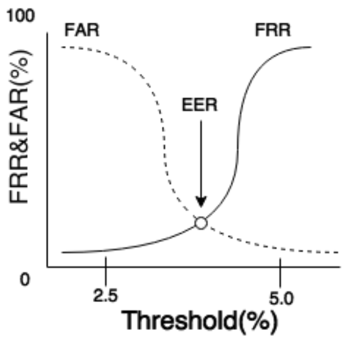

Fig. 1 Curve example of FAR and FRR

In Fig.1, the horizontal axis is a threshold for judging registrants and intruders, and the vertical axis is the probability of FAR and FRR[2][3].

In biometric authentication using EEG, there are already some research cases. Ishikawa et al 's research classifies registrants without considering intruders. At that time, EER: 3.8% was obtained by combining all five tasks with the power spectrum of the four frequency bands of θ wave, α wave, β wave, and γ wave as feature amounts [4].

In other research by Ishikawa et al., We aim to brain wave authentication in a short time, and we are doing research on biometric authentication using brain waves at rest that do not require mental tasks or external stimuli. By using AdaBoost for the feature amount obtained, a learning model was created, and EER: 0.52% was obtained when 32 registrants and 18 intruders [5].

Yoshikawa and colleagues divided the α wave band and the β wave band of 30 subjects who are in operation into a plurality of regions and studied only the frequency band with good authentication rate By using machine learning, we obtained EER: 31% [6].

In the study of Touyama et al., We used auditory stimuli, deriving personal identification accuracy using machine learning method under three conditions of indoor resting seating condition, outdoor resting upright condition, outdoor walking condition, possibility of brain wave personal authentication . About seven subjects realized an individual authentication accuracy of about 87% at indoor resting seating [7].

3. Measurement method of brain waves

In this section, we describe a method for acquiring brain waves using image stimulation. We use Emotiv Epoc+ as a device to acquire electroencephalogram [8].

Emotiv Epoc+ is a noninvasive device and can measure brain activity at a sampling frequency of 128 Hz using 14 electrodes. Mounting 14 electrodes to the subject according to International 10-20 method[9].Obtaining brain waves and presenting image stimuli use OpenVIBE[10].OpenVIBE is a software platform that can measure brain waves while presenting image stimuli in real time.

Fig.2 shows the flow of the image displayed on the monitor when measuring the electroencephalogram. In this research, five cards (Heart A, Clover A, Heart J, Clover J, Joker) are used as image stimuli.

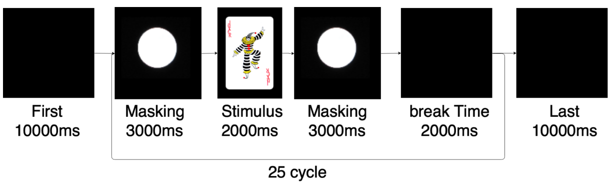

Fig. 2 Flow of one trial

The order of presenting the images is random, and for each kind of images always displayed five times in one trial. The flow shown in Fig.2 is one trial, and the time required for one trial measurement is about 270 seconds. As an environment for measurement, the subject was in the indoor sitting position, and the experiment was performed with the distance between the subject and the monitor fixed at 80 cm. Assuming use in a real environment, measurements were made in a room where living environment sounds, without using a special environment to prevent noise such as shielded room from entering.

4. Proposed method

In this section, we describe a biometric authentication system based on electroencephalogram analysis. Fig.3 shows the outline of the biometric authentication system based on electroencephalogram analysis.

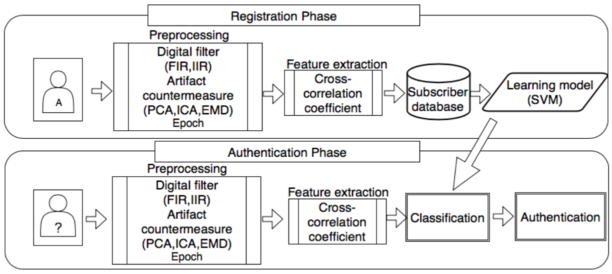

Fig. 3 Authentication system overview

In the registration phase, enter the registration number of the registrant and measure the brain wave. As the brain waves are measured using noninvasive devices, they contain a lot of noise as described later. Therefore, we think that it is necessary to perform the preprocessing shown in Fig.3 before feature extraction. Next, feature extraction is performed. Using the feature of each generated image registration stimulus for each stimulus, a learning model of the registrant is created for each image stimulus. In the authentication phase, the certifier measures brain waves without typing their registration number. Perform pretreatment similar to that performed in the registration phase for brain wave data and perform feature extraction. Then, using the learning model created in the registration phase, calculate which of the registrants the certifier is most similarity.

At that time, depending on the obtained reliability ratio, it is judged whether it is a registrant or an intruder. If the reliability rate is lower than the set threshold value, the certifier is determined to be an intruder. Conversely, when the reliability is higher than the threshold value, the certifier is authenticated as a classified registrant. In the following sections, preprocessing, feature extraction, creation of a learning model and classification / authentication method will be described in detail.

4.1 Preprocessing

From the point of using a noninvasive electroencephalograph and measuring in the indoor where the living environment sound occurs, it is conceivable that the measured electroencephalogram data contains many artifacts. Therefore, artifacts must be removed appropriately. As we call, artifact is all noise other than brain waves. Because the brain wave is very weak, potentials other than brain waves are likely to be mixed in the measurement [11].By performing pre-processing on the measured brain wave data, it is necessary to eliminate artifacts contained in the brain wave data and correct brain wave data watching the image stimulus. Preprocessing performs the following three methods.

- Digital filter
- artifact countermeasure
- Epoch

Each preprocessing will be specifically described in the following section.

4.1.1 Digital filter

The digital filter passes only specific frequency components and reduces other frequency components. There are roughly two types of digital filters. FIR (Finite impulse response) filter and IIR (Infinite impulse response (infinite impulse response) filter [12].An impulse is a waveform when a filter is applied to an instantaneous voltage change. FIR means that the influence of the voltage change at a certain moment only spreads to a limited time point. IIR is that the effect of voltage change at a certain moment remains forever. In this study, we use least squares approximation bandpass filter for FIR filter and Butterworth bandpass filter for IIR filter. By using the band pass filter, frequency bands other than the specific frequency band are reduced. The frequency band passed by the digital filter is 4-40 Hz This frequency band is a frequency band where activity of brain waves is mainly observed.

4.1.2 Artifact countermeasure

Artifact countermeasure are performed using principal component analysis (PCA), independent component analysis (ICA), empirical mode decomposition (EMD). PCA is one of unsupervised learning and is a method of obtaining a linear transformation in a direction in which the variance of learning data is maximized[13].The eigenvector corresponding to the maximum eigenvalue, the linear transformed feature amount is called the first principal component, and the feature amount transformed with the eigenvector corresponding to the kth eigenvalue is taken as the kth principal component. How much information the main component has is called the contribution ratio of the main component. When the total number of principal components is n, the cumulative contribution rate (r_k) up to the k-th component is expressed by equation (1).

$$r_k = \frac{\sum_{i=1}^{k} \lambda_i}{\sum_{i=1}^{n} \lambda_i} \tag{1}$$

We use singular value decomposition as an algorithm of principal component analysis. Singular value decomposition is one of matrix decomposition methods for matrices with complex numbers or real numbers as components. This has the disadvantage that processing speed is slower than finding the covariance matrix. However, there is an advantage that accuracy is improved.

ICA is a method for estimating the original signal of an independent component (IC) separated from the signal observed by a plurality of sensors. An example of the relationship between the original signal and the observation signal is shown in Fig.4 (partly modified in the figure from [14]).

In Fig.4, the observation signal is $X_i(t)$ and the original signal is $S_j(t)$. In the observation signal, multiple original signals are attenuated by Transmission decay a_{ij} and observed in a mixed state [14].For ICA algorithm, fastICA is applied [15].Maximization and minimization of kurtosis are used for the evaluation function. For the optimization, the fixed point algorithm is used.

EMD is a time-frequency analysis method for unsteady signals[16].And divides it for each frequency mixed in the measured signal. By using EMD, the signal $x(t)$ is separated into a plurality of signals called eigenfunction functions (IMF). Assuming that

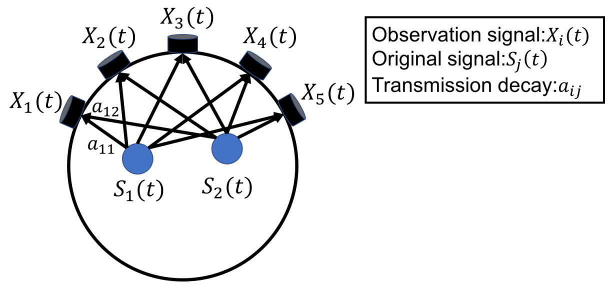

Fig. 4 Relationship between original signal and observation signal

$x(t)$ is an input signal, the total number of signals obtained by EMD is n, each signal obtained by EMD is $k_i(t)$, and the residual is $r(t)$, the following equation (2) Can be expressed.

$$x(t) = \sum_{i=1}^{n} k_i(t) + r(t) \tag{2}$$

The IMF resulting from EMD satisfies the following two requirements.

1. The number of IMF extrema (the number of the maximum value and the minimum value) and the number of zero crossings are equal, at most 1 difference.
2. At any point in the IMF the envelopes defined by the envelope middle value and local minimum value defined by the local maximum are equally 0.

Fig.5 shows the procedure for countermeasures against artifacts.

$V(t)(t = 0 - Tms)$ be the brain wave data of 14 channels for one trial measured. Tms is the time for one trial.

Step1. PCA is applied to $V(t)$, and the number of principal components (k) when the cumulative contribution ratio of the principal components exceeds 80% is N_1.

Step2. Apply ICA to $V(t)$ and separate it into N_1 ICs. $IC_{n_1} = \{ic_1, \cdots, ic_{n_1}\}$ be N_1 sets of ICs separated.

Step3. Apply EMD to each component of IC_{n_1}.Let N_2 be the number of IMFs obtained from $ic_i(i = 1, \cdots, n_1)$ and $K_{n_2} = \{k_1, \cdots, k_{n_2}\}$ be the set of IMFs.

Step4. For each component $K_j(j = 1, \cdots, n_2)$ of K_{n_2}, fast Fourier transform is performed and divided into five frequency bands. Frequency bands are δ wave (1-3 Hz), *theta* wave (4-8 Hz), α wave (9 - 13 Hz), β wave (14 - 23 Hz), γ wave (24 Hz -). The frequency band in which brain wave activity is actively observed is mainly 4-40 Hz. Therefore, $K_{n_2} = \{k_1, \cdots, k_{n_2}\}$ which δ wave contains many in a divided frequency band is eliminated as noise.

Step5. We reconstruct the set of independent components after removal of noise ($IC'_{n-1} = \{ic'_1, \cdots, ic'_{n_1}\}$) using the remaining set of K_{n_2}.

Step6. Reconstruct as $V'(t)$ using set IC'_{n_1}.

4.1.3 Epoch

The epoch is to cut out image stimulation intervals for each time window. In this research, it is used to cut out the section in which the image stimulus is presented from the designated part for the specified number of seconds.

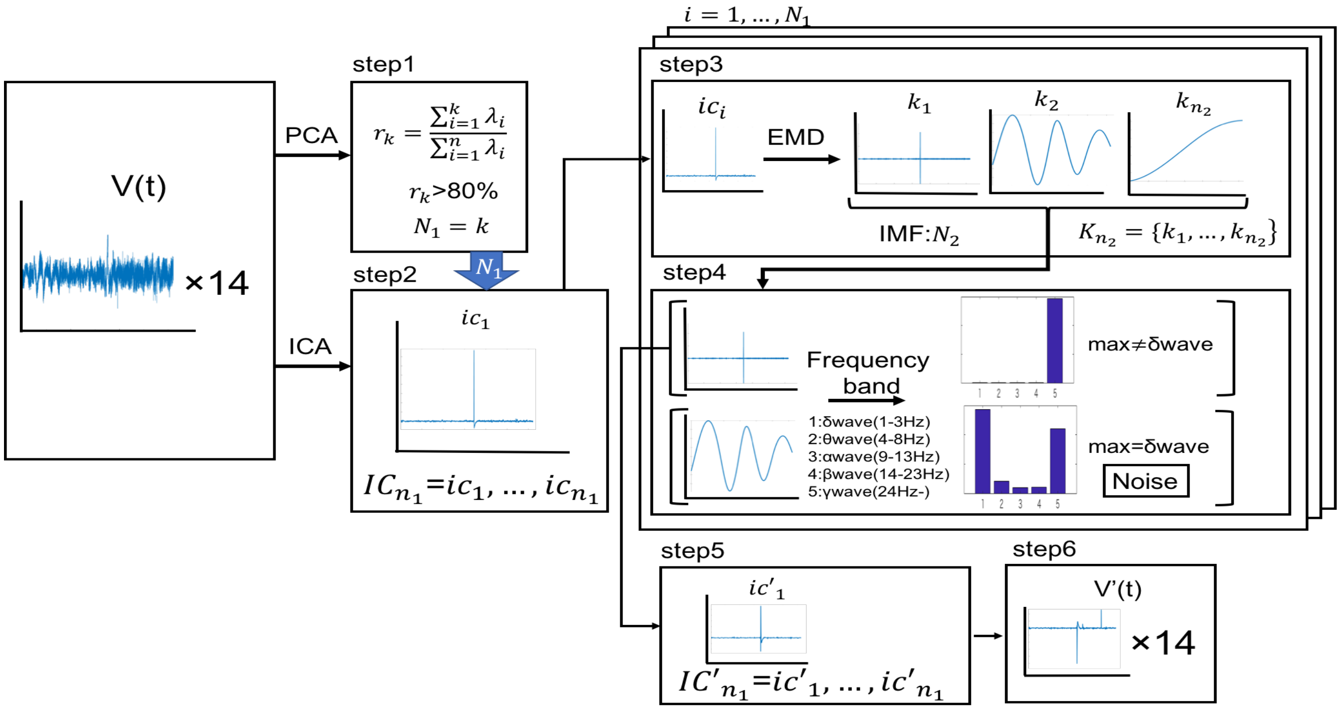

Fig. 5 Flow of countermeasures against artifacts

4.2 Feature extraction

The feature amount is extracted from the data after preprocessing. Due to the cross-correlation coefficient, the similarity between the electrodes when viewing the image stimulus is taken as the feature amount. The cross-correlation coefficient(CC) between the two electrodes (a, b) is expressed by equation (3) [17].

$$CC = \frac{\sum_{k=0}^{N-1} a_k b_k}{\sqrt{\sum_{k=0}^{N-1} a_k^2}\sqrt{\sum_{k=0}^{N-1} b_k^2}} \quad (3)$$

N is the data length at the time of extraction by epoch. a_k, b_k are time series data of electrodes. The cross-correlation coefficient (CC) given by equation (3) has a value from −1 to +1, and it becomes a normalized correlation coefficient.

4.3 Learning model creation / authentication method

Support Vector Machine (SVM) is applied as a method for creating a learning model, classifying and authenticating from feature quantities obtained by feature extraction. SVM is one of pattern recognition learning models . SVM is often used as a method to classify two classes basically. However, since we need to classify multiple registrants in this research, we will perform multi-class classification[18]. In this research, we perform multi - class classification using one - to - one method. In the SVM, it is necessary to calculate the inner product of the feature vectors, but by using the kernel function, it is possible to create a model using curves and the like without calculating inner product. As a kernel function, a radial basis function (RBF: Radial Basis Function) is used. The RBF kernel (G) is given by the following equation.

$$G(x_j, x_k) = exp(-\|x_j - x_k\|^2) \quad (4)$$

When utilizing the learning model, perform scaling processing on the feature quantity and set the value in the range from 0 to +1. This is to prevent loss of information at the time of calculation. In the registration phase, a learning model is created for each type of trump card. In the authentication phase, the confidence ratio is obtained for each registrant in the learning model by passing the feature amount of the certifier. Calculation of the confidence ratio is done using Kullback-Leibler divergence [19].When the maximum confidence ratio obtained in the authentication phase is lower than the preset threshold, the authentication is refused as an intruder. And when it is higher than the threshold, it is authenticated as the registrant who got the maximum confidence ratio.

5. Validation method and it's evaluation

In this section, we show the Verification method of this proposed system and the evaluation result. Evaluation is obtained by the EER described in section 2. For that, it is necessary to obtain FAR and FRR. Based on the confidence ratio of each registrant obtained in the authentication phase, FAR obtains the rate of accepting a certifier who is not a correct registrant as a registrant based on the threshold value. Based on the reliability of each registrant obtained in the authentication phase, FRR obtains the rate at which the authentication fails for each threshold when the authenticator is a correct registrant.

To measure brain waves, 31 male university students are cooperated. One trial was measured three times in one day for one subject. 31 students will be verified with 20 registrants and 11 intruders. There are 15 data for one image stimulus of trump cards. Therefore, verification is carried out using 15 cross validation.

5.1 Verification condition

Verification is performed by combining validation conditions of preprocessing (Digital filter, Artifact countermeasure, Epoch). Validation conditions are used to verify the combination when the lowest EER.

The condition numbers of preprocessing are shown in the table.1

Table 1 condition numbers of preprocessing

Condition number(A)	digital filter
A1	No digital filter
A2	IIR filter for one whole trial
A3	FIR filter for one whole trial
A4	IIR filter for data after epoch
A5	FIR filter for data after epoch
Condition number(B)	Artifact countermeasure
B1	No artifact countermeasure
B2	With artifact countermeasure
Condition number(C)	Epoch
C1	1000ms(Starting point:1 to 129)
C2	2000ms

The number of dimensions of the digital filter is fixed by 4-dimensional, band pass filter, and the frequency band to pass is fixed at 4-40 Hz. By the epoch, the length of the image stimulation interval taken out is 1000 ms or 2000 ms. The sampling frequency of the electroencephalograph is 128 Hz, so there are 256 data points in 2000 ms. At the time of 1000 ms, there are 129 leading positions from which data points are cut out from 1 to 129. Therefore, there are 130 validation patterns of epochs. The combination of all the validation conditions is 1,300 patterns.

5.2 Evaluation result

Preprocessing of 1300 patterns was performed, and the one with the lowest EER was verified. We changed the number of image stimuli when used for authentication and verified whether EER decreases. When performing authentication using a plurality of image stimuli, classification and authentication are performed after adding the obtained reliability and then averaging them. Table 2 indicates the EER and its condition number when the minimum EER is obtained for each number of image stimuli used for authentication. In the condition number shown in Table 2, each condition number is entered in the order of Digital filter - Artifact countermeasure - Epoch (Starting point).

Table 2 lowest EER at multiple image stimuli

Number of image stimulus	EER(%)	Condition number
1	5.602	A2-B2-C1(112)
2	2.419	A2-B2-C1(104)
3	1.748	A1-B1-C1(1)
4	1.202	A1-B1-C1(2)
5	0.944	A1-B1-C1(34)

Table 2 shows that EER decreases by increasing the number of image stimuli and performing authentication. In authentication, it is thought that it is more effective as an authentication method to use electroencephalogram data that saw multiple image stimuli than to use electroencephalogram data when viewing a single image stimulus. However, when using multiple of image stimuli, there is a tradeoff that the time required for authentication increases because the time during which the user is viewing the image stimulation increases. Also, when the number of image stimuli during authentication is 1 and 2, the artifact countermeasure was the minimum EER, but when it is more than 3, the digital filter is not performed and artifact measures are not taken resulted in obtaining the smallest EER.

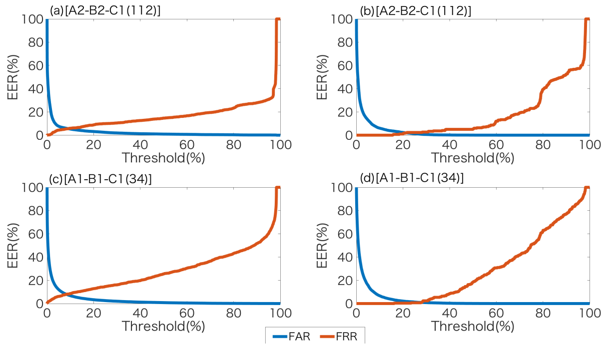

Fig. 6 Graph of FAR and FRR

Fig. 6 shows the graph of FAR and FRR verified by the condition numbers when the number of image stimuli shown in Table 2 is 1 and 5. The graphs (a) and (b) in Fig. 6 are condition number A2-B2-C1(112). Similarly, the graphs of (c) and (d) are condition number A1-B1-C1(34). Graphs of (a) and (c) is when the number of image stimuli used for authentication is 1, graphs of (b) and (d) is when the number of image stimuli is 5. Looking at the graphs of (a) and (c) shown in Fig. 6, the FAR is almost the same, whereas the FRR of (a) is lower than (c). It can be seen that the FRR rapidly increases near the threshold value of 95%. Graph (b) was EER:2.000%, while graph (d) was EER: 0.944%. It can be confirmed that the FRR of (b) is increased around the threshold value of 20% as compared with the FRR of (d). This is probably because the confidence ratio of the correct registrant has locally decreased due to the digital filter and artifact countermeasure. However, when threshold is set to 60%, (b) is FAR: 0.0222%, FRR: 12.000%, (d) is FAR: 0%, FRR: 30.667%. The details of FRR for each threshold in graph (b) and graph (d) are shown in the Table 3.

Table 3 FRR details of graph (b) and graph (d)

Threshold(%)	FRR(%)[A2-B2-C1(112)]	FRR(%)[A1-B1-C1(34)]
0	0	0
10	0	0
20	1.33	0.33
30	2.66	2.33
40	5.00	8.66
50	5.33	18.33
60	12.00	30.66
70	19.33	41.66
80	39.33	63.00
90	52.66	77.33
100	100	100

It can be seen that FRR decreases by carrying out preprocessing at (b). From this reason, it was suggested that applying artifact countermeasure as preprocessing is effective for improving the authentication accuracy.

6. Conclusion

In this paper, we propose and evaluate a biometric authentication method based on electroencephalogram analysis using image stimulation. We verified the combination that obtains the minimum EER by combining preprocessing from the proposed method and performing authentication using multiple image stimuli. When authentication was performed using one image stimulus, the minimum EER was 5.602%. At this time, preprocessing was carried out by artifact countermeasure and digital filter (IIR), and when data of 0.875 ms from the image stimulus presentation was cut out for 1000 ms by epoch. By increasing the number of image stimuli used for authentication, it can be confirmed that EER decreases, and the minimum EER: 0.944% was obtained. However, the preprocessing at this time was when artifact countermeasure and digital filtering were not done. EER was 2.00% when the preliminary processing at the time of obtaining the minimum EER when authentication was performed using one image stimulus was performed using five image stimuli and the authentication was performed. This is worse than the minimum EER when 5 image stimuli. As a cause of such a result, there was a possibility that some of the features of the registrant disappeared due to artifact countermeasure, and the confidence ratio of registrants declined. It is conceivable that the confidence ratio other than the correct registrant has increased. However, it was confirmed that the ratio of FRR when the threshold value is set to 60% is lower than when the minimum EER is obtained. When the countermeasure against artifact is taken according to the threshold value and the digital filter is performed, authentication was able to show that the result will be better.

As a future task, this paper uses brain wave data of examinee for verification without dividing registration and authentication for the three trial. Hereafter, I think that it is necessary to verify whether the brain wave authentication is possible even after a time such as one week, by separating the measurement separately for the registration and the authentication. In addition, it is necessary to verify whether authentication can be performed even if brain waves are measured in a state other than the sitting state in the authentication phase by creating a learning model in the sitting state at the time of registration. Furthermore, in this example, the image of the trump cards was used for the image stimulation, but by using other image stimuli, what kind of change occurs in the reaction of the brain waves is studied, and by using what kind of image stimulus, It is necessary to check for individual examinee whether the difference can be made large. In the current research, it is the authentication accuracy in the state of measuring indoors only in the rest state. It is necessary to verify the influence on the authentication accuracy depending on the surrounding environment and the state of the certifier. It is difficult to wear the current electroencephalograph alone by one person or wear it for a long time. Because it is wet type, it is necessary to wet the part of the sensor. Also, it is necessary to match the electrode to the correct position when the electroencephalograph is attached. In the future, it is desirable to develop an electroencephalograph that can be easily attached by one person and can be used for a long time.

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