Applied Soft Computing 30 (2015) 663–674

Contents lists available at ScienceDirect

Applied Soft Computing

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

Electroencephalogram-based emotion assessment system using ontology and data mining techniques

Jing Chen[a], Bin Hu[a,b,*], Philip Moore[a], Xiaowei Zhang[a], Xu Ma[a]

[a] School of Information Science and Engineering, Lanzhou University, Lanzhou 730000, China
[b] School of Computing, Telecommunications and Networks, Birmingham City University, Birmingham B42 2SU, UK

ARTICLE INFO

Article history:
Received 9 April 2013
Received in revised form 23 August 2014
Accepted 5 January 2015
Available online 14 January 2015

Keywords:
Emotion assessment
Human–machine interaction
Electroencephalogram
Ontology

ABSTRACT

Currently, emotion is considered as a critical aspect of human behavior; thus it should be embedded within the reasoning module in an intelligent system where the aim is to anticipate or respond to human reactions. Therefore, current research in data mining shows an increasing interest in emotion assessment for improving human–machine interaction. Based on the analysis of electroencephalogram (EEG) which derives from automatic nervous system responses, computers can assess user emotions and find correlations between significant EEG features extracted from the raw data and the human emotional states. With the advent of modern signal processing techniques, the evaluative power of human emotion derived from EEG is increased exponentially due to the huge number of features that are typically extracted from the EEG signals. Notwithstanding that the expanded set of features could allow computers to evaluate emotions in an accurate way, it is too complex a task to manage in a structured way and, for the reasons stated, methods and approaches to enable both EEG information management and evaluation are necessary to support emotion assessment. Starting from this consideration, this paper proposes an enhanced EEG-based emotion assessment system exploiting a collection of ontological models representing EEG feature sets and arousal–valence space (two-dimensional emotion scale), statistical tests capable of evaluating the gender-specific correlations between EEG features and emotional states, and a classification methodology inferring arousal and valence levels. As will be shown in the experimental section where the proposed approach has been tested on a public dataset, the experimental results demonstrate that better performance in emotion assessment can be achieved using our framework as compared with other studies using the same dataset and with three other classification techniques.

1. Introduction

The capability to adapt machine feedback to users in the form of self-adaptation has become one of the most promising research directions within human–machine interaction (HCI) and data mining. For interactive machines to execute intended actions, however to achieve this aim it is often necessary to understand human affective behavior [1]. Affective computing (AC) is an emerging research field which aims to improve the interaction between human beings and machines, and further to improve task performance of machines and user satisfaction levels [2]. In aviation safety and repetitive work, a state of boredom and low vigilance with high levels of automation may increase the risk of accidents. In other areas such as tutoring, training and driving it is often necessary to maintain or prevent particular affective states (e.g., nervousness) to realize optimal performance levels and improved user experience. The core element that makes these applications successful is the assessment of human emotional states during HCI. In this regard, two important questions still need to be answered: (1) How can we effectively record emotional indicators without interference in real time (e.g., by physiological signals or questionnaire responses)? and (2) How can we measure and predict user emotional states in the interaction process? These two questions are often approached in the form of either a subjective route (psychology-oriented) by means of monitoring/observing questionnaire responses of a subject, or a more objective route (neurophysiology-oriented) by means of monitoring the subject's behavioral indicators and/or physiological signals [3,4]. Subjective approaches generally have some weaknesses, such as selective reporting biases by users, interference with data collection in real time, and further resistance to data analysis required in a vast number of HCI applications [3]. A large body of literature addressing psychological issues points toward the hypothesis that emotions result from a series of cognitive processes [5,6], and direct communication between human brain and external machines could lead to natural human machine interaction. Additionally, electroencephalogram (EEG) data can be acquired in a continuous manner consistent with the way people perceive affect and thus allow users' affective states to be evaluated in real time.

Furthermore, with the development of advanced signal processing methods such as wavelets and fast Fourier transform (FFT), the power of EEG data to infer human emotions is strongly increased due to the huge set of features extracted from EEG signals. This expanded set of features enhances the accuracy of emotion detection and evaluation. However, the manual management of this expanded set

* Corresponding author at: School of Information Science and Engineering, Lanzhou University, Lanzhou 730000, China. Tel.: +86 931 8912779.

E-mail addresses: chenj12@lzu.edu.cn (J. Chen), bh@lzu.edu.cn (B. Hu), ptmbcu@gmail.com (P. Moore), zhangxw@lzu.edu.cn (X. Zhang), max2012@lzu.edu.cn (X. Ma).

http://dx.doi.org/10.1016/j.asoc.2015.01.007
1568-4946/© 2015 Published by Elsevier B.V.

of features by researchers and the storage of unstructured data result in a very complex task. As a consequence of supporting systems in their interaction activities with human, automatic methods of representing and evaluating EEG data for emotion assessment are necessary. In this scenario, soft computing techniques provide several benefits both in terms of quality of assessment and knowledge representation.

Starting from this consideration, this paper proposes an enhanced EEG-based emotion assessment system to evaluate gender-specific EEG features and arousal–valence levels by combining ontological modeling, statistical tests and a classification mechanism. In detail, our proposal of EEG-based emotion assessment system is based on the design of

1. Complex ontologies representing raw data and EEG features, and other contents which are useful in the assessment of emotion, such as the date of data capture, the duration of an experiment and user gender, for a detailed representation see [7].
2. An EEG-based emotion assessment system performing correlation analyses and evaluation of arousal–valence levels using analysis of objective EEG features.

The integration of soft computing techniques (ontologies, statistical tests and a classification methodology) provides several benefits to our proposal of EEG-based emotion assessment system. Indeed, our system is able to:

1. Improve the expressiveness and structure of affective computing related knowledge using a simple representation in the form of semantic sentences which may make it easier for computers to process information units.
2. Provide valid support for emotion assessment based on correlation analyses and a classification mechanism capable of detecting emotions effectively during HCI.
3. Achieve interoperability feature to implement the psycho-physiological application on different hardware platforms owing to ontology language providing a flexible and interoperable scheme.

To prove the suitability and good performance provided by the proposed system, a test on the public dataset *DEAP*[1] has been led in the experimental section. In detail, our system is exploited to accomplish correlation analyses and classification tasks involving 32 healthy participants of which 50% are female. The accuracy of our approach and the F1-scores support the conclusion that our system provides good performance in the classification task.

The paper is organized as follows: Section 2 describes previous work related to the use of ontological methods in affective computing, statistics and classification mechanisms used on emotion assessment concerning EEG signals. Section 3 presents the basic concepts that underlie our proposal: the background knowledge related to EEG domain and the arousal–valence emotion space. Section 4 describes the proposed EEG-based emotion assessment system and all its components. Before concluding in Section 6, Section 5 sets out the experimentation with the results and a discussion.

2. Related work

In our system we combine ontologies for the management of EEG- and emotion-related information, and apply statistical tests and a classification technique to evaluate human emotional levels starting from a collection of EEG signals. Therefore, in this section, literature related to ontologies and mining techniques for EEG-based emotion assessment is reported.

The use of ontologies to model knowledge has been applied in many domains, including meeting scheduling [8], medical information systems [9], software engineering [9], healthcare [10,11]. Zhou et al. [12] propose a framework of emotion-aware ambient intelligence [13]; it integrates ambient intelligence, AC, emotion-aware services, an emotion ontology, service-oriented computing, and a service ontology. Zhang et al. [7] provide an ontology-based context model for emotion recognition capable of reasoning in pervasive computing environments. Zhang et al. [14] propose the use of an ontology for modeling low-level biometric features and mapping them to high-level human emotions so that the context model can provide active and reliable services for individuals or communities in an intelligent or smart hyper world. Mathieu [15] presents a semantic lexicon in the field of feelings and emotions which is described using an ontology. Words in the lexicon are emotionally labeled as positive, negative and neutral. With the support of ontology techniques, users can retrieve information in a semantic manner. Focusing on speech, Galunov et al. in [16] introduced an ontology for speech signal recognition and synthesis where emotion was taken into account. Focusing on the context-awareness, Benta et al. in [17] presented an ontology-based representation of affective states for context aware applications which allows the complex relations between affective states and context elements to be expressed.

On the other hand, there is an increasing body of psychological literature pointing toward the hypothesis that emotions result from a series of cognitive processes [5,6]. Murugappan [18] presents in the research documented promising results from EEG analysis for emotion detection under an audio–visual stimulus environment. A higher dimensional complexity of EEG activity over frontal cortical regions was found during emotional imagery than was exhibited during mental arithmetic tasks. The association of positive and negative emotional experience with higher EEG dimensional complexity estimates indicates that increased activity of the thalamic and reticular projections in response to emotional challenges lead to more complex and less predictable dynamics in the regulation of cortical networks [19]. Aftanas et al. [20] report differences in event-related desynchronization and synchronization during the visualization of more or less arousing images. In the emotional recall context, Smith et al. [21] identifies an augmentation of activity in the connections between the hippocampus and the amygdala during the recollection of negative events compared to neutral events. In [22], statistical t-test and a univariate feature selection method using Cohen's effect size f^2 from analysis of variance were implemented for electrode and feature selection. Electrodes and features found by these approaches resulted in a small variance in classification accuracies across subjects. Knott et al. [23] used three-way multivariate analysis of variance (MANOVA) and t-test for absolute power, relative power and hemispheric asymmetry measures. He found that absolute and relative power in the beta frequency band, but not in the delta, theta or alpha frequency bands, differentiated the depressed group and control/normal group. Chanel et al. [24] asked participants to recall an episode in their life that corresponded to positive emotions and one that corresponded to negative emotions. A classification accuracy of 63% was reported using the short-time Fourier transform for feature extraction and a linear Support Vector Machine (SVM) for classification. Frantzidis et al. [4] propose a combination of a C4.5 decision tree algorithm and a Mahalanobis distance classifier to differentiate four different affective states with multiple physiological recordings including EEG and skin conductance response (SCR); they gained an average recognition rate around 78% among 28 participants. These studies emphasize the importance of using brain signals to improve accuracy in emotion assessment.

Inspired from these research achievements and their good results, this work proposes an EEG-based emotion assessment system exploiting ontological knowledge representation, statistics and classification methodologies to enable effective computation for the system with the provision of satisfactory services.

3. Basic concepts and background: EEG and emotion models

In this paper, our idea is to design an efficient EEG based emotion assessment system enable the discovery of strong associations between EEG features and arousal–valence levels and supporting emotion recognition. For this reason, in order to understand our proposal, a description of the basic EEG concepts (Section 3.1) and emotion models (Section 3.2) is given.

[1] http://www.eecs.qmul.ac.uk/mmv/datasets/deap/index.html.