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Eigenbrains and Eigentensorbrains: Parsimonious bases for EEG biometrics

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ABSTRACT

The use of electroencephalography (EEG) for biometric recognition purposes has recently received an increased level of attention thanks to some of its appealing properties. Among them, it is worth mentioning the universality, the intrinsic liveness detection capability, the possibility to perform a continuous identification, and the robustness against spoofing attacks. In this paper we exhaustively analyze the recognition performance achievable when using a parsimonious representation, in the frequency domain, of EEG signals acquired in both eyes-closed (EC) and eyes-open (EO) resting conditions. Specifically, we evaluate the effectiveness of EEG templates obtained as projections onto subspaces defined through eigenbrains (EBs) or eigentensorbrains (ETBs), two bases for EEG signals here defined by means of principal component analysis (PCA) and multilinear PCA (MPCA). An extensive set of experimental tests, conducted on a database comprising EEG recordings acquired from 30 subjects during two separate sessions, in different days, is performed to compare the recognition capabilities of the considered representations under different system configurations.

1. Introduction

The use of biological signals for people recognition purposes is recently receiving an increasing attention from both the general public and researchers. In this paper we focus on electroencephalography (EEG) signals which represent the brain electrical activity measured sensing the voltage fluctuations on the scalp surface [1]. Such signals depend on the ionic current flows within the neurons of the brain, therefore describing the activation patterns of each functional brain region. They can be acquired through non-invasive electrodes placed according to specific spatial configurations named *montages*, such as the 10–20 International system [2] depicted in Fig. 1. An amplifier with a very high rejection to noise, and conductive gel to be used between the scalp and the electrodes to reduce skin impedance, are typically required for properly acquiring EEG signals, whose amplitude ranges in the interval [10; 100] μV for a healthy awake person. When considering subjects in resting conditions, the most relevant cerebral activity is in the [0.5; 40] Hz band, and five main rhythms are commonly detected from an EEG recording: δ ([0.5; 4] Hz), θ ([4; 8] Hz), α ([8; 14] Hz), β ([14; 30] Hz) and γ ([30; 40] Hz). It is assumed that the slowest brain rhythms are dominant during an inactive state, while the fastest are typical of information processing phenomena.

Even with the limited spatial resolution achievable with practical montages, EEG is widely employed for medical purposes, allowing to diagnose epilepsy, strokes, and other brain disorders [3]. It is also used to automatically diagnose sleep diseases such as insomnia and obstructive sleep apnea [4]. Moreover, it is employed for brain–computer and brain–machine interfaces, with both rehabilitative and entertainment applications [5].

Additionally, EEG signals have been also proposed as biometric identifiers: as first postulated in [6], the way brain structures are organized and coordinated during specific cognitive functions or mental states is specific for each subject, due to both morphological and functional traits. Several researches recently confirmed the capability of EEG in providing discriminative information for efficiently performing automatic people recognition [1]. Moreover, it has to be remarked that EEG signals offer some unquestionable advantages with respect to more conventional biometrics. In fact, brain signals guarantee a very high level of universality. They are also significantly robust against spoofing attacks, being very unlikely for an attacker to be able to capture EEG signals and feed them to the electrodes at a later time. Covert acquisition at a distance is also unpractical. Additionally, their use also allows performing continuous recognition, while inherently accomplishing liveness detection, a sensitive issue in nowadays biometric systems [1].

Along with such notable benefits, it has to be mentioned that the major drawback associated with the adoption of EEG for people

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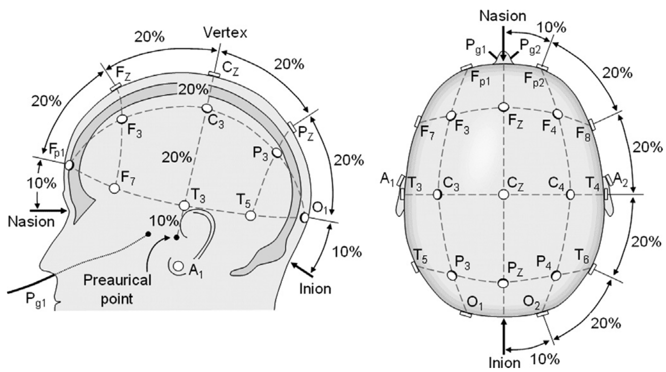

Fig. 1. The International 10–20 montage (adapted from [2]).

recognition is the inconvenience of the acquisition process. In fact, it may be quite uncomfortable, being necessary to put a relevant number of electrodes on the users' scalp, while using conductive gel to reduce skin impedance. Nonetheless, a lot of efforts are currently devoted to the development of EEG recording systems for user convenient real-life applications, mainly for entertainment and medical purposes. Some recent developments have been presented in [7], where some prototypal contactless electrodes made of flexible polymeric material, not requiring any electric contact with the scalp, have been proposed. Moreover, some attempts to use EEG-based systems in real-life conditions have been already taken into account in [8], where single-trial EEG signal collection in outdoor walking for brain–computer interface purposes has been addressed, or in [9] where a mobile-based scenario, employing low-cost acquisition devices, is considered for EEG-based recognition systems. A wireless EEG headset based on dry electrodes with integrated skin-to-electrode impedance monitoring, representing a notable step towards reliable high-quality wearable EEG monitoring systems, has been also recently presented [10]. The rapid development of such technologies makes absolutely plausible to have devices allowing practical EEG-based recognition systems in the near future.

In this paper we therefore analyze the discriminative capabilities of EEG signals with the aim of designing an EEG-based biometric recognition system. Specifically, we evaluate the recognition performance achievable when exploiting novel characterizations of EEG data recorded during resting states, with both eyes-closed (EC) or eyes-open (EO) conditions. In more detail, we exploit EEG spectral characteristics to define two different bases for the considered signals, here indicated as *eigenbrains* and *eigentensorbrains*, obtained by means of principal component analysis (PCA) and multilinear PCA (MPCA). The proposed projection bases provide compact representations of EEG data, while maintaining most of the original information relevant for recognition purposes, and allowing to reduce artifacts due to the acquisition process.

Section 2 provides a brief overview about EEG biometrics state of the art. The proposed compact representations for EEG signals are then introduced in Section 3. The performances achievable with the proposed approaches are compared through the tests described in Section 4. Specifically, a large database comprising EEG recordings from 30 subjects, taken during two separate sessions with a temporal distance of about one month between them, is exploited to evaluate the recognition capabilities of the considered representations under different system configurations. Conclusions from the obtained results are eventually drawn in Section 5.

2. EEG biometrics

Brain activity can be analyzed to perform user recognition during different cognitive tasks, defining acquisition protocols based on the presentation of a given stimulus, and the subsequent recording of a brain response. Visual and auditory events can be for instance employed for provoking event related potentials (ERPs), characterized by a precise temporal reference for the analysis of specific EEG segments: the EEG recorded when self-face and non-self-face images are shown to a subject has been for example employed for person recognition in [11]. The execution of real or imagined tasks such as body movements, mental calculation or speech has also been considered for generating brain responses commonly evaluated in terms of their spatial and spectral distributions [12]. Moreover, very simple and highly effective protocols require the subjects being recognized to just maintain a relaxed state, while remaining awake and alert. Specifically, resting states in either EC or EO conditions currently represent the most widely employed acquisition protocols for EEG biometric recognition [1]. It is also worth observing that such protocols can be easily exploited in both instantaneous and continuous recognition scenarios, being more practically feasible to include resting sessions during a computer-based activity than resorting to audio and visual stimuli provoking precise ERPs.

As already mentioned in Section 1, the aim of the present paper is to analyze the recognition rates achievable with EEG data acquired in resting conditions, when representing their spectral characteristics through projections obtained with two novel bases. The spectrum of EEG signals has been in fact already employed for extracting biometric features in [13], where the Fast Fourier Transform (FFT) is applied to single-channel EEG signals acquired in EC scenarios. Moreover, the power spectral density (PSD) of a single-channel EEG is also employed in [14] for designing a covert warning system in EC conditions. As experimentally verified in Section 4, the projections introduced in Section 3 provide compact representations of the considered EEG spectral characteristics, still guaranteeing improved recognition rates.

It is worth remarking that, in order to verify the effectiveness of the proposed approaches, the performed experimental tests are carried out by using EEG signals of 30 subjects, recorder during two distinct acquisition sessions approximately one month apart each other. Such experimental conditions have been actually rarely evaluated when investigating EEG biometrics. In fact, in most of the works in the current literature, signals recorded during only one single session for each subject have been made available, making it necessary to generate the enrollment and the test samples through different partitions of the same acquisitions [15]. EEG signals from different sessions have been exploited for testing purposes in papers such as [14,16,17], and [18]. Nonetheless, in all these latter cases, the available recordings have been mixed altogether and randomly chosen for generating the enrollment and testing datasets, thus not allowing again to properly investigate the permanence of EEG signals over time.

Actually, scenarios where distinct recording sessions have been exploited for separately generating the enrollment and recognition datasets have been considered in few papers, such as in [19] where EEG signals from 20 people have been recorded in EC resting conditions during two separate sessions, and represented through the amplitude and the frequency of the PSD peak. A database containing EEG signals taken in an EC scenario from 9 subjects during two distinct sessions has been considered in [20], while signals in both EO and EC conditions have been recorded during two sessions from each of 9 subjects in [21]. EEG recordings from four distinct sessions have been also analyzed for recognition purposes in [22], where acquisitions from 9 persons have been taken while performing motor imagery (MI) or word generation tasks. Moreover, a biometric system based on an imagination task performed by 6 subjects, whose EEG signals are recorded during three separate sessions, has been analyzed in [12].

The database exploited for analyzing the proposed approaches in Section 4 is therefore the largest one so far exploited to properly