Expert Systems With Applications 53 (2016) 117–128

Contents lists available at ScienceDirect

Expert Systems With Applications

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

Functional brain network and multichannel analysis for the P300-based brain computer interface system of lying detection

Hong Wang*, Wenwen Chang, Chi Zhang

Department of Mechanical Engineering and Automation, Northeastern University, 110004 Shenyang, Liaoning, China

ARTICLE INFO

Keywords:
Lie detection
Event related potential
Brain computer interface
Bootstrapped geometric difference
Nonlinear interdependence
Graph theory

ABSTRACT

Deception is a complex cognition process which involves activities in different brain regions. However, most of the ERP based lie detection systems focus on the features of ERPs from few channels. In this study, we designed a multi-channel ERP based brain computer interface (BCI) system for lie detection. Based on this, two new EEG feature selection approaches, bootstrapped geometric difference (BGD) and network analysis were proposed and applied to feature recognition and classification system. Unlike other methods, our approaches focus on the changes of EEGs from different brain regions and the correlation between them. For the test, we focus on visual and auditory stimuli, two groups of subjects went through the test and their EEGs were recorded. For all subjects, BGD of the P300 for all the scalp electrodes combined with SVM classifier showed the average rate of recognition accuracy was 84.4% and 82.2% for visual and auditory modality respectively. Statistical analysis of network features indicated the difference in the two groups were significant and the average accuracy rate reached 88.7% and 83.5% respectively, and the guilty group showed more obvious small-world property than innocent group. The results suggest the BGD and network analysis based approaches combined with SVM are efficient for ERP based expert and intelligent system for detection and evaluation of deception. The combination of these methods and other feature selection approaches can promote the development and application of ERP based lie detection system.

1. Introduction

Terrorist attacks and other criminal activities often involve some crime scene information. When they would be terrorist or criminal are confronted with these information, they try to hide their true purpose in order to avoid raising any suspicion (Stedmon et al., 2015). However, some response data that are collected across psychological, physiological and biological parameters (Stedmon et al., 2015) are obviously different from ordinary people's data. At this time the concealed information test or deception detection will work. For more than half a century, various physiological systems for deception detection have been studied (National Research Council, 2003). One of the most traditional methods, polygraph test system that based on autonomic nervous system activity, has been reported to be widely used for the detection of concealed information (National Research Council, 2003; Wang, Miao & Blohm, 2013). But because of the indirect and limited view of the complexity of brain process in the polygraph methods (Abootalebi, Moradi & Khalilzadeh, 2006), and also the validity of polygraph detection has been repeatedly questioned (Verschuere, Crombeza, Kostera & Clercq, 2007). Other brain imaging based methods, especially the BCI based system, have been developed and widely used in brain research, such as electroencephalography (EEG), positron emission tomography (PET), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS) (Wang et al., 2013; Wolpaw, Birbaumer, McFarland, Pfurtscheller & Vaughan, 2002). And some of these methods have been applied in lie detection systems.

Comparing with other methods, the EEG based lie detection system measures event-related-potentials (ERPs) through electrodes placed on the scalp which reflect the event-related changes in brain activities. ERP reflects the activities of central nervous system related to information processing rather than emotion-dependent activities of autonomic nervous system (Abootalebi et al., 2006; Fang, Liu, & Shen 2003; Hidalgo-Muñoz et al., 2013), and it has a high time resolution and is considered to be relatively convenient, inexpensive and harmless. The extensive research

* Corresponding author. Tel.: +86 24 83681942; fax: +86 24 83681942.
E-mail addresses: hongwang@mail.neu.edu.cn (H. Wang), changwenwen11@mails.ucas.ac.cn (W. Chang), zhch_angi@163.com (C. Zhang).

http://dx.doi.org/10.1016/j.eswa.2016.01.024
0957-4174/

of the ERP based methods has achieved satisfying result (Farwell, & Donchin, 1991; Matsuda, Nittono, Hirota, Ogawa & Takasawa, 2009; Rosenfeld, Biroschak & Furedy, 2006). A widely used endogenous positive ERP is P300, which is evoked between 300 ms and 800 ms from the stimuli onset (Cutmore, Djakovic, Kebbell & Shum, 2009; Jung, Kang & Kim, 2013; Winograd & Rosenfeld, 2011).

The P300 is usually elicited in an "oddball" paradigm, where subjects are required to discriminate a set of infrequently presented target stimuli from another set of frequently presented non-target stimuli by pressing one button for target and the other one for non-target (Bergström, Anderson, Buda, Simons, , Simons, Richardson-Klavehn , 2013; Jung et al., 2013; Mameli et al., 2010). Because the subjective probability of a stimulus is usually inversely related to the P300 amplitude (Patel & Azzam, 2005), a larger proportion of irrelevant are intermixed with a small proportion of target to make it rare, which can intensify the differences of P300. Studies have shown that P300 can help investigators to identify people with concealed information through the concealed information test (CIT) (Farwell & Donchin, 1991; Jung et al., 2013). The CIT is a type of oddball paradigm using target, probe, and irrelevant stimuli.

In a typical P300-based CIT system, The targets (T), presented rarely, are usually irrelevant items which have been made task relevant through instructions, and serve to ensure participants cooperation because subjects are required to discriminate the targets items from others. The irrelevants (I), presented frequently, are neither related to the criminal act nor related to the experimental task. The underlying principle of the item is that subjects will have different responses to stimuli according to their crime-relevant status. The probes (P), also presented infrequency, are the stimuli of the critical details, and they elicit P300 only for subjects with knowledge of the crime. In this study, two probes are set for the same subject. Probe1 is irrelevant to the subjects which act as the innocent. It is indistinguishable from irrelevant items therefore elicits no special brain response (Abootalebi et al., 2006; Hidalgo-Muñoz et al., 2013). Probe2 is related to concealed information and is only known to the deceivers. In this case the subjects act as the guilty and want to deny it. Thus this recognition elicits an enhanced P300 similar to targets. Guilty groups show enlarged P300 to both probe2 and target because both types elicit recognition, whereas innocent groups only show enlarged P300 to target but not to probe1(Rosenfeld et al., 2006; Winograd & Rosenfeld, 2011).

Interpretation of the ERP signals to understand the features of subject's brain electrical activity is a fundamental problem of BCI system. The conventional method for feature extraction and selection in P300 based lie detection system is to compare the amplitude of P300 response in probe and irrelevant stimuli, which are recorded at the scalp sites along the mid line of the head (Pz, Cz and Fz) (Rosenfeld, Soskins, Bosh & Ryan, 2004). In recent years, the functional and anatomical networks of the brain nervous system have been widely studied by using the graph theory tool (Basset, Meyer-Linderberg, Achard, Duke & Bullmore, 2006; Stam & Reijneveld, 2007a), however, for P300 based lie detection system there is almost no research from the network perspective. Thus we tried to analyze the functional connectivity of the brain network under deception condition and extracted the network features. And firstly, the correlation between different electrodes was analyzed. Among the time series of signals obtained from different brain regions, there may be some non-linear or linear interdependence which can reflect the interactions between the brain regions and functional connectivity (Fingelkurts, Fingelkurts & Kähkönen, 2005; Friston, 2001; Lee, Harrison & Mechelli, 2003). The graph theory can provide a method, a complex networks model, to give a better understanding of the relations between network structure and the processes taking place in different brain regions

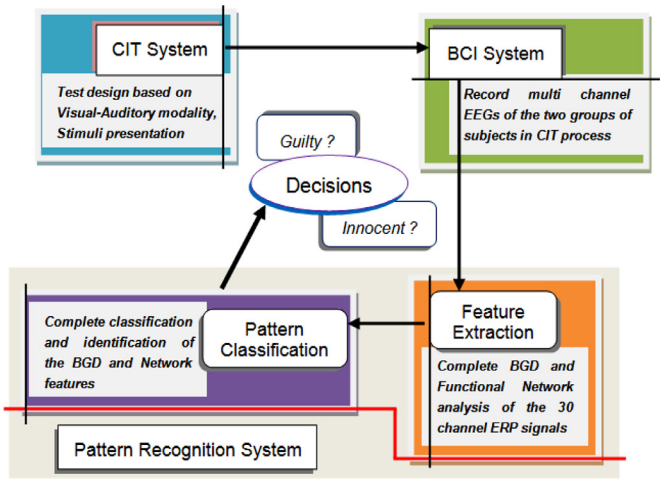

Fig. 1. Block diagram of the ERP based lie detection system.

(Leistedt et al., 2009; Rubinov & Sporns, 2010; Wang, Zhang, Shi, Wang & Ma, 2015; Stam, de Haan, Daffertshofer, Jones & Manshanden, 2009).

Based on the above discussion, we designed the ERP based lie detection system, as shown in Fig. 1. There are four parts in the system, which are CIT system, BCI system, Patter Recognition (PR) system and Decision part, and the PR system contains feature extraction and pattern classification. Similar to other lie detection methods, the CIT system includes a paradigm for conducting the test and presenting the stimuli (Abootalebi et al., 2006), and the scenario in the test contains two stimuli paradigms (visual and auditory). BCI system is used to record the 30-channel EEG signals through the scalp electrode of the subject in the test process. Pattern recognition method for the EEG signal assessment is the most important section, and building a usable and reliable ERP based lie detection system requires an accurate and efficient feature extraction and classification of multichannel EEGs.

In this study, two novel pattern recognition methods were proposed for ERP based lie detection system. Firstly, we constructed the network by using the nonlinear statistical interdependencies between P300 signals from the 30 scalp electrodes for the whole brain, and some network parameters based on graph theory were calculated and analyzed to detect the concealed information. Secondly, based on the bootstrapped amplitude difference analysis (Rosenfeld et al., 2004), we proposed another new method BGD, which used the bootstrapped geometric difference as the feature for lie detection. These feature vectors were extracted and then provided as the input of the SVM classifier. The two methods were based on the P300 signal which was extracted in delta frequency band through the wavelet packet analysis of the ERP signal (Başar, Schürmann, Demiralp, Başar-Eroglu & Ademoglu, 2001). Decision was made about the PR result to distinguish the innocent from the guilty. The purpose of the study is to examine the feasibility of the two methods by using the P300 based CIT in a lab analogue experiment. Unlike other systems, our methods explore multi-channel EEGs, claiming that combining a multi-BGD and network parameters based feature extraction and SVM classifier may improve the accuracy of the lie detection test.

2. Material and methods

2.1. Subjects

Twenty right-handed postgraduates (seven female) aged between 22 and 30 (M = 23.6, SD = 5.3) years participated in this