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Poincaré's section analysis for PPG-based automatic emotion recognition

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ABSTRACT

Given the importance and abundant use of emotional recognition in the human–computer interfaces and multimedia applications, several methods for designing such systems have been reported in the literature. However, the performance of the photoplethysmography (PPG) signal in these devices has not been sufficiently studied. In addition, details of the phase space geometry of this signal have not been investigated in the emotional states up to now. In connection with this issue, Poincaré's sections can quantify the geometric patterns of the trajectory in the high-dimensional phase space. Therefore, this work attempted to propose an automatic emotion recognizer which can characterize the PPG signals during the exposure of emotional music-video. Our focus was to detect and classify dynamical behaviors of the PPG trajectories in three emotional classes of love, hate, and fun using Poincaré's section measures. To this effect, the 2D phase space of PPG was firstly reconstructed. Then, forming the Poincaré's sections in different angles, some geometric indices were extracted. Finally, using support vector machine, the PPG measures were classified into emotional states. Our results showed that basin geometry of the PPG phase states was significantly different in different emotional states. The maximum accuracy rates of 96.67% and 91.11% were achieved for a binary and multi-class classification scheme, respectively. The proposed framework was fast and operated using the single-sensor signal. In conclusion, the dynamical Poincaré's section indices of PPG signals during three emotional states paved the way for designing an online emotion recognition system.

1. Introduction

Emotion is an intricate inner state that directs people's behavior and response to the events surrounding them. It is known as a complex interaction between hate, love, happiness, sadness, fear, etc., which is tightly associated with fluctuations in biomedical signals. However, this relationship between biological responses and emotions should be carefully monitored and studied. Due to a large amount of information contained in the biomedical signals, this monitoring process is very difficult and time-consuming. Consequently, the creation of computer-based analyzers can be very useful in detecting emotion responses.

The special position of the automatic human emotion recognition in the multimedia fields and human–computer interfaces (HCI) has attracted many researchers towards designing such systems. Nowadays, a broad range of biomedical signals, stimulation paradigms, and signal processing styles have been employed for the computer-aided design of affect recognizer.

Biological signals may be used in the form of multi-modalities or single-modality, or multi-channel or single-channel. Some of the most important biomarkers are the electroencephalogram (EEG), electrocardiogram (ECG), heart rate variability (HRV), galvanic skin responses (GSR), facial electromyogram (EMG), and photoplethysmography (PPG) [1–12]. However, it should be noted that the use of multiple signals simultaneously (multi-modal or multi-channel schemes) is not convenient in empirical applications because it can interfere with the individuals daily performances. In addition, it implicates a large amount of computation and intricacy, and their analysis is time-consuming.

To make emotions in research laboratory environments, various paradigms such as film, music, image, sound, music-video, etc. have been examined [3,5,6,10,13,14]. It seems that films and music-videos are better able to fulfill this induction because they recruited both audio- and visual-sensory, simultaneously.

One of the most important parts of the emotion recognizer is the signal processing unit, which generally consists of two major parts: (1) the feature extraction that provides relevant physiological responses to the definite stimulation and (2) clas-

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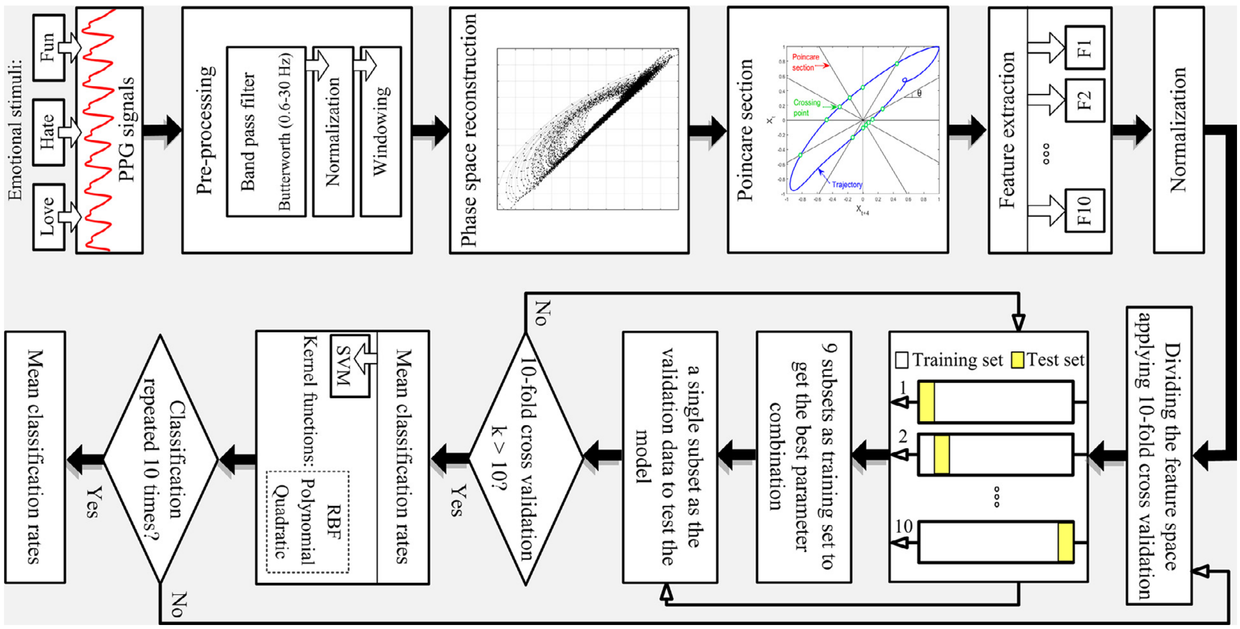

Fig. 1. Suggested methodology.

sification. For the former, a remarkable number of researchers have carried out based on linear signal processing analysis, which includes morphology-based indices, time domain measures, statistical features, spectral analysis, and wavelet-based methods [2,3,6]. Although relatively good results have been obtained using such techniques, they appear to provide only a limited amount of information on the data because they ignore the dynamics and nonstationarity of the biomedical time-series. Accordingly, a significant number of investigators have focused on chaotic and nonlinear measures, including entropy, Lyapunov exponent, correlation dimensions, recurrence quantification analysis, and embedding dimension to evaluate the dynamics of bio-signals during emotion induction [2,4,6,7,9]. Applying these indices, global information about the trajectory of the signal in the reconstructed state space is achieved. However, these indices are impotent to describe the shape of trajectories in detail [15,16]. Phase space-based indices and Poincaré measures can overcome this issue. Previously, lagged Poincaré method was successfully applied in the problem of emotion recognition [5,8]. Another of such indices is Poincaré's section [15,16], which quantifies the geometric patterns of the trajectory in the high-dimensional phase space.

Totally, there are some advantages for the Poincaré measures to the conventional indices. A stationary assumption for the analyzed signal should be made for the conventional methods. For example, for the spectral analysis of PPG, a large number of PPG cycles are required to estimate the power spectrum accurately. The Poincaré measures provide additional analytical information and complement customary time and frequency-domain analyses of the signal. The Poincaré based analyses are easier to understand and interpret. In addition, since they are calculated based on a simple plot, they can be used on portable devices like Holter signal analysis.

In this work, it was hypothesized that a 2D phase space trajectory quantification using Poincaré's section can obtain distinctive measures which can characterize three emotion sets. Consequently, the objective of this research was to classify the emotional responses of PPG time-series based on the Poincaré's section quantifiers.

2. Material and methods

Fig. 1 displays the recommended procedure schematically. The proposed framework covers four main parts, including the PPG data, pre-processing, the feature extraction procedure, and the classification scheme, which are designated in detail in the following sub-sections.

2.1. Data

In this study, PPG data of DEAP database [14] were used, which is publicly available. DEAP involves 8 peripheral bio-signals and 32-channel EEGs. In this study, 30 participants (15 male and 15 female) incorporated in the test. Their age range was 19–36 with the mean age of 26.87 ± 4.21.

Each subject was asked to watch the music videos carefully and their bio-signals were acquired simultaneously. PPG signals were acquired from the thumb finger. Data were recorded at the sampling frequency of 512 Hz. Then, PPG signals were down-sampled. Finally, each signal smoothed with a moving average filter. The window size was fixed at 256 points [14].

Employing the self-assessment manikins (SAM) introduced in 1995 [17], the volunteers rated each music video clips based on the levels of like/dislike, valence, arousal, dominance, and familiarity. In this study, we examined the data while subjects watching love, hate, and fun music video clips.

2.2. Preprocessing

The components of the PPG signals are located at frequencies below 30 Hz [18]. In addition, there were some baseline noises in the PPG signals of DEAP database that occurred during the data acquisition. Therefore, in this study, all of the PPG records were filtered using a Butterworth filter (band pass filter: 0.6–30 Hz). In the next stage, the PPG signals (X) were normalized in the range of $[-1,\ 1]$ as follows:

$$X_{normalized\ PPG} = 2\frac{X - \min(X)}{\max(X) - \min(X)} - 1 \quad (1)$$

Fig. 2 shows raw PPG time-series of one subject (top frame) while watching the emotional music video stimuli (love category) and the corresponding filtered and normalized PPG signal (bottom frame).