Computers and Electrical Engineering 72 (2018) 383–392

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Emotion recognition using empirical mode decomposition and approximation entropy☆

Tian Chen[a,b], Sihang Ju[a,b], Xiaohui Yuan[c,*], Mohamed Elhoseny[c,e], Fuji Ren[a,b,d], Mingyan Fan[a,b], Zhangang Chen[a,b]

[a] School of Computer and Information, Hefei University of Technology, Hefei, Anhui, 230601, China
[b] Anhui Key Laboratory of Affective Computing and Advanced Intelligent Machine, Hefei, Anhui, 230601, China
[c] Department of Computer and Engineering, University of North Texas, Texas, 76203, USA
[d] Tokushima University, Tokushima, 770–8506, Japan
[e] Faculty of Computers and Information, Mansoura University, 35516, Egypt

ARTICLE INFO

Article history:
Received 27 April 2018
Revised 28 September 2018
Accepted 28 September 2018

Keywords:
Emotion recognition
Electroencephalogram
Classification
Empirical mode decomposition
Approximate entropy

ABSTRACT

Automatic human emotion recognition is a key technology for human-machine interaction. In this paper, we propose an electroencephalogram (EEG) feature extraction method that leverages empirical mode decomposition and Approximation Entropy. In our proposed method, Empirical Mode Decomposition (EMD) is used to process EEG signals after data processing and obtains several intrinsic eigenmode functions. The Approximation Entropy (ApEn) of the first four Intrinsic Mode Functions (IMFs) is computed, which is used as the features from EEG signals for learning and recognition. An integration of Deep Belief Network and Support Vector Machine is devised for classification, which takes the eigenvectors from the extracted feature to identify four principal human emotions, namely happy, calm, sad, and fear. Experiments are conducted with EEG data acquired with a 16-lead device. Our experimental results demonstrate that the proposed method achieves an improved accuracy that is highly competitive to the state-of-the-art methods. The average accuracy is 83.34%, and the best accuracy reaches 87.32%.

1. Introduction

Automatic human emotion recognition is a key technology for human-machine interaction [1,2]. Many research on emotion recognition relies on data from images, audio, and videos [3–5]. Discrete models [6] and dimensional models [7] are proposed to describe emotional states. Among a variety of data, physiological signals such as electroencephalogram (EEG), electrocardiogram (ECG), and electromyography (EMG) signals have been employed for emotion recognition [8]. EEG signal is closely correlated with brain activities and is more promising for recognizing emotional states [9–11].

Most recently, Hu et al. [12] proposed a classification method that combines Correlation-based Feature Selection (CFS) and a k-nearest-neighbor (KNN) algorithm for attention recognition. Lin et al. [4] used Support Vector Machine (SVM) to classify the emotional states based on EEG into four categories and found that the frontal and temporal lobes of the brain are the main areas of emotion generation, and the average classification accuracy of emotion achieves 82.29%. Goyal

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. Guanglong Du.
* Corresponding author.
E-mail address: xiaohui.yuan@unt.edu (X. Yuan).

https://doi.org/10.1016/j.compeleceng.2018.09.022

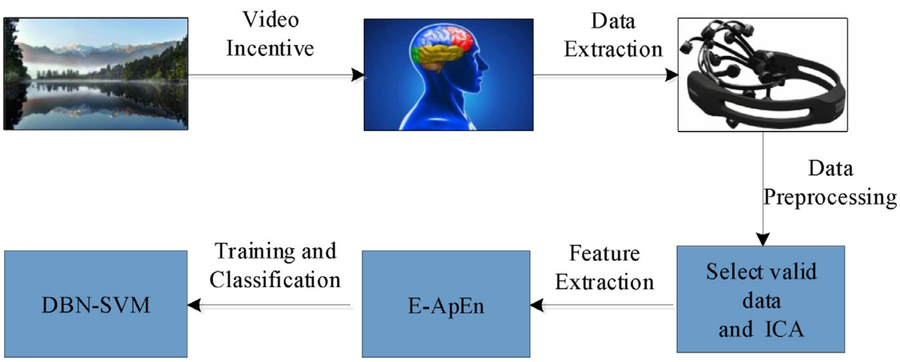

Fig. 1. The flow chart of the proposed emotion recognition method.

et al. [13] described the acquisition of EEG signals on frontal electrodes from five subjects for the classification of emotions. Gonuguntla et al. [14] analyzed the network mechanisms related to human emotion based on synchronization measure phase-locking value in EEG to formulate the emotion-specific brain functional network.

In addition to the development of classification methods, signal processing techniques have been studied. Empirical mode decomposition methods based on the Hilbert-Huang Transform (HHT) have been explored in the field of signal processing to improve the recognition performance [15,16]. HHT includes empirical mode decomposition (EMD) and Hilbert transformation. It decomposes a signal into several approximate cosine waves and looks into their periods and amplitudes, which effectively suppresses noise and obtain the time-frequency characteristics of the signal. Such methods achieved greater results when dealing with non-stationary signals.

Despite the advancements in emotion recognition using EEG signals, there is much room to improve. This paper integrates EMD and Approximation Entropy (ApEn) and proposes an EEG feature extraction method (namely EMD-Approximation Entropy, in short E-ApEn) for feature extraction. This combined feature extraction method reduces the complexity of feature extraction. Using the emotion recognition model and integrating Deep Belief Network (DBN) and Support Vector Machine to get the feature vectors for training and classification, It is expected that a higher rate of emotion recognition can be achieved.

The rest of this paper is organized as follows: Section 2 presents our proposed method for emotion recognition using EEG signals. The section starts with an overview of the framework followed by the feature extraction method that integrates EMD and ApEn. A DBN-SVM is discussed, which makes multi-class decisions for emotion recognition. Section 3 discusses our experimental results and the section includes a description of data acquisition and preprocessing, as well as a comparison study with the state-of-the-art methods. Section 4 concludes this paper with a summary of our work and a highlight.

2. Emotion recognition model

2.1. Framework of the proposed method

The framework of our proposed method is shown in Fig. 1. The process of establishing the emotion recognition model using EMD decomposition and approximate entropy consists of the following four steps:

1. The signal is preprocessed to get signal clips of a fixed size and an independent component analysis (ICA) is used to suppress noise.
2. For each attribute of a signal clip, EMD is used for decomposition, and the approximate entropy of the first 4 IMFs of the decomposed signal is calculated.
3. Select the appropriate combination of attributes and feed the entropy of the selected attributes to the DBN network to feature extraction.
4. The features extracted by DBN network are classified with SVM classifiers for emotion recognition.

In this paper, videos are used to stimulate emotions of the subjects, and the EEG data is recorded and different channel combinations are extracted for emotion recognition.

2.2. Feature extraction

Approximate entropy is a method to measure the complexity and regularity of time series [17], which relies on a less amount of data to calculate and is robust to noise. Li et al. [18] used approximate entropy to characterize brain electrical signals and uses these characteristics to study the phenomena of the brain. This paper proposes a method that applies EMD to decompose EEG signal and calculates the ApEn of the decomposition, which is named E-ApEn. EMD is a time-frequency analysis method for nonlinear and unsteady signals [15]. It decomposes nonlinear and non-stationary signals into