An Investigation of using SSVEP for EEG-based User Authentication System

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Abstract— **User authentication system to identify individual by using electroencephalograph (EEG) feature based on steady-state visual evoked potential (SSVEP) has been proposed. Recently, SSVEP has been used as a stimulator due to it plays an important role in the response to various visual stimuli, i.e., flickering rate (F), intensity (I), and duty cycle (D). Moreover, the SSVEPs are practical and useful in research because of its excellent signal-to-noise ratio and relative immunity to artifacts and succeeded in many disciplines. In this paper, therefore, we investigate individual SSVEP corresponding to the different visual stimulation in terms of frequency component analysis in the four principal frequency bands, i.e., delta (0.1-3.5 Hz), theta (4.0-7.5 Hz), alpha (8.0-13.0 Hz), and beta (14.0-30.0 Hz). Subjects were instructed to fixate an LED light source then record associated SSVEP waveform. The variation in displaying of the presentation stimuli during a task was examined thereby demonstrating the high usability, adaptability and flexibility of the visual stimulator and determine the optimal parameters for the subject comfort. The experiment achieved the true acceptance rate of 60% to 100% approximately revealing the potential of proposed system for user classification/identification.**

I. INTRODUCTION

Nowadays, in this computer-driven era, people losing their privacy and property stolen. For example, passwords were copied or sneaked. A biometrics authentication system involves confirming or denying the identity claimed by a person. Many biometrics applications have been introduced for years, but only a few of them have gained wide acceptance. In practice, there are many biometric systems that can be realized based on physiological and behavioral for examples, fingerprint, face recognition, DNA, hand and iris recognition, typing rhythm, gait, and voice. However, each has completely different characteristics in terms of user's purpose like simple use, error incidence, accuracy, user acceptance, needed security level, and stability, and system value.

For instance, fingerprint recognition or fingerprint authentication is that the machine-controlled technique of collateral a match between human and fingerprints. Fingerprints area unit one in all several varieties of statistics accustomed establish people and verify their identity. Unfortunately, approximately 1-4% of the population cannot use their fingerprint to log-in [1], and many people cannot provide clear fingerprint images. This example showed that the unstable of the authentication using fingerprint because accident can be occurred any time in subject's daily life. Furthermore, the problem of the fingerprint recognition and the iris recognition are the hygienic condition, especially Japanese and Korean because the subjects have to interact with these biometric applications directly. The face recognition and the iris recognition are the very low-speed biometrics authentication applications in the process of time of identifying the one subject compared to other applications. In [2]-[3], there are several requirements that essential to be covered by any biometric system: i) Changeability: if the user's authentication information is compromised, ii) Shoulder-surfing resistance, iii) Theft protection: this includes physical theft and the computational infeasibility of guessing attacks, and iv) Protection from user non-compliance: to discourage unintended transfer to other parties, the user should not be able to write down (in a manner useful to an attacker) or share their authentication information.

Recently, it is a challenging issue to develop a novel authentication system using electroencephalogram signal (EEG) or called "EEG password" [4]. EEG password is almost impossible to steal. For the related works, the application of using steady-state visual evoked potential (SSVEP) based system has succeeded widely in many disciplines. Especially, the SSVEP-based brain-computer interface (BCI) system detects EEG over an occipital lobe position (the anatomical region of the visual cortex, i.e., O1 or O2, when a visual stimulus is flickering at a constant frequency [5]. EEG-based user authentication using artifacts [6], mental tasks [7][8], visual evoked potential [9], or physical task [10]. These specific tasks were given to the subject. However, the effectiveness and correctness of EEG-based authentication system depends on a uniqueness of individual characteristic as it corresponds to a specific task. The objective of this paper is to investigate a possibility of using EEG's user accessing to the system on the basis of individual SSVEP response.

II. MATERIAL AND METHOD

EEG data were acquired by using a wireless Emotiv™ headset at the sampling rate of 128 Hz and 14-bit resolution, with a band-pass filter of 0.2-45Hz, digital notch filters at 50Hz. Five healthy subjects participated in this study (3 males and 2 females, the average age of 22.2 years old.), i.e., NC, CY, AK, PP and CC. These subjects had no report of an epileptic seizure. For each trial, all the subjects were instructed to fixate stimuli displaying on an RGB LED stimuli provided by Gerora with driver WS2812S that can be programmed using the Arduino microcontroller for displaying in front of them. Distance is set approximately one meter. Based on the studies in [11]-[14] found that the optimal parameter for the subject to reduce visual fatigue or visual discomfort. For each trial, therefore, we set the duty cycle (D) is 0.7, flickering rate (F) is varied 6-9 Hz, light intensity (I) is 50%, and chromatic color (C) is green as shown in Fig. 2. The subjects observed the visual stimulus for ten trials. During the experiment, all procedures were carried out under the controlled external lighting chamber, and multi-channel visual display composed of four different flickering rates.

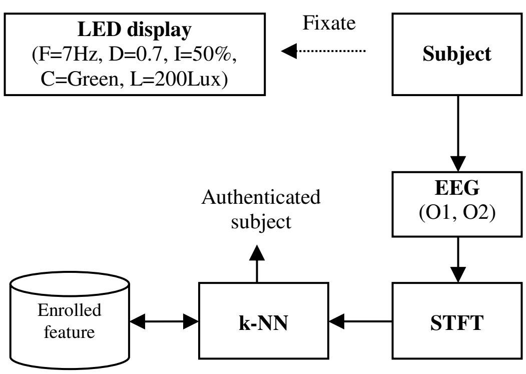

Fig 1. Overview of the proposed system.

A. *Preprocessing*

In this paper, we considered two channels, i.e., SSVEP signal from the occipital lobe of left (O1) and right (O2) cerebral hemispheres. The recorded EEG signal will be processed by normalizing to deal with the range of raw data varies for every trial from the experiment. Therefore, the range of all data should be normalized so that each trial contributes proportionately to the final feature. Normalization is the process of scaling individual samples to obtain unit norm in which the process is considered as pre-processing. The objective of preprocessing is to automatically zero-mean transform and scaling to unit length, i.e., the range of -1 to 1.

B. *Feature extraction*

Different visual stimulation in terms of frequency component analysis in the four principal frequency bands, i.e., delta (0.1-3.5 Hz), theta (4.0-7.5 Hz), alpha (8.0-13.0 Hz), and beta (14.0-30.0 Hz) was analyzed by using the short-time Fourier transform (STFT). The STFT was used to determine the spatial-temporal content, i.e., peak magnitude and its corresponding peak frequency. In the sampled SSVEP, $x(m)$ at time m, the data to be transformed into sub-frames (or called window), $w(m)$, by using discrete Fourier transform as follows:

$$X(n,\omega) = \sum_{m=-\infty}^{\infty} x(m)w(m-n)e^{-j\omega m} , \quad (1)$$

The peak fundamental frequency, $F_{\max}$, of squared magnitude was then computed as follows

$$F_{\max}(\tau,\omega) = \max_{\tau \in L_w} \log\left(\left|X(\tau,\omega)\right|^2\right) . \quad (2)$$

where L_w was a window length and ω was a frequency component. The feature extraction process is depicted in Fig. 3. In the experiment, we set window length $L_w = 30$.

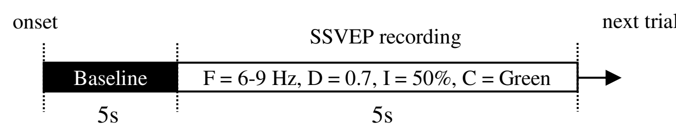

Fig. 2. Experimental paradigm presented for a one trial.

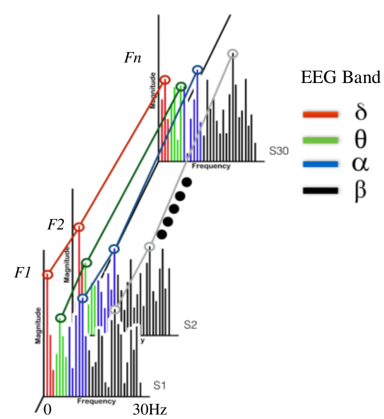

Fig. 3. Peak magnitude of each EEG band computed based on STFT.

C. *Identification*

We employed the k-nearest neighbors (k-NN) algorithm to calculate the distance between the enrolled features and the input EEG data. After template matching is processed, a machine using the k-NN algorithm to make a decision whether it will accept the authentication of the subject or not. If the calculated distance of the k-NN algorithm is equal or higher than the customized threshold the authentication will be rejected.

III. EXPERIMENTS AND RESULTS

For the enrollment phase, after the feature out of the subject's SSVEP using feature extraction method, the system allows the attempt of the incoming authentication. The shortest distance from the current authentication to the one determines the most possibility to gain the login permission to the system. If that shortest distance is the same person as the current authentication, it means this authentication is permitted and allows this person to access the system.

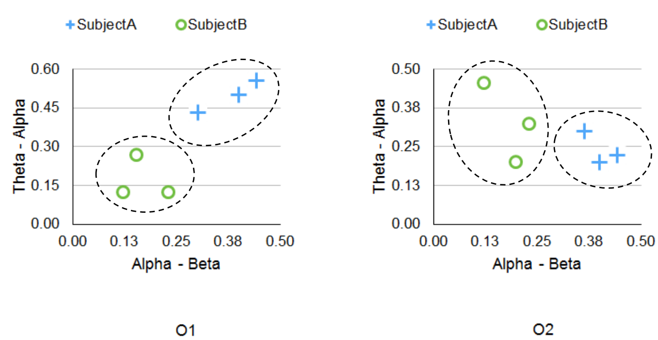

Fig. 4. Typical example of the best feature space obtained by the optimal bands (Alpha, Theta, and Beta)

IV. DISCUSSIONS

In Table 1, the result of the experiment showed every distance in the authentication. To determine the distance values using k-NN algorithm, we applied the Euclidean distance in the k-NN algorithm to calculate the distance between the training current authentication and the others. The successful authentication should be the minimum summation of the both distance O1 and O2 according to the result, the total average true acceptance rate (TAR) of 60% to 100% approximately. However, there were the interesting issues, in this experiment that one of the subjects almost completes their authentication 5 times perfectly. There was a subject AK who was successfully accessed to the system 4 out of 5 times whereas the subject CY who totally denied from the system with the 0 out of 5 attempts.

TABLE I. THE NORMALIZED K-NN DISTANCE VALUE IN AUTHENTICATION AMONG 5 SUBJECTS.

Sub.	NC	CY	PP	CC	AK	Total (%TAR)
NC	**1**	0	0.6302	0.295	0.106	4/5 (80%)
	1	0.2924	0.302	0.008	0	
	0.755	0.9362	0.8355	0	**1**	
	1	0.2299	0	0.552	0.779	
	1	0.5802	0.778	0	0.662	
CY	0	0.536	**1**	0.581	0.374	3/5 (60%)
	0	**1**	0.981	0.710	0.860	
	0.215	**1**	0.853	0.623	0	
	0	0.792	**1**	0.531	0.306	
	0.030	**1**	0.747	0.356	0	
PP	0.297	0	**1**	0.775	0.832	4/5 (80%)
	0.182	0.008	0.070	**1**	0	
	0	0.253	**1**	0.462	0.763	
	0.349	0	**1**	0.525	0.799	
	0	0.102	**1**	0.160	0.297	
CC	0	0.562	0.955	**1**	0.691	5/5 (100%)
	0.272	0.826	0.251	**1**	0	
	0	0.236	0.617	**1**	0.812	
	0	0.042	0.722	**1**	0.742	
	0.372	0.625	0	**1**	0.687	
AK	0.038	0	0.694	0.223	**1**	4/5 (80%)
	0	0.893	0.272	0.736	**1**	
	0.649	0	0.434	0.482	**1**	
	0	0.722	0.477	0.382	**1**	
	0.702	**1**	0.277	0.821	0	

Feature comparison: From feature extraction method, we compared all possible frequency bands. Two features have been compared; the first method the extracted parameters of peak magnitude are used as a feature vector and in the second method the different magnitudes are used as a feature vector. The results showed that the difference in frequency band was statistically significant in the beta, theta and alpha bands ($p <$ 0.001). Fig. 4 shows the best bands and corresponding frequency. Other feature extraction method might be applied, i.e., wavelet transforms (WT) [15]. However, the real-time processing and the composition time must be considered when implementing the system.

Authentication: The proposed system applied k-NN algorithm as a classifier due to the easiest implementation for real-time processing. The results showed that the k-NN is able to identify an individual effectively. We tested the system by leave-one-out cross validation. The average rejection rate in authentication was 0-10%. However, it still requires changing process of the system and the algorithms implementation, i.e., linear discriminant classifier, support vector machine or neuron network [16]-[17], to improve the system's performance.

Scenario: This experiment considered the scenario that the user was preferably instructed to fixate on one of four visual stimulations that contain different flickering rate during the enrollment process. For the testing process, the user has to fixate the same visual stimulation. Based on these results, we recommend the optimal range as a feature for potential SSVEP-based applications. Accordingly, not only the parameters of the visual stimulator were affected to the experimental results while recording SSVEP, but also, the external environment. Other light sources, signal interfered by electronic devices, and subject's comfort should be addressed to acquire better recording SSVEP. Moreover, well preparation before doing the experiment that might improve the correctness of the authentication.

V. CONCLUSIONS

In this paper, we have developed the new alternative way of the authentication using individual SSVEP response to grant access to the system. The EEG-based authentication has the advantage to identify individuals by using their biometric information. Various techniques for making the SSVEP becomes the unique feature of each subject such as peak magnitude of the selected bands, including the optimal parameter to reduce visual fatigue or visual discomfort. We investigated the suitable approach of using EEG brain activity as a biomarker to classify individuals by using STFT-based peak magnitude of frequency bands as a feature and the k-NN algorithm as a classifier. The associated SSVEP was real-time analyzed. Two features have been compared; the first method the extracted parameters of peak magnitude are used as a feature vector and in the second method the different magnitudes are used as a feature vector. The experiment achieved the TAR of 60% to 100% approximately revealing the potential of proposed system for person classification and identification.

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