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Review

Heart rate estimation using facial video: A review

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ABSTRACT

Photoplethysmography and Ballistocardiography are two concepts that are used to measure heart rate from human, by using facial videos. Heart rate estimation is essential to determine the physiological and pathological state of a person. This paper presents a critical review of digital camera based heart rate estimating method on facial skin. This review extends the investigation on to the principles and theory behind photoplethysmography and ballistocardiography. The article contains reviews on the significance of the methods and contributions to overcome challenges such as; poor signal strength, illumination variance, and motion variance. The experiments were conducted to validate the state of the art methods on a challenging database that is available publicly. The implemented methods were validated using the database, on 27 subjects for a range of skin tones from pearl white, fair, olive to black. The results were computed using statistical methods such as: mean error, standard deviation, the root mean square error, Pearson correlation coefficient, and Bland-Altman analysis. The results derived from the experiments showed the reliability of the state of the art methods and provided direction to improve for situations involving illumination variance and motion variance.

Contents

1. Introduction

Heart rate estimation is an essential component to determine the physiological and pathological state of a person/individual. The heart is one of the most important organs in the human body. The function of the heart is nothing more than to pump blood through-

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out the body by beating approximately at 60 to 100 beats per minute (bpm) [1]. Heart rate above 100 bpm which is known as Tachycardia and heart rate below 60 bpm is known as Bradycardia are considered as abnormalities [2]. Abnormalities in the heart rate are caused by physiological and pathological factors that disrupt the normal electrical impulse which controls the heart's pumping action. Tachycardia is usually a cause of high blood pressure, smoking, fever, sudden stress, side effects of medications and damage to heart tissues from heart disease. Bradycardia is usually a cause of hypertension, rheumatic fever, obstructive sleep apnea, myocarditis and heart tissue damage related to aging. The risk factor to either of these abnormalities would result fatally.

Estimation and monitoring of heart rate have been essential in the fields of medicine and biomedical engineering. Researchers have developed various methods to estimate the heart rate from contact to non-contact sensors. Reviews have been written on contact and noncontact heart rate measuring methods (for recent reviews, see [3,4]). The standard and established heart rate measuring methods are in contact with the body such as: electrocardiogram and photoplethysmography which are based on conductive electrodes and phototransistors. Non-contact, experimental methods are microwave/ultrasound distance measurement, optical vibrio cardiography, thermal imaging, and RGB imaging (see Table 1). The common object of either of these methods is the extraction of physiological parameters to estimate and monitor the heart rate in a reliable manner.

The progress on non-contact heart rate measurement have attained much focus since remote sensing has emerged. Remote sensing has minimized the amount of cabling and cluttering associated with contact based heart rate measurement methods. Heart rate estimation using digital camera sensor is a rapidly growing research area due to its low cost and non-invasive nature for measuring the heart rate. The heart rate estimation using digital camera sensor is mainly operated based on the concepts of photoplethysmography and ballistocardiography. The digital camera based heart rate extraction methods have evolved from using high definition charge coupled device (CCD) and complementary metal-oxide-semiconductors (CMOS) camera sensor to cellphone and webcam camera sensors [4]. Therefore, heart rate measurement from facial videos using digital camera sensors has become one of the motivative directions to extract physiological signals in a non-invasive approach.

The progress of heart rate measurement using facial videos has given a new course towards health monitoring in fields of health care, telemedicine, rehabilitation, sports, and ergonomics [5]. This paper will discuss the development and present the state of the art on heart rate measurement using facial videos. The remaining of the paper will be discussed based on the two main concepts: photoplethysmography and ballistocardiography, that are used to measure heart rate from facial videos. Sections 2 and 3 will discuss on methods related to ballistocardiography and photoplethysmography, the principles and theory behind concepts; the recent developments, significance and challenges on heart rate estimation. Section 4 will discuss the experiment design to test state-of-the-art methods on a common platform to determine the reliability of the methods. Section 5 will cross-validate the derived results, qualitatively and quantitatively and Section 6 will report the conclusions of the study and future direction in the research area.

2. Ballistocardiography

2.1. Theory

Ballistocardiography is a method for measuring the heart rate by estimating the motion generated by pumping of blood from the heart at each cardiac cycle. It is one of many methods that rely on the mechanical motion of the cardiovascular systems, such as apex cardiography, kinetocardiograph, phonocardiograph, and seismocardiography. Ballistocardiography (BCG) was initially discovered in the 19th century and became the focus of interest in research from the 1940s to 1980s, after which the method faded away. BCG is defined by Newton's Third law of force (acceleration, velocity, or displacement), whereas the whole body is subjected to a rigid motion due to the cardiac ejection of blood. Therefore, the physiological signals obtained from BCG are more related to describing the blood flow within the heart, inside the arteries (mainly the aorta), and the movement of the heart itself. The most typical BCG extraction methods involve the subject to lay on a plane bed or sitting on a chair with minimal voluntary and involuntary movement [6].

Fig. 1. Illustration on involuntary head movement due to the blood circulation from heart to head.

The main motivation to extract BCG signals from the facial video was due to the involuntary head movement caused by blood flow from the heart to the head. At each cardiac cycle, when the heart beats, the left ventricle contracts and ejects blood at a high pressure to the aortic arch. This flow of blood at each cycle pass through the carotid arteries on either side of the neck, generating a force on the head (see Fig. 1). Therefore by Newton's 3rd law of force, this force created by the blood flow on the head, equals the force of the head acting on the blood flow causing reactionary cyclical head movement. White arrows illustrate this in Fig. 1. This head movement is too small to be noticed by the naked eye. However, the work presented in [7], by using video amplification, proved that the head moves periodically to the motion of the heart rate at a smaller amplitude.

2.2. Related work

In 2013, Balakrishnan et al. [7], proposed a heart rate estimation method using facial video based on BCG. This method focused on extracting the involuntary head motion in the video. The heart rate from the facial video was extracted by tracking velocities of feature points on the face region. The velocity of the feature points was extracted to track the microscopic movement of the head. The feature points of the head were extracted from the region of interest (ROI) specified by the authors. The authors used a combination of regions above the eye line (i.e. forehead) and the region below the eye line which includes the cheeks and the upper portion of the lips. The justification for the selection of ROI is that the area selected contained much of the capillaries which branch out from the carotid arteries. The eye line was excluded because blinking of the eye would result in motion artifacts in the extracted BCG signal.

The authors used the Viola-Jones face detector [8], to detect the face and extract the ROI. The feature point of the ROI was tracked by using Kanade Lucas Tomasi (KLT) face tracking algorithm [9]. The tracked points were temporally filtered using a bandpass filter