International Journal of Psychophysiology 116 (2017) 1–8

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

A new approach to analyze data from EEG-based concealed face recognition system

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ARTICLE INFO

Article history:
Received 15 January 2016
Received in revised form 13 January 2017
Accepted 7 February 2017
Available online 10 February 2017

Keywords:
Concealed face recognition test
Single-trial ERP
Non-linear features
Recurrence Quantification Analysis

ABSTRACT

The purpose of this study is to extend a feature set with non-linear features to improve classification rate of guilty and innocent subjects. Non-linear features can provide extra information about phase space. The Event-Related Potential (ERP) signals were recorded from 49 subjects who participated in concealed face recognition test. For feature extraction, at first, several morphological characteristics, frequency bands, and wavelet coefficients (we call them basic-features) are extracted from each single-trial ERP. Recurrence Quantification Analysis (RQA) measures are then computed as non-linear features from each single-trial. We apply Genetic Algorithm (GA) to select the best feature set and this feature set is used for classification of data using Linear Discriminant Analysis (LDA) classifier. Next, we use a new approach to improve classification results based on introducing an adaptive-threshold. Results indicate that our method is able to correctly detect 91.83% of subjects (45 correct detection of 49 subjects) using combination of basic and non-linear features, that is higher than 87.75% for basic and 79.59% for non-linear features. This shows that combination of non-linear and basic- features could improve classification rate.

1. Introduction

The lie has been used as a means of concealing crimes and deceptions by humans throughout the history. Finding methods for detecting lies have constantly been a desirable goal for people and a matter of investigation for scientists in this field. A great deal of studies has taken various approaches into consideration for detection of concealed information, including measurement of peripheral signals that created by autonomic nervous system and electroencephalogram (EEG) signals analysis techniques.

The Guilty Knowledge Test (GKT) is a physiological technique that can be used in detection of concealed knowledge of guilty people (Lykken, 1959). This technique is theoretically more sound and ethically acceptable in compare with some other methods of psychophysiological assessment (such as Control Question Test (CQT)) (Meijer et al., 2014). Previous studies have indicated that P300 component of the Event Related Potentials (ERPs) can be used successfully for detection of concealed information in a P300-based GKT (Abootalebi et al., 2006; Gao et al., 2010).

P300 component appears in response to rare, meaningful stimuli (oddball-stimuli) in EEG signals (Polich, 1991). It can be identified as positive deflection in the EEG signal that is elicited approximately 300–1000 ms after stimulus presentation. The amplitude of this component is attenuated from Pz to Fz (Pz and Fz are two midline scalp sites) (Rosenfeld et al., 1999).

GKT method has three types of stimuli:

1) Probe (P) stimuli: These types of stimuli are related to concealed information that only guilty people and authorities are familiar with, whereas innocent subjects are not, such as pictures of weapon, knife or face of a victim that are taken from murder scene.
2) Irrelevant (Irr) stimuli: They do not have any relationship with the crime scene, so it is expected to be unknown to all subjects.
3) Target (T) stimuli: they are unrelated to the crime scene but are known to all subjects, and it is used to estimate the cooperation of subjects with test scenario.

In the GKT method, the numbers of Irr-stimuli are greater than P and T-stimuli. Therefore, P and T are rare stimuli. Based on above definition, T-stimulus in all subjects and P-stimulus in guilty subjects are oddball-stimuli and it is expected to generate P300 component in responses to these stimuli.

Generally, previous P300-based GKT studies included the Bootstrapped Amplitude Difference (BAD), and the Bootstrapped Correlation Difference (BCD) and some pattern recognition systems (Abootalebi et al., 2006; Gao et al., 2010; Abootalebi et al., 2009). The

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http://dx.doi.org/10.1016/j.ijpsycho.2017.02.005
0167-8760/

BAD method was firstly introduced by Rosenfeld (Rosenfeld, 2002). In this method the amplitude of responses to P and Irr-stimuli are compared with each other. It is expected to see P > Irr in guilty subjects and no difference between those in the case of innocent ones. The BCD method was proposed by Farwell and Donchin (1991), this method is based on the assumption that in a guilty person, cross-correlation coefficients between responses to P and T-stimuli are larger than those between P and Irr-stimuli. However, in an innocent subject no significant difference between these correlation values is expected.

One of the drawbacks of the BAD and BCD methods is that the averaging technique is used to improve the Signal to Noise Ratio (SNR), so they cannot be resulted from single-trial ERPs. Second, the latency of biological signals may change in time especially in cognitive processes, so applying averaging methods to these signals can cause morphological changes in signal (Kandel et al., 1995). Therefore, it is reasonable to use methods based on single-trial ERPs. Third, the BAD and BCD are based on signal shape in the time-domain in which neglects frequency and phase information. Hence, pattern recognition systems seem to be more appropriate tools for GKT studies than BAD and BCD (Gao et al., 2010).

In previous P300-based GKT studies, frequency, wavelet, and time-domain features were used to design pattern recognition systems (Gao et al., 2010; Abootalebi et al., 2009; Shojaeilangari and Moradi, 2012), although many other studies have indicated that non-linear methods such as Lyapunov Exponent (LE) (Übeyli, 2010), Fractal Dimension (FD) (Yargholi and Nasrabadi, 2013; Ahmadlou and Adeli, 2012), entropy (Abasolo et al., 2008), Empirical Mode Decomposition (EMD) (Shalbaf et al., 2012), etc. can be applied to the EEG signals for different biomedical applications. These analyses can provide extra information about phase-domain. Another non-linear analysis method is Recurrence Plots (RPs) that can be used even for short and non-stationary time series (Schinkel et al., 2007). RPs and Recurrence Quantification Analysis (RQA) have been successfully applied to several EEG processing studies, such as episodic memory retrieval (Talebi and Nasrabadi, 2010; Ghoshuni et al., 2007), ERP components detection (Schinkel et al., 2009; Marwan et al., 2007), epileptic seizure detection (Thomasson et al., 2010), sleep (Wang et al., 2013) and anesthesia analysis (Shalbaf et al., 2014). In this study we extracted RQA measures from single-trial ERPs and used them together with some morphological, frequency and wavelet features as feature set.

Some pattern recognition systems in GKT application were designed using database that was recorded in object-based protocol. In the other word, the pictures of some objects (e.g. gold coins, watches, etc.), which some of them were related to crime scene, were applied as stimuli. However, according to the Meijer et al. (Meijer et al., 2007), P300 component is sensitive to the concealed face recognition; therefore, we used pictures of faces as stimuli. Using picture of faces in P300-based GKT helps authorities to apply more information of crime scene to identify guilty person (e.g. to identify murderer by showing face of victim).

We first describe the protocol of experiments and then methods of feature extraction and selection. Following that, the classifier and algorithm of detection guilty/innocent subjects will be described. Finally, the performance of the designed pattern recognition system to classify guilty and innocent groups will be reported.

2. Materials and methods

2.1. Protocol

We employed 65 subjects in the experiments (18–32 years old, 30 males and 35 females, undergraduates or postgraduates). Participants did not have any psychiatric or neurological disease, and they had normal or corrected to normal vision. They were randomly divided into two groups (i.e. innocent and guilty groups). EEG signals were recorded using Ag/AgCl electrodes from three midline sites of the head (Pz, Cz, and Fz) with 10–20 international system. The vertical and horizontal Electrooculogram (EOG) signals were recorded from electrodes that placed above and below the right eye. EEG signals were filtered using 0.5–35 Hz zero phase band-pass filter and sampled at 256 Hz. This frequency range is used in many P300-based GKT studies (Abootalebi et al., 2009). Before starting the experiments, six different face pictures, taken of six different people, were prepared for each subject. Among these six pictures, one was P-stimulus, the other was T, and the rest were Irr-stimuli. It was necessary that subjects recognize the T-stimulus well that was a picture of one of their family members. It can also be selected from well-known people, such as sport stars, politicians or celebrities. Pictures of unfamiliar people were used as Irr-stimuli. P-stimulus for guilty subjects was taken from familiar people, such as a family members or one of their intimate friends. In the case of innocent subjects, the P-stimulus had not been seen by them and they did not have any information about those pictures.

Subjects were instructed to press a button in one hand whenever they want to say “Yes, I know”, and press another one in the other hand when they want to say “No, I do not know”. Innocent subjects replied honestly to all stimuli, but guilty subjects replied honestly only to target and irrelevant ones. They replied falsely to P-stimulus. These pictures were presented randomly at the center of computer screen and each stimulus was presented for the duration of 1000 ms for 30 iterations with an Inter Stimulus Interval (ISI) of 1000 ms.

This protocol is approved by the psychology ethics committees of Shahed University and Research Center of Intelligent Signal Processing.

At first data were filtered and then separated into epochs of 1000 ms (from presentation of each stimulus to 1000 ms after that). Each epoch was checked for eye blink artifacts using visual inspection of EOG data and epochs with this artifact were removed. In this stage three qualifications were checked and subjects that did not have one of them were excluded.

1- If a subject presses the buttons wrongly more than 30% of the total number of stimuli, we assumed that he/she did not have noticed to experiment.
2- If more than 50% of the total P-stimuli in each subject were removed for eye blink artifacts.
3- If P300 component is not appear in T-stimuli averaged by visual inspection.

Finally, 49 cases (22 guilty and 27 innocent subjects) were reminded for further analysis. As mentioned, the highest amplitude of P300 component is in Pz; therefore, in most P300-based GKT studies, only Pz waveforms were noted. In this study only Pz data were used for analytic procedure as well. After data collection and preprocessing, feature extraction from each single-trial, feature selection, and finally classification were applied to identify guilty subjects from innocent ones.

2.2. Feature extraction

At first, 21 features including two morphological, two frequency and 17 wavelet features were extracted from the recorded data. Abootalebi et al. (2009)) reported that these features lead to achieve a high performance in a P300-based GKT (here we called them basic features). After that, features set were extended by RQAs. These non-linear features can quantify phase space; therefore, it is expected to be effective to improve the performance of our pattern recognition system. Moreover, 21 basic features and 23 non-linear features were extracted from each single-trial ERP.

• Morphological features

This type includes two features that were previously applied to P600 component detection (Kalatzis et al., 2004) which was also successfully used in a P300 based GKT (Abootalebi et al., 2009). Let $x(t)$ denotes a single-trial ERP from 400 to 800 ms after stimulus presentation. This range is selected in order to detect P300 component.