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Person Authentication Using Brain Waves Evoked by Individual-related and Imperceptible Visual Stimuli

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Abstract: Person authentication using biometric information has become increasingly popular owing to the fact that continuous authentication is required in most user management systems. This study introduces an individual-related stimulus, instead of common stimuli, to improve the verification performance based on biometric authentication using brain waves evoked by imperceptible visual stimulation. Imperceptible visual stimulation is considered over visual stimulation to overcome obstacles that a user may face when using a system. Compared with previous studies that used circular figures as common stimuli, herein, we ensured a higher evoked response by using individual face image stimulation. Imperceptible stimuli were confirmed by changing the image intensity and presenting a high-speed stimulation. Individual imperceptible face image stimulation confirmed that the following event-related potential (ERP) components: N 170, N 250, and N 400 were obtained. Furthermore, by using various time zones, including the ERP components as features, we verified the performance of eight subjects and achieved an equal error rate (EER) of 6.2%.

Keywords: EEG, Event-related potential, Wavelet transform, Imperceptible visual stimuli.

1 Introduction

Biometric recognition systems can verify the identities of people based on their physiological and/or behavioral personal characteristics, and hence, such systems are widely used as essential safety precautions in various fields such as the military, organizations, universities, banks, airports, as well as in e-commerce. Usually, biometric traits are extracted from facial images, fingerprints, iris images, and palm prints; however, such traits may be easy to steal and copy [1, 2, 3]. Considering that it is possible to forge authentication systems using stolen data by performing spoofing attacks, it is worthwhile to explore more unique biological signals for biometric authentication purposes. However, several authentication methods do not support the replacement of users in user management systems after authentication considering that users are authenticated only once before system use. Therefore, conventional biometric traits are only used in the begining of user verification process, and hence, such traits may be unsuitable for continuous authentication [4].

An electroencephalogram (EEG), a record of the electrical activity of the brain captured by electrodes, is considered a potential user authentication method aimed at overcoming the above-mentioned issues with several security advantages of being unique, difficult to spoof, and continuously generated [5, 6]. Considering that an EEG is not something that

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is exposed on the body surface, it is difficult to copy or falsify. Additionally, an EEG is continuously generated and hence can be used in a continuous authentication system.

In Ref. [5], brain waves evoked by imperceptible visual stimuli were used as confidential biological information. If a continuous authentication system uses visible stimuli, the user can observe the stimuli, which hinders the user's actual task. To overcome this issue, an imperceptible visual stimulus is generally considered instead of a visual stimulus. Additionally, in Refs. [6, 7], a scalogram was obtained by time-frequency analysis as an individual feature that contained both the time and frequency information of an EEG. Later, a synchronization method using correlation for matching scalograms was introduced, and the verification performance was evaluated based on the Euclidean distance method.

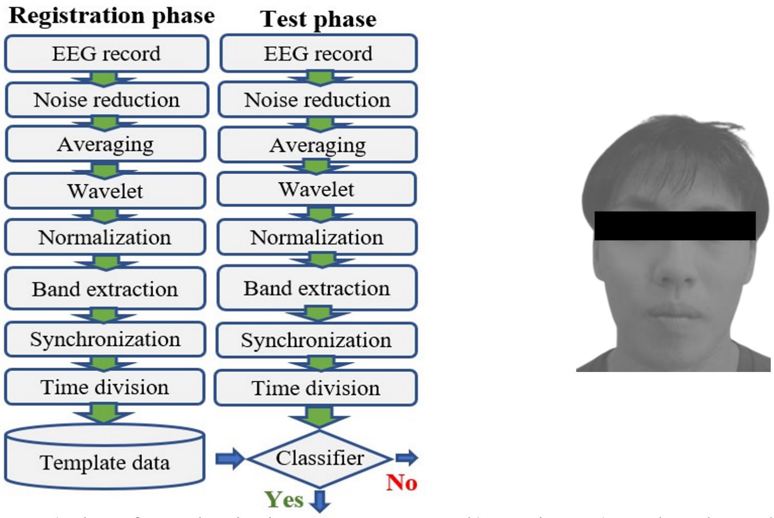
This paper proposes the use of individual-related stimuli to enhance the ERP response of each individual using evoked EEG signals, which is in contrast to the common stimuli used in Refs. [5, 6]. The individual differences in the evoked response were expected to increase when using visual stimuli associated with each subject, which are called individual-related stimuli. In addition to Ref. [6], the alpha waveband scalogram was used for synchronization herein. However, a specified band that is more effective for calculating the correlation in the scalogram may exist. Based on the foregoing, specific frequency bands and time zones were extracted from the scalogram as feature quantities based on the characteristics of the power of the alpha waveband when the stimuli were presented.

2 Related Studies

Current one-time authentication systems utilize conventional authentication methods such as fingerprints, facial recognition, and IC cards. In one-time authentication, authentication is only performed when the system is first used; therefore, it is not possible to respond to replaced users once authentication is complete. Conversely, in continuous authentication [8], in addition to the sign-in authentication performed when the system is first used, additional verification is performed to ensure that others cannot impersonate while using the system. Therefore, individual identities are always guaranteed when a system is used.

An EEG presents slight potential differences between the two electrodes attached to the head [9]. Considering that an EEG can only be recorded by wearing an electroencephalograph, it ensures high resistance against spoofing. To wear an electroencephalograph is inconvenient for the user, but once the user wears it, after that EEG data can be recorded without any user co-operation. Moreover, it is necessary to use biometric information that does not interfere with the actual ongoing task at the time of authentication.

The person authentication technology authenticates a person by comparing the information on the person presented for authentication with the information registered in advance. In previous studies, the use of brain waves as biometrics has been considered [10, 11]. Brain waves as biometrics are suitable for continuous user authentication in systems, particularly in systems with high security requirements. Assuming continuous authentication, Nakanishi et al. proposed person verification using EEG signals evoked by invisible visual stimulation [5, 6]. The authentication process comprised two phases: the registration



a) Flow of an authentication process　　b) Face image (Actual one has no bandage)

Fig. 1: Authentication process and facial image

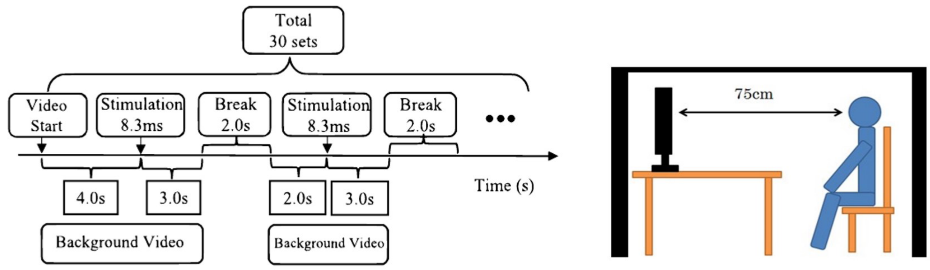
phase and the test phase, as illustrated in Fig. 1(a). During the registration stage, EEG signals were recorded from the subjects using the proposed method. An average amplitude of ±100 μV or more of the acquired EEG data was considered as noise. The noise in the recorded EEG data was eliminated and ensemble-averaged. Furthermore, continuous wavelet transform, which is a time-frequency analysis method, was performed on the ensemble-averaged EEG data to extract the scalogram as a feature quantity for feature extraction. The Euclidean distance between the template and test data was calculated to evaluate the verification performance. The test data with distances similar to the predefined threshold were considered genuine, while the rest were rejected.

3 Introduction of personal stimuli

Common stimuli were presented to all participants as invisible visual stimuli [5, 6]; however, the individual difference in the evoked response was insufficient considering that the stimulus was common for all subjects. Therefore, there existed a fair possibility of the evoked response being recorded insufficiently. In this study, individual-related stimuli were used that could potentially result in more evoked EEG signals than common stimuli, thereby improving verification performance.

3.1 Facial images as individual-related stimuli

Ref. [12] reported that in contrast to situations wherein dots or letters are presented as stimuli, situations wherein facial images are used result in a higher response of ERP com-



a) Flow of individual-related stimuli

b) Relationship between display and subject

Fig. 2: Flow of individual-related stimuli and the experimental environment

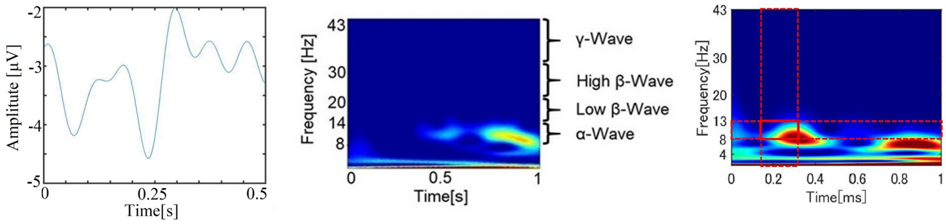
ponents, called N 170, N 250, and N 400. N170 is a negative-going deflection in the ERP waveform that peaks between 130–200 ms at occipitotemporal electrodes, among other ERP components. Furthermore, Refs. [13, 14, 15, 16] reported that the higher the intimacy with the presented facial image, the greater the ERP of N 170 and N 250. Therefore, in this study, mirrored personal facial images were used to ensure higher intimacy, considering that they are most commonly used as an individual-related stimulus. Fig. 1(b) presents an example of a facial image.

3.2 Flow of stimulus presentation

A background teapot video similar to that used in Ref. [7] was played for a duration of 2s with an added break time, and each personal stimulus was inserted in the background video. Fig. 2(a) illustrates the stimulus presentation flow. When the background video was played, the teapot began to rotate in a cycle of 2 s and continued until the video ended. After 4 s from the starting point of the video, the first stimulus was presented such that it overlapped with the teapot in the background. The duration of the stimulus was approximately 8.3 ms, and after 3 s, a white background was presented as a break for 2 s. The second stimulus was inserted after 2 s and was repeated 30 times. The total video duration was approximately 210 s.

3.3 EEG measurement environment

Measurements were performed on eight male subjects aged between 20 and 26 years. We used 24 datasets (8 subjects×3 data) for training and 64 datasets (8 subjects×3 genuine data and 8 subjects×5 other data) for testing to evaluate the verification performance. Each subject was asked to sit at a distance of 75 cm from the display, as illustrated in Fig. 2(b). The subjects were instructed to take breaks, wherein they could blink or close their eyes, when a white background was presented. An electroencephalograph called Emotive Epoc+ was used to conduct the EEG measurements.



a) ERP waveform (personal stimuli) b) Power distribution in a scalogram c) Time zone extraction

Fig. 3: ERP response and feature extraction methods

3.4 Investigation of evoked responses

To evaluate the verification performance, the proposed stimuli was used to determine whether an ERP component was present. Initially, individual-related stimuli were applied to two subjects, and the EEGs were recorded. Fig. 3(a) illustrates an example of an ERP waveform with personal stimulation. However, the derived ERP has a latency of approximately 250 ms, and it reveals a different evoked reaction from N170 owing to a discrepancy between the actual presentation of the stimulus image and the specific time in the video.

We recorded the changes in the amount of light during the stimulus presentation by attaching a photodiode to the display, measuring the output voltage of the photodiode with an oscilloscope, and determining the time lag. Time lag refers to the interval of display lag between the moment at which the start button on a device is pressed and the time at which the actual video is played on the display. The average time lag in our experiment was 65 ms. By sliding the waveform as shown in Fig. 3(a) by -65 ms, the true latency was found to be approximately 180 ms, and a reaction similar to that of N170 was obtained. Therefore, we concluded that the ERP component was confirmed when an imperceptible visual stimulus was presented.

4 Improvement of feature extraction method

4.1 Effect of splitting the alpha waveband

In Ref. [17], authors investigated and confirmed that the cerebral cortex responses increased in the alpha-band power for subliminal and supraliminal visual stimuli. Furthermore, it was confirmed that the best results were obtained when synchronization was performed using only the alpha waveband [6]. To verify the foregoing, the verification performance using the EEG database used in Sect. 3.3 was evaluated using a similar verification process as that presented in Fig. 2. Fig. 3(b) presents the power distribution of the EEG scalogram, where the blue (dark in grayscale) and red (light in grayscale) colors indicate the non-significant and most significant areas of power distribution, respectively. Therefore, to further improve the verification performance, the alpha waveband was split

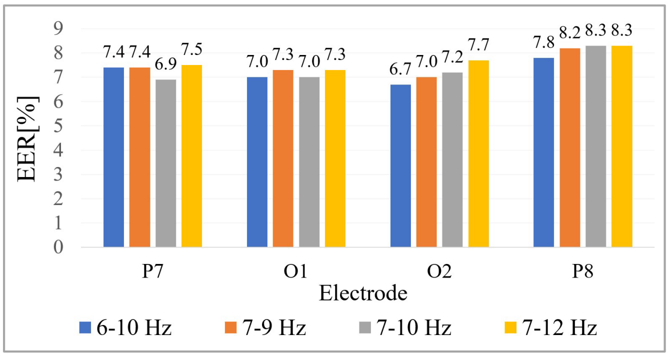


Fig. 4: Verification performance of each sub-band

into sub-bands. The sub-bands were extracted as features from the scalogram based on the power distribution. The sub-bands considered were 6-10 Hz, 7-9 Hz, 7-10 Hz, and 7-12 Hz. The verification performance was evaluated for O1, O2, P7, and P8 electrodes in a computer simulation. These electrodes were chosen considering that they were positioned in the occipital area, which is primarily responsible for visual processing. Fig. 4 illustrates the verification results for the above-mentioned sub-bands. Cross-validation was performed 10 times. The EERs for all electrodes were found to be between 6–8 %, and the best EER was 6.7 %. The overall verification performance was good between 6-10 Hz.

The verification performance degraded slightly as the bandwidth increased. However, almost no change was observed in the EER owing to the difference in bandwidth, considering that the amount of data used for verification was small. Therefore, owing to the small amount of data, the EER value deteriorated by 6.7 % and 13.3 % for a single synchronization error and two synchronization errors, respectively. It is necessary to increase the number of subjects and measured data to effectively evaluate the effect of the extracted frequency band. The EER deterioration percentage is decreased for a single synchronization error when the amount of data is increased.

4.2 Effect of time zone extraction

To improve the verification performance, a scalogram was divided into several time zones based on the ERP component as presented in Fig. 3(c). Table 1 lists the extracted time zones while considering the time period of the ERPs; the information in the limited area was extracted as a feature. For the frequency band, an alpha waveband of 8–13 Hz was used.

The verification performance was re-evaluated at the P7, O1, O2, and P8 electrodes. The time zone of 130–300 ms presented better results compared with the other time zones, considering that the N170 and N250 ERP components were included in this time zone, as illustrated in Fig. 5. For facial image stimulation, N170 and N250 had higher ERP

Extracted time zone	ERP Component
130-200 ms	N170
250-300 ms	N250
300-500 ms	N400
130-300 ms	N170, N250
130-500 ms	N170, N250, N400

Tab. 1: Extracted time zones with corresponding ERP

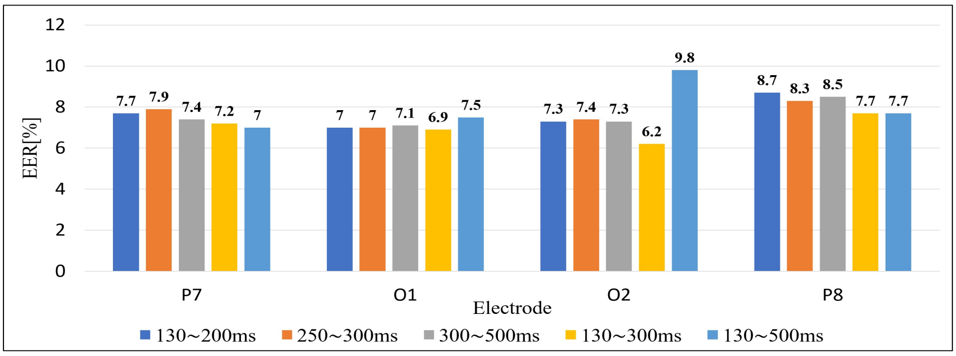


Fig. 5: Verification results for each time zone

responses than the others. The best EER was 6.2 % for the O2 electrode in the 130-300 ms time zone. Therefore, it was confirmed that better results could be obtained by including both N170 and N250 in the verification process.

5 Conclusion

For continuous authentication, it is desirable to present an external stimulus that cannot be perceived by any user. We studied person authentication using an EEG evoked by imperceptible visual stimulation. In this study, we introduced individual-related stimuli, instead of using the common visual stimulus to improve the verification performance. Time-zone and frequency sub-bands feature extraction method was also introduced, which improved the verification performance. While the improved result was confirmed with an EER of 6.2 %, it was not sufficient for practical person verification. It is necessary to reduce the EER into 0 %.

In future, we must re-examine the feature extraction method for brainwaves, including the ERP evoked by facial image stimuli. Furthermore, we should also evaluate the verification performance of person authentication using the re-examined features. In this study, we used a tea-pot video as background. We must evaluate the verificationperformance using various background. Moreover, it also appears necessary to increase the number of experimental subjects to improve the reliability of the results obtained in this study.

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