CIBA: Continuous Interruption-free Brain Authentication

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Abstract: The performance of contemporary biometrics systems based on electroencephalography (EEG) suffers from a low signal to noise ratio due to the properties of the human EEG and the measurement on the scalp. There is a trade-off between accuracy and the time required for data acquisition. Additional time is needed to mount an EEG headset so that authentication requires several minutes, rendering it not very usable for most scenarios. In a scenario where an EEG headset is already worn for a different purpose, the setup time can be neglected and the time for data acquisition may be extended if it does not interfere with the subject's actual task, allowing continuous authentication. However, most proposed EEG-based authentication systems require the user to perform a certain task during data acquisition, distracting the user from the actual task. We conceptualize an EEG-based continuous authentication scheme that does not require the user to perform a task in addition to working at a screen. We propose two approaches based on well known brain responses, SSVEP and ERP.

1 INTRODUCTION

With availability of consumer grade headsets, EEG-based biometrics systems seem to become more applicable, increasing research interest in such systems. Nevertheless, EEG-based biometrics have not established themselves in real world applications yet. A key impediment is the noisy nature of the electroencephalogram (EEG). To extract discriminant information, current EEG biometrics approaches capture about five minutes of EEG data, whilst only achieving accuracies lower than desirable for practical applications (Gondesen et al., 2019a). Accuracy can be increased by capturing longer time series of the EEG, but extending the time for data acquisition also reduces practical applicability. This is typically even more inconvenient for the subject compared to more commonly used biometrics, as most EEG-based schemes require the user to perform a task during data acquisition. The period of inconvenience for the subject is extended by the time required for properly mounting the EEG headset which may range from few seconds to several minutes (Gondesen et al., 2019a; Gondesen et al., 2019b). These properties render current EEG biometrics approaches unsuitable for standard applications of biometrics as unlocking a phone but may be suitable for a continuous authentication scheme, especially in cases where an EEG is already worn for other purposes. In recent studies, EEG was used to determine mental parameters like awareness, stress and workload in safety critical scenarios like air traffic control (Lim et al., 2018; Yeo et al., 2017; Debie et al., 2019). Safety critical work places are also likely to be security critical, calling for continuous authentication. But in such a scenario, subjects may not be interrupted or distracted from their critical work, which would be a requirement for most EEG-based biometric schemes.

Therefore we present two possible concepts for continuous interruption-free brain authentication (CIBA), i.e., EEG-based continuous authentication schemes aiming not to distract the users from their work. Both concepts rely on delivering subliminal stimuli to the subject by an off-the-shelf (gaming) screen. The concepts are described and evaluated based on related research efforts. Both approaches utilize well known brain responses, namely steady state visually evoked potential (SSVEP) and event-related potential (ERP).

The paper is divided into the following sections: In Sections 2 and 3, we explain the two approaches and discuss their feasibility. In Section 4, we discuss common issues of the proposed concepts. Section 5 provides a conclusion.

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2 SSVEP

2.1 Prerequisites

When observing flickering lights, the subject's EEG may exhibit activity at the flicker frequency and its (sub)harmonics, dominantly at the visual cortex. The effect can be identified by peaks in the spectrum when compared to the spectrum without stimulus. Brain-computer interfaces (BCIs) based on SSVEP typically use multiple simultaneous flickering stimuli with different frequencies or phases, adding up to a complex spectrum. To input data via such a BCI, the user focuses on a single flicker stimulus. The attention to this single stimulus modulates the signals so that the components elicited by the unattended stimuli are decreased relative to the components elicited by the stimulus focused on. The attention does not necessarily need to be on the stimulus itself, it is only important to direct the attention to the space where the stimulus is located, allowing the user for example to read a text on a flickering background (Morgan et al., 1996).

The SSVEP paradigm works at frequencies of about 3.5 Hz to 75 Hz (Herrmann, 2001; Amiri et al., 2013). Similar to the pink noise characteristics of the EEG baseline, the power decreases with increasing frequency. BCIs often test a range of frequencies to identify the frequencies with the best signal to noise ratios for each user to select optimal stimulus frequencies. Hence, frequency responses contain discriminant information. The permanency, i.e., the proportion of the individual frequency responses remaining constant over subsequent measurements, is not extensively researched. In two studies the permanency of an SSVEP biometrics identification scheme could be shown in multiple sessions with accuracies over 90% (Piciucco et al., 2017; Falzon et al., 2017).

2.2 CIBA SSVEP

As the SSVEP paradigm does not require the subject to perform any task other than attending the location of the stimulus, which can be the background of the screen, it does not interrupt the user's workflow. Nevertheless, flicker in the frequency range used for SSVEP typically causes discomfort and strain and may even cause epileptic seizures. For mitigation, duty cycle and stimulus frequency can be optimized. (Lee et al., 2011) showed that discomfort can be decreased by increasing the duty-cycle when using a 13.16 Hz stimulus. (Won et al., 2015) found no effect of longer duty cycles on the comfort for frequencies 26 Hz to 34.7 Hz, but adverse effects on the performance. This frequency range was reported to cause less discomfort than 6 Hz to 14.9 Hz. If higher frequencies generally decrease discomfort, one should consider going to the limits of SSVEP. It has been shown that the SSVEP paradigm works at frequencies above the flicker fusion threshold (Herbst et al., 2013; Sakurada et al., 2015). A system that relies only on frequencies above the flicker fusion threshold can be regarded as subliminal.

Implementation. In the CIBA SSVEP concept, a PC screen with a high refresh rate would be used to probe the subject for the responses to different stimulus frequencies. The system can be tuned to test previously determined, most discriminant frequencies. The stimulation could be realized by a software that creates a top layer which changes between a transparent and a non-transparent black screen. This layer should not capture inputs, as the subject must be able to perform regular work. A normal screen with a fixed refresh rate will most likely not suffice, as properly realizable stimulation frequencies are limited to even divisors of the refresh rate. Scheduling of the operating system might also cause slight glitches in timing, creating visible artifacts that might be disruptive to the user. Instead of a fixed refresh rate screen, a screen with an adaptive synchronization technology, such as *FreeSync*, should be used. In a certain frequency range, this allows arbitrary intervals between two frames, enabling seamless delivery of a wide range of stimulus frequencies. Gaming screens supporting *FreeSync* often support refresh rates of 144 Hz or higher, which allows to deliver stimuli in the range of the flicker fusion threshold. As the flicker fusion threshold is higher in the outer visual field (Lee et al., 2011), especially on large screens, flicker might be recognizable. By using an eye-tracker, the flickering area of the screen could be limited to the area observed.

The CIBA setup including an eye-tracker is shown in Fig. 1. A possible sequence of SSVEP stimuli is shown in Fig. 2. By default, the stimulation layer is set to a transparency level that darkens the screen to a gray level adjusted to the perceived brightness of the SSVEP stimulation above the flicker fusion threshold. During a trial, a circular area around the point of gaze is switched between full transparency and black. Trials are separated by interstimulus intervals (ISIs) that are used for baseline correction.

Discussion. The applicability of the CIBA SSVEP concept mainly depends on having sufficient discriminant information in the responses to stimuli above the flicker fusion threshold for all users. If lower

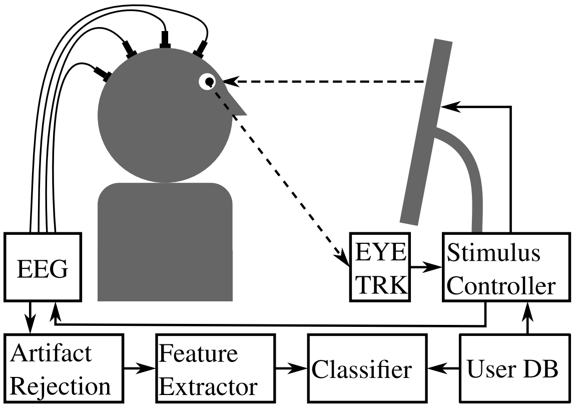

Figure 1: The setup for CIBA consists of a stimulus controller presenting stimuli on the screen at the point of gaze, which is obtained from the eye-tacker (EYE TRK). Stimulus information consisting of timing, position and type of stimulus is added to the EEG. Appropriate stimuli are selected from the user database. Artifacts are removed from the EEG before feature extraction. For the authentication decision the classifier compares the extracted features to templates stored in the user database.

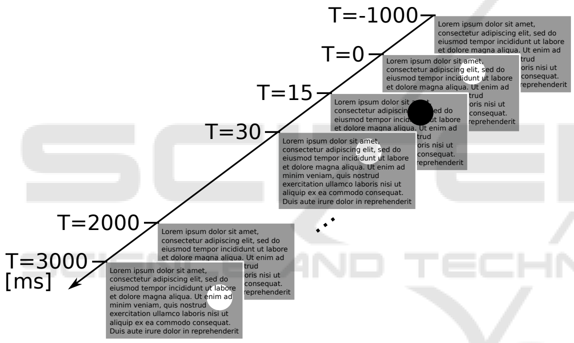

Figure 2: Sequence of SSVEP stimuli with a 66.67 Hz trial of 2 s. The stimulation is limited to an area around the point of gaze.

frequencies need to be used, the system is rendered non-subliminal, uncomfortable to use and may even pose risks to the users' health. Using only high frequencies might decrease accuracy, requiring an extended sliding window for continuous authentication. It has to be made sure that this is within the security requirements. Additionally, permanency needs to be assessed. It is possible that the templates will change over time, requiring an adaptive approach.

3 ERP

3.1 Prerequisites

An event-related potential (ERP) is the signal component in the EEG that is caused by an event, for example the presentation of a visual stimulus to the subject. As the ERP is relatively weak, stimuli are typically repeated to average out unrelated EEG components. The ERP's waveform varies with the type of event and individual characteristics of the subject, hence ERPs are widely used in biometrics approaches. There are a few paradigms that affect the components of the ERP in certain ways. One of the most famous is the oddball paradigm, where two types of stimuli are delivered randomly, with one type only occurring rarely. The ERP of this rare event contains a peak after about 300 ms and is therefore called P300. The amplitude of the P300 component is increased if the stimulus is relevant to the task of the subject. This property can be used to create an EEG-based authentication system that is based on knowledge instead of biometrics (Gondesen et al., 2019b). (Das et al., 2015; Das et al., 2016) used an oddball paradigm for biometric authentication achieving equal error rates about 14%. Permanency was verified over a couple of weeks.

ERPs are susceptible to eye artifacts. Moving or blinking eyes induce waves with relatively high amplitudes in the EEG. If an ERP is superimposed with such an artifact, it will not be easily averaged out and might lead to a misclassification.

3.2 CIBA ERP

Common ERP-based biometrics approaches require the users to pay attention to (most commonly visual) stimuli, which are presented multiple times to increase the signal to noise ratio. This contradicts the CIBA concept, which does not allow disruptions of the normal workflow. ERPs are elicited even without a task related to the event, but this may affect components that otherwise contain discriminant information. In addition to not including an authentication task, stimulus presentation time needs to be limited so that the subject cannot consciously perceive it. (Bernat et al., 2001) used pictures of two words as oddball stimuli presented for only 1 ms, ensuring subliminal stimulation. The P300 component was found to be increased for the rare case. (Frank et al., 2017) conducted an ERP experiment aiming to probe if a face is known to the subject. The subjects were instructed to watch a movie, where occasionally a known face or blurred face was inserted for an interval of 13.3 ms, which was subliminal to only four of 22 subjects. The other subjects perceived the images to different degrees, seven being able to name the depicted person. The known face was shown rarely, creating an oddball paradigm. The known face could be detected from the EEG in most cases. As the experiment did not contain non-blurred unknown faces, the effect might only be caused by a general face detection, not by the known face. Detection whether a face is known to the subject could be seen as a knowledge factor for an authentication system. Non-subliminal ERP studies aiming to identify known faces in a concealed information test (CIT) were conducted by (Meijer et al., 2007; Meijer et al., 2009). Detection of known faces did not succeed under one experiment variant where the depicted person was of lesser importance for the subject and not a part of the subject's task. It was concluded that recognition of a familiar face may suffice to elicit a P300, but the P300 may increase with stronger familiarity or an associated task. The experiments also indicate that mere recognition of autobiographical information elicits a P300. The properties of information being autobiographical or faces being known depend on the individual subject, i.e., they contain discriminant information, rendering autobiographical data and known faces promising candidates for stimuli in the CIBA paradigm.

Implementation. To deliver stimuli for a very short duration, a screen with a high refresh rate is required. With an off-the-shelf gaming screen with 144 Hz, stimuli are at least displayed for 6.9 ms, which might not be subliminal for all users. Reaching 1 ms is not feasible with current off-the-shelf monitor technology. As subliminality does not only depend on the duration, it should be considered to design the stimulus delivery system to mask the stimuli, making it harder to perceive them. This could be done by delivering stimuli temporally and spatially aligned with other events happening on the screen, as a stimulus on a static background can be more easily noticed. Stimuli could also be selected or modified to be more similar to the background where they are placed. An eye-tracker can help to place stimuli in the foveal area to make sure it is observed. (Brunner et al., 2010) showed increased accuracy in a P300 BCI study for gaze directed to the target stimulus. This effect may also apply to CIBA ERP. An eye-tracker can also help identifying eye artifacts. Removing eye artifacts is important as the user cannot be instructed to abstain from blinking and fixating a certain spot on the screen in the CIBA scenario.

The CIBA setup including an eye-tracker is shown in Fig. 1. A possible sequence of oddball stimuli is shown in Fig. 3.

Discussion. The studies discussed indicate that a passive, subliminal oddball paradigm can be used to evoke a P300 component, but do not answer whether the P300 contains sufficient discriminant information.

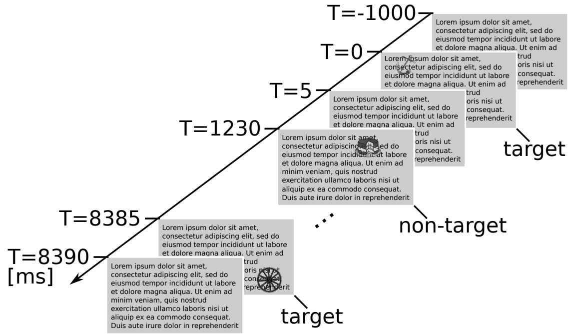

Figure 3: Sequence of oddball stimuli using simple objects (obtained from (Rossion and Pourtois, 2004)) flashed at the point of ganze for 5 ms.

It also remains open to which degree knowledge factors like known faces, or general familiarity with the stimuli can contribute. If familiarity is an important feature, it needs to be investigated whether subliminally shown pictures of unfamiliar persons or items may render them familiar over time.

The P300 depends on the difficulty of the task, showing decreased amplitudes for more difficult tasks (Kok, 1997). As more difficult recognition tasks also extend the P300 length (Twomey et al., 2015), classification accuracy might not degrade. It should be also investigated to which extend difficulty affects the passive, subliminal paradigm and if it is effected by masking.

4 DISCUSSION

The approaches presented rely on well-established paradigms used in BCIs, but these paradigms are rather uncommon in EEG-based biometrics. Hence, it is not clear if sufficient discriminant information can be identified. The quality of the information can usually be improved by capturing more EEG data. The CIBA concept allows to adjust the sliding window of EEG data used for continuous authentication. But increasing the window size increases the response time for deauthentication, rendering the system less secure. Rather than mitigating the time-accuracy trade-off, the CIBA concept impairs accuracy due to the requirements of not using a task and using subliminal stimuli, eliminating the subjects attention. In both paradigms, (spatial) attention improves the underlying EEG signals. In addition, both paradigms need to be used with unusual parameters like very high frequencies or short stimulus intervals, contributing to weaker signals.

In the CIBA concept the continuous authentication process must not distract the subject from regular work, but the EEG data must contain discriminant information. Evoking EEG signals by subliminal stimuli means that the stimuli are processed subconsciously by the brain. This might create a conflict in allocation of brain resources, limiting regular work or the accuracy of the authentication. (Allison and Polich, 2008) showed that the P300 of an auditory counting task decreased with the difficulty of a game played simultaneously.

Besides the performance of the subject, it also needs to be studied how subliminal continuous authentication affects the subject's well-being. Both might not only be affected by the subliminal stimulation itself, but also by the subject knowing to be probed continuously or a lack of accuracy leading to occasional false negatives, deauthenticating a valid user.

5 CONCLUSION

Both CIBA approaches are based on well known paradigms that are widely used in BCI research. In both cases the parameters are pushed to the limits where it is not clear how well the paradigms work and if they can deliver sufficient discriminant information without requiring a sliding window that is too large to meet the security requirements. It can be expected that real world applications will not only need research in the feasibility of the approaches but also in the optimization of data acquisition and feature extraction algorithms.

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