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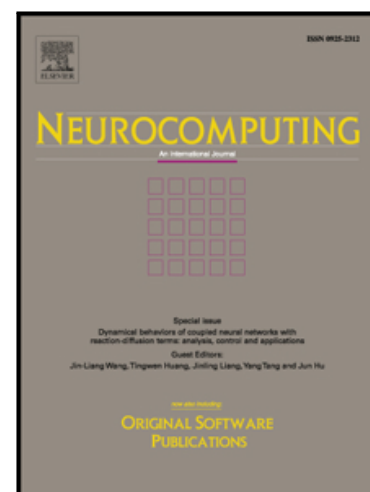
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Fusing highly dimensional energy and connectivity features to identify affective states from EEG signals

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Abstract

In this paper, a novel method for affect detection is presented. The method combines both connectivity-based and channel-based features with a selection method that considerably reduces the dimensionality of the data and allows for an efficient classification. In particular, the Relative Energy (RE) and its logarithm in the spacial domain, and the spectral power (SP) in the frequency domain are computed for the four typical frequency bands (α , β , γ and θ), and complemented with the mutual information measured over all channel pairs. The resulting features are then reduced by using a hybrid method that combines supervised and unsupervised feature selection. First, a Welch's t -test is used to select the features that best separate the classes, and discard the ones that are less useful for classification. To this end, all features where the t -test yields a p -value above a threshold are eliminated. The remaining ones are further reduced by using Principal Component Analysis. Detection results are compared to state-of-the-art methods on DEAP, a database for emotion analysis composed of labeled recordings from 32 subjects while watching 40 music videos. The effect of using different classifiers is also evaluated, and a significant improvement is observed in all cases.

Keywords: EEG, connectivity features, energy features, emotion recognition, feature reduction, feature extraction

1. Introduction

To endow computers with the ability to successfully infer or respond to affect, it is necessary to combine research results in diverse areas, which include computer sciences, signal processing and cognitive sciences [1]. The interpretation of affect on bio-signals could lead computers to be affect-responsive, enhancing the user's experience by adapting feedback and modifying the behavior of applications in real-time.

The first step to be able to respond to emotions is affect recognition, that focuses on identifying emotions and other affective phenomena on the subject. The evaluation of the affective state is usually done according to an emotional model that suits the particular application. One of the simplest models is the one described by Ekman, which is composed of six discrete primitive emotions, namely *anger*, *fear*, *sadness*, *surprise*, *disgust* and *happiness* [2]. Other alternative models include Plutchik's Wheel of Emotion [3], and Russell's Circumplex Model [4], which locates emotions in a 2D space defined by the arousal (or activation) and valence (or positiveness). The latter was extended in [5] by adding a third dimension (dominance) to avoid overlapping of certain emotions.

In general, these models are used to build a classification scheme that uses features as an input, and yield a prediction related to the user's emotional state as an output. Features can

be of a very diverse nature, but one major factor that affects the system's performance is related to the existing implicit relations between the selected features and the user's reaction to changes in the variables considered in the emotional model. Many research works have measured and investigated subject's reactions by using biological signals [6]. These signals include Electroencephalography (EEG), an electrophysiological monitoring method that uses multiple electrodes placed on the scalp to measure voltage fluctuations that result from ionic current flows within the neurons of the brain.

From a classification perspective, a shared difficulty among related research on affect recognition is the relatively low number of samples available for training. This fact restricts the use of high dimensional models, that in the case of EEG-based systems is usually proportional to the number of channels recorded by EEG. One line of work has focused on the use of feature reduction and feature selection methods [7, 8, 9]. Nevertheless, it is common to find in the literature models with more than 50 dimensions for 40 samples [7, 10]. Another line of work has concentrated on using different features. For example, Chen [11] demonstrated that connectivity features can also be used to detect the affective state, at a reasonable level of accuracy.

In this paper, we build on a preliminary version of this work reported in [12], and present a low-dimensional classification scheme that combines a number of features of different nature, namely channel-based (including both time-domain and frequency-domain) and connectivity features. The method relies on a novel adaptive feature reduction scheme that integrates a supervised feature selection mechanism based on a Welch's t -test with a Principal Component Analysis (PCA), to yield low-

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