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REAL-TIME HEART RATE ESTIMATION USING FAST INDEPENDENT COMPONENT ANALYSIS AND HANGOVER-TIME FILTER

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ABSTRACT: Heart rate is one of the physiological parameters which is measured for our health and well-being. By estimating it one can act pre-emptively in case of emergencies. In the past few years, various techniques were proposed, subjecting motion artifacts to increase the robustness of the system. This paper presents a real-time method of detecting the human heart rate, remotely, using a laptop camera. This paper also proposes on using a Hangover-Time filter for robust detection. Following the recent research [1], this project also utilizes OpenCV for face detection and isolating the forehead region, Fast Fourier Transform Analysis and Band-Pass Filter. Compared to the adaptive filter, the hangover-time filter has a difference in a mean error of ~0.26BPM and the corresponding Complement of the Absolute Normalized Difference (CAND) of 95.05% is achieved.

Keywords: Rppg; Vital parameters; Independent component analysis; Hangover-time filter; Adaptive filter; Heart rate estimation

INTRODUCTION

Plethysmography (‘Plethysmos’ means ‘to increase’ in Greek is a technique that can detect a change in the amount of blood present in an organ such as the heart. Photo-plethysmography (PPG), in particular, is a method of detecting a plethysmography signal by the effect of light reflectance or transmission from the skin. PPG was introduced in 1937 [2] and works on the principle that blood absorbs light and that variations in blood volume influence the amount of light’s reflectance or transmission. This serves as a potential tool to determine vital signs through the skin, thus opening numerous applications in the field of medicine and home automation systems. Cardiac activity measurement is an essential tool in medical practice to measure a person’s physiological state.

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Traditional contact methods, such as electrocardiograph (ECG) offer high accuracy in measuring the cardiac cycle. ECG was developed by Willem Einthoven in 1901, which measures the electric potential between two points on the skin of a human body. ECG is the most common instrument used in the medical field. This project also utilizes ECG technique for benchmarking and testing purposes. The first contactless vital sign measurement was proposed in 1997 [4]. The system was developed to pick up heartbeat and respiration signatures from 10 meters using a radar-based system. Based on the Doppler variations built on the chest movements, this system was used in 1996 Olympics for assessing an ath lete's performance in archery and rifle competitions. Since radar can also pass through walls, this system could detect heartbeat through the walls. The only disadvantage of the system was that artifacts introduced by the subject's movement contaminated the measurements. By using the same principle, near infrared (IR) light source developed by Humphreys et al. [5] was the first PPGbased system for detecting cardiac activities. Humphreys et al. [5] subjected the near IR light on a finger and looked at the transmitted light on the other side, through a CMOS camera. The camera was placed above the finger at a height of 30-50cm. Similarly, a contact-based PPG system was developed by [6] in 2006, where PPG signals were found by studying the variations in the light that's been reflected or unabsorbed by the finger. It is noteworthy to point out that this is the basic concept used in smartwatches and finger-tip-based measurement systems. In 2007 [7], IR-based cameras were used for measuring cardiac pulses. The study used periodic properties of the cardiac pulse's thermal field, which was later analyzed through Fourier transform. However, it was not until 2008 [8] where contact-less PPG-based measurement of heart rate was performed in the visible spectrum using the fact that the green light is absorbed more into the blood, containing oxygen, than red or blue light. By analyzing the amount of absorption of green light, we can analyze the variation in blood flow in the vessel, indirectly measuring the heartbeat. The study [8] used pre-recorded RGB videos in ambient light conditions. They concluded in their research that among the three-color channels, green-

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Vol 13,Issuse 3.july 2023

channel contained more PPG signal than red, blue-channels. Thus., they could successfully measure heart rate and respiration-rate of a person. This research required the subjects to be stationary in order to reduce motion artifacts, establishing a promising framework and methodology for carrying out non-real time remote-sensing PPG in the visible spectrum. Nonetheless, this technique suffered from low accuracy and artifacts due to poor resolution of low-cost visible light cameras. The research done in 2010 [3] has drawn a lot of attention towards heart rate detection, which inspired a new method in blind-source separation using joint approximation diagonalization of eigenmatrices (JADE) algorithm. Consumer laptop cameras, in recent years, have improved spatial and temporal resolution, which make this method easy to implement and use. This is a noncontact-based system, which is an advantage over the traditional contact-based system. This system avoids skin irritations and other discomforts provided by contact-based systems. Blind Source Separation (BSS) method is one of a prominent method in digital image processing. Independent Component Analysis (ICA) is one of BSS technique, where independent signal sources can be filtered from a mixed signal. The same procedure is done by [8], instead of directly analyzing the three-color channels into Fourier analysis, ICA can be used as an intermediate filter before FFT [2]. By implementing ICA as a blind source separation technique [2], the system equipped with a laptop camera pointed on the entire face managed to reduce small motion artifacts, thereby increasing the stability in heart rate estimation. Later, this idea inspired another work [11] by which temporal filters were used only on the forehead region of the face. A similar technique was used in [12] in near IR spectrum which made the system motion robust. Using the forehead region made it much more convenient to develop the system. Another approach was proposed in [13], where principle component analysis (PCA) was used as a BSS technique in order to decrease the computational complexities while comparing to ICA. Implementing a new PPG-based method of BSS called FastICA was developed by Wiede et al. [1]. FastICA reduces complex multiplication when compared to traditional ICA. Post fast ICA, they implemented an adaptive filter in order to combat motion artifacts introduced by the subject's motion.

SYSTEM OVERVIEW

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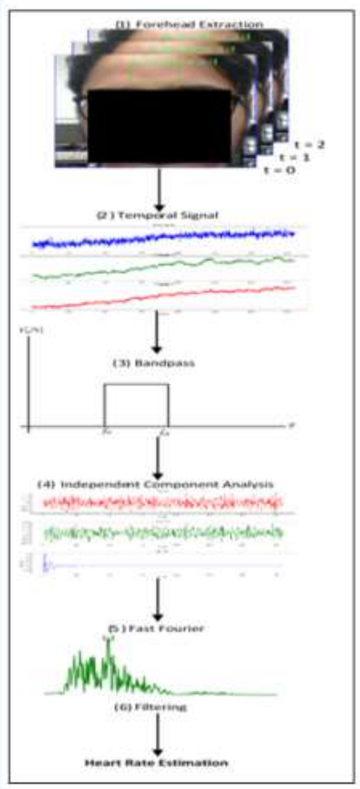

Figure 1: An overview of the system flow. After isolating the forehead

1. The data is separated to three-color channels
2. From there the three-color channels are fed to bandpass filter
3. After filtering out improbable frequencies, the data is fed to ICA
4. From there a Fourier analysis is done for all the three channels
5. After using filtering methods
6. The heart rate is estimated

Figure 1 describes the flow of the design. The design contains the following modules: Temporal Signal Extraction, Band Pass Filtering, Independent Component Analysis, Frequency Analysis, Adaptive and Hangover-time Filters. At the start, frames are acquired and then facial detection in each frame is processed. After the detection and isolating of the forehead, with the command from the user, frames are sent to temporal extraction. Temporal extraction is separating the three-color channels from the frames. After color separation, the three signals are sent to a bandpass filter. Bandpass filter filters out the signal containing frequencies other than the natural frequency of the human heart rate. After bandpass, the data is sent to ICA and from there to Frequency analysis which determines the final (raw) heart rate. The final heart rate signal contains outliers which can be filtered out by using an adaptive or hangover-time filter. A laptop (Dell Inspiron 5558) equipped with a webcam was used for image acquisition. The frames per second parameter was set by default to ~30fps. The webcam provided 640x480 resolution and before the user command, the automatic controls for exposure and white balance are set to true. After the user command, it's set to false. The intensity of the color channels can be tracked by using a simple camera. Hue, saturation, lightness (HSL) is an alternative to RGB color channels. Intensity or brightness or lightness is a component that is a part of the color channels. But to look at the intensity of the color, it should be converted into a pure black and white frame, where black and white corresponds to darkness and brightness respectively. Although HSL model is better compared to RGB model, it is suggested to stick to RGB model. So, it is only advisable to use this algorithm in RGB setting. The computational speed of the algorithm takes

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approximately 34ms; which corresponds to 30fps for detecting, analyzing and deriving the heart rate. To increase the computational speed, analyzing red and green components of RGB channel is suggested. There are a wide variety of applications for remote estimation of heart rate. Home health care systems can implement such an algorithm. These systems can monitor the heart rate and act pre-emptively before an emergency occurs. Most of the health care systems are IOT based devices. Such systems can monitor people from remote locations. In Kinesiology; in monitoring an athlete's performance. This system can also be upgraded to monitor multiple athlete's heart rate, who are performing the same task. Thus, eliminating contact-based interferences to the system. Since polygraph systems detect the sudden changes in respiration and heart rate patterns, this system can be used as a lie detector. There are publications [8,14], who estimated the respiration rate with the same data used for estimating the heart rate of a person. Implementing such a system in real time can eliminate the contact-based polygraph system.

CONCLUSION There are some other techniques in drawing a ROI on the forehead. By tracking the location of the eyes [11], ROI can be drawn on the forehead with some variable constants. One can also achieve this simple implementation by tracking the eyebrows and draw an ROI where the lines intersect. For future work, using an advanced camera can increase the total resolution of the system. The algorithm can also favor other cameras like IR camera. Using Xbox Kinect, which has RGB, IR and depth sensor capabilities can be an advantage for further research. Increasing the frames-persecond can affect the results greatly, which is an advantage. The more the data intake in less time, the faster the results. In this paper, a hangover-time filter is discussed. Hangover-time filter is an upgrade to the adaptive filter. Heart rate is estimated remotely, using ICA and hangover-time filter. With the upcoming surge in cloud computing, this project can be utilized for computing a person's heart rate remotely.

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