Automatic Webcam-Based Human Heart Rate Measurements Using Laplacian Eigenmap

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Abstract. Non-contact, long-term monitoring human heart rate is of great importance to home health care. Recent studies show that Photoplethysmography (PPG) can provide a means of heart rate measurement by detecting blood volume pulse (BVP) in human face. However, most of existing methods use linear analysis method to uncover the underlying BVP, which may be not quite adequate for physiological signals. They also lack rigorous mathematical and physiological models for the subsequent heart rate calculation. In this paper, we present a novel webcam-based heart rate measurement method using Laplacian Eigenmap (LE). Usually, the webcam captures the PPG signal mixed with other sources of fluctuations in light. Thus exactly separating the PPG signal from the collected data is crucial for heart rate measurement. In our method, more accurate BVP can be extracted by applying LE to efficiently discover the embedding ties of PPG with the nonlinear mixed data. We also operate effective data filtering on BVP and get heart rate based on the calculation of interbeat intervals (IBIs). Experimental results show that LE obtains higher degrees of agreement with measurements using finger blood oximetry than Independent Component Analysis (ICA), Principal Component Analysis (PCA) and other five alternative methods. Moreover, filtering and processing on IBIs are proved to increase the measuring accuracy in experiments.

1 Introduction

Usually, medical instruments supporting contact measurements (*e.g.* electrocardiogram, arm blood pressure monitor and auscultoscope) bring much discomfort to patients in constant monitoring. One possible approach to overcome the contact with skin is to use webcam to collect the PPG signal for measurements. PPG is a photoelectric technology of detecting the blood volume changing in living tissues. It provides the information of BVP that propagates throughout the body, which can be used for heart rate extraction. Based on this idea, Ming-Zher Poh *et al.* tried to apply ICA on video images of human face to extract

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underlying BVP for cardiac pulse rate measurement [1]. Similarly, Magdalena Lewandowska obtained heart rate directly from webcam with PCA [2]. According to the Beer-Lambert law, reflected light intensity traveled through facial tissue varies nonlinearly with distance. Neither ICA nor PCA could extract the pure BVP from collected data, as both of them are based on linear hypothesis.

This paper proposes a novel webcam-based method to measure human heart rate using LE [3]. In our approach, the red, green, and blue (RGB) color sensors of webcam collect the changing signal of reflected light intensity on human face. The source signal is a mixture of BVP along with other sources of fluctuations in light. As LE is a *manifold learning* method using for uncovering the inner structure of data, we apply LE to extract BVP from the collected signal. Then we do some simple but effective data processing with the extracted BVP, and get heart rate based on the calculation of IBIs. The step of extracting BVP from signal source counts much, which is also a process of dimensionality reduction for raw data. PCA [4], Linear Discriminant Analysis (LDA) [5] and ICA [6] are classic linear dimensionality reduction methods. In addition, manifold learning methods proposed in recent years, such as Isomap [7], Locally Linear Embedding (LLE) [8], LE, Local Tangent Space Alignment (LTSA) [9], Maximum Variance Unfolding (MVU) [10], and Linearity Preserving Projection (LPP) [11] can also be used for dimensionality reduction. All of these methods could also be applied for the BVP extraction in our application. Through the comparison of nine dimensionality reduction methods: Isomap, LLE, LE, LTSA, MVU, LPP, PCA, LDA and ICA, it reaches a conclusion that LE generates the best results.

Our contributions are as follows:

1. We use LE to extract BVP from video images of human faces.
2. We propose a robust heart rate calculation method based on IBIs calculation from the desired BVP.
3. We do extensive experiments on other eight alternative methods: Isomap, LLE, LTSA, MVU, LPP, PCA, ICA and LDA, and give the conclusion that LE is a reasonable choice for this application.

The rest of the paper is organized as follows: Section 2 puts forward some related work. Section 3 introduces the heart rate extraction model based on LE. Section 4 shows the results of experiments compared with other alternative methods. Section 5 presents the conclusion.

2 Related Work

PPG is a non-invasive photoelectric means of detecting the changes in blood volume of living tissue [12]. The basic clinical application of PPG technology is blood saturation measurements [13]. In 1996, Nakajima *et al.* successfully used the PPG collected at the earlobe to extract heart rate [14]. Johansson designed a heart rate and respiratory rate detection system based on PPG in 1999. They also used it to monitor new-borns for up to eight hours [15]. Aoyagi and Miyasaka in 2002 extracted the oxygen saturation (SpO2) and heart rate information through