Research on Non-contact Heart Rate Detection Algorithm

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Abstract. The heart rate is one of the important characteristic of human health. Fast and convenient heart rate measurement has become one aspect of daily life. The non-contact measurement method of heart rate gathers information of face via color video camera, analyzes the change of displacement of the surface of the skin and body color, then uses the methods such as filtering, spectrum analyze and peak detection to analysis the heart rate quantitatively. What's more, we study a non-contact method to detect the implementation of the heart rate based on the video acquisition, image processing and signal processing technology. We have done a thorough study of the implementation framework of the non-contact measurement of heart rate.

Keywords: Photoplethysmography · Non-contact
Independent component analysis

1 Introduction

Heart rate is a very important parameter in the diagnosis of today's medical treatment. Non-contact heart rate measurements have also attracted increasing attention, especially for newborns and the elderly, whose skin is very fragile and traditional contact heart rate measurements may make them feel uncomfortable. In addition to providing a non-contact way to measure heart rate, the method can also be used to monitor subtle changes in heartbeat for long periods of time as other basis for clinical diagnosis. This method of heart rate monitoring can be widely recognized by using the camera to collect face information, which non-contact to measure the heart rate, instead of contacting with skin.

In this article, we use the heartbeat cycle caused by the delicate changes in the head color to extract the information of heart rate. With blood flowing through the abdominal aorta and neck arteries to the head, the head will produce cyclical changes in color.

X. Gu et al. (Eds.): MLICOM 2017, Part II, LNICST 227, pp. 316–325, 2018.
https://doi.org/10.1007/978-3-319-73447-7_35

2 Relate Works

2.1 Photo-Plethysmo-Graphy

Photo-plethysmo-graphy (PPG) is a non-invasive photo detection device that detects blood volume changes by means of optoelectronic devices. Hemoglobin is different for red and infrared light absorption, so we can measure hemoglobin in the blood by measuring the degree of weakening of each light reflected or transmitted by blood [1]. At present, the market of PPG sensors are usually more cost-effective LED and red photodetector with the use. In addition, it is also important to select photodetectors whose spectral characteristics match the light source. [2] PPG signal acquisition system is as follows (Fig. 1):

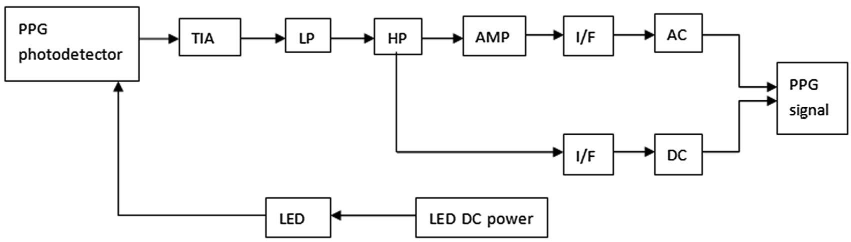

Fig. 1. PPG signal acquisition

2.2 Existing Detection Program [3]

General contact heart rate testing equipment is expensive, and the user is not convenient to carry. So people began to explore non-contact detection of heart rate. At present, the non-contact methods for determining heart rate are laser Doppler, Doppler radar, biological radar, thermal imaging and so on.

3 Algorithm Principle

This paper presents a method of non-contact heart rate testing. The method uses a camera to collect color images of the face and analyzes the changes in human skin color. And then use filtering, spectral analysis, peak detection and other methods in signal processing to analyze the heart rate characteristics. Compared with the existing PPG detection technology, the detection method uses a conventional digital camera as a detector, rather than using a photodiode. While the light source required by the method is only normal ambient light.

The main research algorithms are: face detection, independent component analysis, peak detection and so on.

3.1 Face Detection [4]

Face detection as the first stage of face recognition system, is recognized by most experts. Face detection methods are method based on the face gray model, method based on the feature space and method based on the neural network.

The detection method based on the face gray scale model is: First extract the geometry, gray level, the skin lines and other characteristics of the face. And then check whether the results extracted above are consistent with the prior knowledge of the face.

Based on the feature space method, the face region image is transformed into a feature space. And then it is divided into "human face" and "non-human face" two types of models according to its distribution in the feature space. Principal Component Analysis (PCA) is a commonly used method. It is orthogonal according to the statistical properties of the image to eliminate the correlation between the components of the original vector. The eigenvectors from transformation whose eigenvalues are decremented in turn are eigenfaces.

The artificial neural network (ANN) method is based on the statistical characteristics of the model implicit in the ANN structure and parameters. For the complex, difficult to describe the model, the ANN-based approach has a unique advantage.

3.2 Independent Component Analysis [5]

Independent Component Analysis (ICA) is a statistical and computational technology. It is used to reveal hidden components in random variables, measured data and signal. For a multivariate observation data usually given in the form of a large number of sample databases, ICA defines a generation model. This model assumes that the observed variable is a linear or non-linear blend of some unknown intrinsic variables. And not only the intrinsic variables are unknown, but the system that achieves the mix is also unknown. We also assume that those intrinsic variables are non-Gaussian and independent of each other and call them an independent component of the observed data. These independent components (also known as sources or factors) can be found by ICA.

In order to give the strict definition of ICA, we can use the "hidden variable" statistical model. We can assume that random variables $x1, \cdots, xn$, are observed, these variables are linearly combined by the other random variables $s1, \ldots, sn$. In this model, we also need to assume that the variable si is statistically independent of each other.

What is mentioned above is the model of ICA. Since this model shows how we see the data from si, we refer to this model as the generation model. Among them, si as an independent component, cannot be directly observed by us, so we call it "hidden variable". In this model, the only thing we can know is that the random variables $x1, \ldots, xn$. So, when we do independent component analysis we cannot ignore the commonly used assumptions. So that we can only use our observed variables to get all the unknown.

3.3 Peak Detection [6]

As shown in Fig. 2, P1 and P2 is the peak that we want to detect. We have to pre-set the amount of rise and fall. The core of the peak detection algorithm is: the peak point is the maximum value of the waveforms we studied, which has the rising and downward quantities. We must first determine a gate value, which is to give up some smaller voltage change caused by noise. For the voltage below the gate voltage, we set it directly to 0 and the voltage higher than the gate voltage, we can retain its original data. Finally, we start to check one by one to find all the qualifying data, and that is the peak we want.

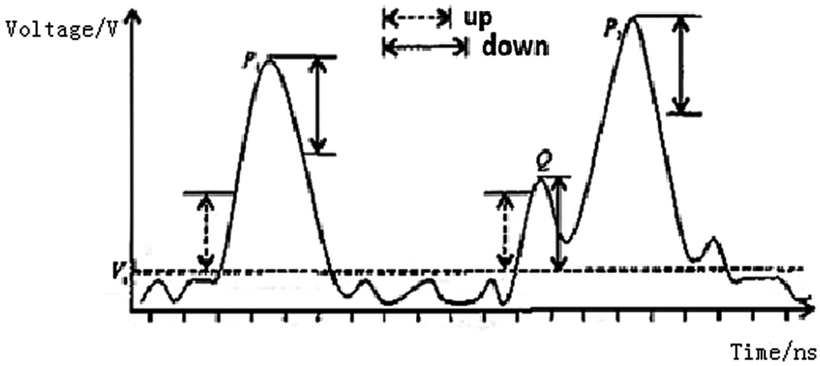

Fig. 2. Peak detection diagram

4 System Framework

Non-contact heart rate detection implementation process is shown in Fig. 3. The algorithm steps are: first in the natural light, use a video camera to collect information of a face; the face detection algorithm is used to extract the faces from each frame of the image. Then, we will separate each frame face image and generate R, G, B three-channel image. We can use the mean of all the pixels in each image as the eigenvalues of each channel and signals XR (t), XG (t) and XB (t) are used to represent the signals generated by the three channels. Next, we make independent component analysis of the three signals after standardization, so that three new signals YA (t), YB (t) and YC (t) independently of each other are obtained. Then, we use correlation analysis, filtering, and peak detection to obtain the heartbeat frequency (sub/min).

4.1 Image Acquisition

By the PPG measurement principle, video acquisition is an important step in the detection of heart beat frequency. The light that is reflected and scattered by the incident light through the skin, blood vessels, muscles and other tissues need to be recorded and the optical signal is converted into an electrical signal [2]. The camera is the most convenient photoelectric conversion device, which is our preferred

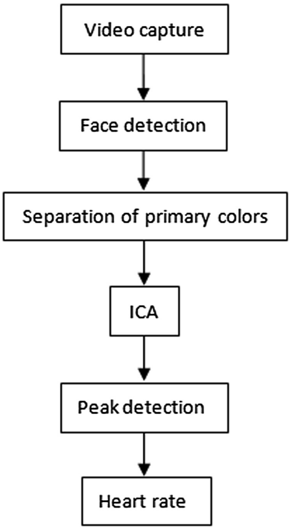

Fig. 3. Non-contact heart rate detection implementation process

measurement equipment. We use the ordinary light or natural light as the light source; The resolution of the camera is the pixel 640 $\times$ 480 and the frame rate is 30 frames/s; The image color space is RGB; Then we can obtain a face video of 450 frames, 15 s. We use the other measuring instruments to measure the heart rate while shooting the video. The measuring device is shown in Fig. 4:

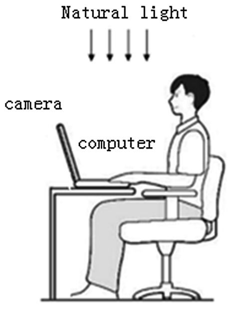

Fig. 4. Non - contact heart rate measurement device

In the video capture, to reduce noise, there are four main points to note. (1) Try to shoot in good light conditions. The more the light is, the more the change in the color of the face is. (2) Turn off the camera's white balance performance. The camera automatically detects the environment and adjusts the color with white balance, which can destroy useful color information. (3) People in the video shooting time should not be too much action. The action will provide artifacts, which will cause the noise in the extracted signal. (4) When video has been captured, in order to prevent the camera just started will affect the color extraction, we need to intercept the middle of 15 s to analyze. We then turn the video into a frame format, and continue to the following analysis.

4.2 Face Detection

As the video in this paper requires the participants' action range cannot be too large, and the participants are almost completely static, so the video is only composed of a large number of static image sequences. Through the analysis of each face detection algorithm, we use the face detection algorithm is based on skin color characteristics of human detection technology. This kind of face detection algorithm is relatively simple, and the video collected in this article is only a person's head, so it is easier and more accurate to achieve.

As the light changes will also affect the effect of face detection, so before the face detection, we need light compensation for the image. Histogram equalization is the simplest method of lighting compensation. It can eliminate the effects caused by the changes in lighting conditions. Although this method has poor effect on face image processing under extreme light conditions such as high light and all black, before the face detection, we use the histogram equalization method to carry out its light compensation considering that the algorithm generally requires better lighting conditions, extreme light conditions do not occur.

When a face detection for each frame is successful, the image should be saved on the computer for the primitive PPG signal.

4.3 Separation of Primary Colors

When a face detection for each frame is successful, the image should be saved on the computer for the primitive PPG signal.

We detect the face, and then we split the color signal in order to get R, G, B channel color components and save it as a three-dimensional matrix. Taking the pixel mean of the face image as our sample value, we can get three consecutive channels with heart rate information for 15 s. Three-channel sampling signal is shown in Fig. 5:

Details show that in the study of human blood cells to absorb light capacity, we found that blood cells absorb green light or yellow light ability is stronger than other colors of light. So we can conclude that the green waveform is most correlated with heart rate information in the above three waveform signals.

4.4 Independent Component Analysis

Since the heart rate signal is usually mixed with a variety of physiological signals such as respiratory waves, we cannot obtain the source signal of heart rate through priori knowledge, and we can estimate the source signal only through the observation data. Therefore, separating the source signal from the mixed observation signal is a typical blind source signal separation problem. So we use the ICA algorithm to divide the above three channels of the initial signal into three independent source signal.

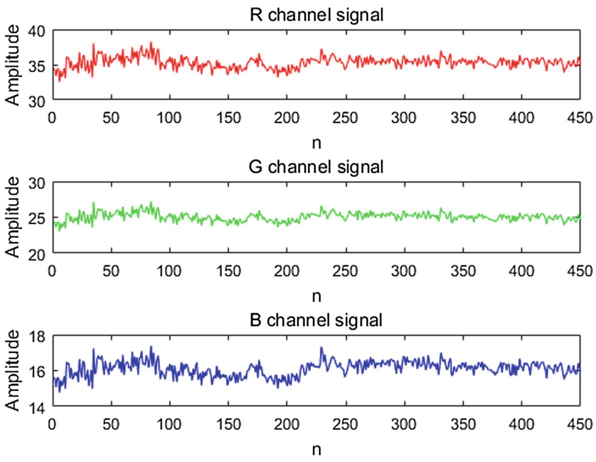

Fig. 5. Three-channel sampling signal (Color figure online)

First of all, the above three signals should be standardized, mean 0, variance of 1. Standardized signal is shown in Fig. 6. Then we use the ICA algorithm to remove the noise, and we will get three independent source signal. The three independent source signal is shown in Fig. 7. Since the three signals are disordered, it is not possible to determine which of the three separate signals corresponds to the signal in the mixed signal before separation. So we need to use the correlation analysis method to screen out the most relevant signal with the heart beat. Select a signal that is most relevant to the green signal for the next analysis. In order to find the independent source signal most relevant to the green channel signal, we need to calculate the correlation coefficient between the three independent source signals and the green signal separately,

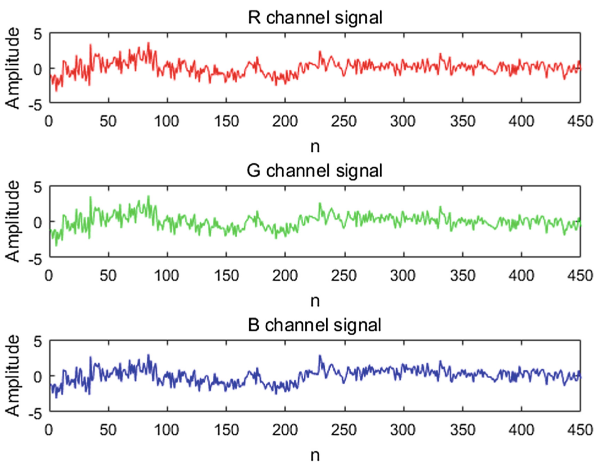

Fig. 6. Standardized signal (Color figure online)

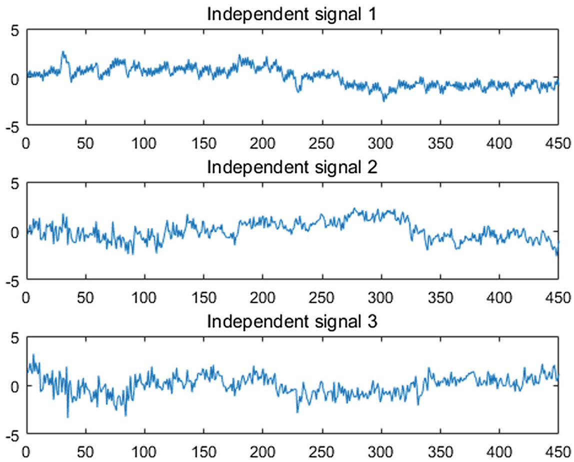

Fig. 7. The three independent source signal (Color figure online)

which requires the correlation function corrcoef in Matlab. The correlation between the three signals and the green signal is 0.4749, 0.3260 and 0.9400. So the green signal is most relevant to the third signal.

4.5 Signal Processing

The collected heart rate signal also contains some high-frequency noise, making the signal "glitch", which requires us to use some signal processing methods to filter out. Studies have shown that a normal adult's resting pulse rate [0.75, 2] HZ, so it can be filtered using 5-point moving average filter, and then using a band pass [0.75, 5] HZ Butterworth filter. The signal processing results are as follows (Figs. 8 and 9):

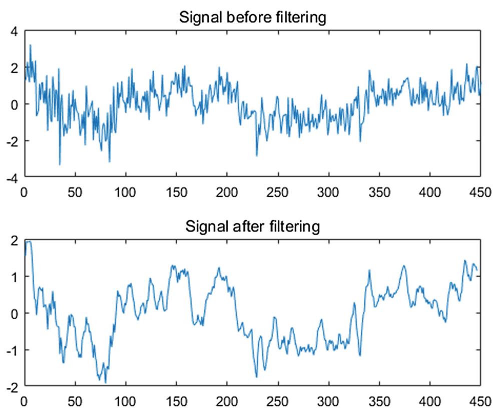

Fig. 8. Comparison of signal before and after the first filter

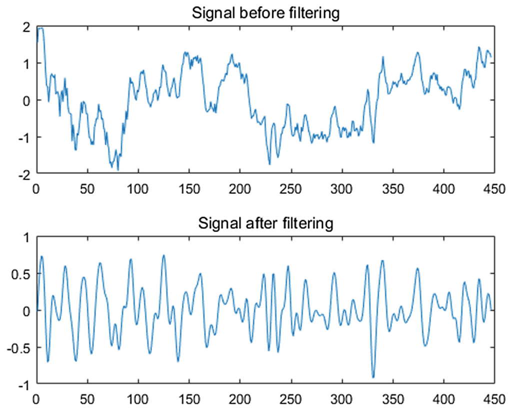

Fig. 9. Comparison of signal before and after the second filter

Peak detection of the above signals which has been subjected to the necessary filtering and calculate the average of the time interval between each peak. We use the peak detection algorithm to measure the heartbeat interval time so as to get the maximum peak frequency f. Heart rate calculation method: HR = 60 * f. The signal processing results is shown in Fig. 10. The heart rate is 96 times/min.

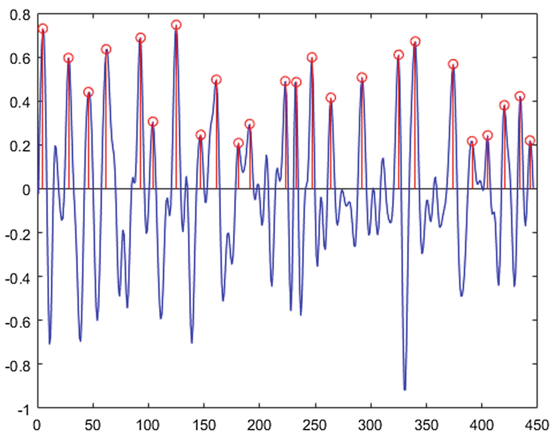

Fig. 10. Peak detection processing results

Acknowledgment. This work was supported by the National Science and Technology Major Specific Projects of China (Grant No. 2015ZX03004002-004) and the Fundamental Research Funds for the Central Universities (Grant No. HIT. NSRIF. 201616).

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