A Machine Learning Approach for Detecting Heart Pulse from Facial RGB Color Video using Webcam

P.V.P. Sai Kiran
B.Tech Student, School of Computer Science & Engineering, Lovely Professional University, Punjab, India
Email: saikiran660@gmail.com

Sujith Reddy Vangala
B.Tech Student, School of Computer Science & Engineering, Lovely Professional University, Punjab, India
Email: sujithreddyvangala@gmail.com

Mamoon Rashid
Assistant Professor, School of Computer Science & Engineering, Lovely Professional University, Punjab, India
Email: mamoon873@gmail.com

***Abstract*— Heart Rate (HR) is one of the determining parameters about one's physiological state and is therefore important to monitor. Detecting such parameter often requires costly equipment and calculations which are complex especially with sensory devices. Remote photoplethysmography (rPPG) allows a non-contact measurement of the heart rate using low-cost RGB imaging equipment. This paper presents a working solution on the live video stream i.e., in the real time. Face Detection along with object tracking is used to establish a set of rectangles, which are later used in pipeline of color variations. The average of the color, in the Region of Interest (ROI) chosen on the face (forehead region). Using signal processing, a heart rate frequency can be obtained from this signal. This paper discusses the reimplementation of one such approach that uses fast fourier transform (FFT). Researchers can now refer to the reviewed and classified algorithms as a starting point to improve aspects of the rPPG.**

Keywords*— *Heart Rate, non-contact, remote, Fast Fourier Transform, photoplethysmography, laptop camera-based, Heart rate Monitoring.

I. Introduction

The heart being one of the vital organs in a human body is subjected to many risks. A person's Heart rate (HR) can be a result of their lifestyle such as health, physical exercises, anxiety, stress and more. The above-mentioned factors in the previous statement differ from each person. General circumstances to measure Heart rate would be in a hospital environment. In the beginning of monitoring of heart rate, physical touch was required for equipment to work and precisely generate results of the patients.

The Cardiac pulse is typically measured in clinical settings using electrocardiogram (ECG), which required them to wear such gear on their bodies which proved to abrasive and uncomfortable. Later years, the method to measure or monitor Heart rate has changed significantly, which resulted in using sensors that may be worn on the fingertip or earlobe. Hence, after moving to the adaptation of sensors, one of the inferences to target mainly is that they were discomforting as well.

Furthermore, in acknowledging such situations over the past few decades, a non-contact means of detecting Heart rate was developed. Such a method would be very beneficial. Non-contact Heart rate measure through a simple camera either on laptop, computer or phone. Interest in fitness, has made people health conscious and thus resulting in software implementations.

Earlier studies have shown that heart rate can be calculated using a person's face in a color video. So, our research can be simple stated as reimplementation of one such approach that uses fast fourier transform on mean pixels within a region of interest (ROI). Then, we explore the subject's head movement and bound their face and forehead-the region of interest in a box, to measure the Heart rate more accurately.

A measured Heart rate is obtained from a volumetric measurement (plethysmogram) of the heart as the number of contractions per minute. Moreover, photoplethysmogram (PPG) application which exists in smart watches today and other fitness tracking products proven to have some sought of physical touch on a wearer which is discomforting in the long run.

Many researchers have been trying to perfect the application by any means necessary. The studied techniques use a color model based on the colors- red, blue and green (RGB) imaging to acquire a signal by placing the person few meters from the camera. Later, it was slowly taking the shape and named as remote photoplethysmography (rPPG). The main aim of our research is to observe, study and lend a hand in such important applications which makes life easier and predictable.

Two such approaches proven main to focus have emerged from existing studies on rPPG: 1. Heart Rate Monitoring based on skin color variation, and 2. Heart Rate Monitoring based on periodic head movement. Both of those observable phenomena are caused by the cardiac cycle and thus allow researchers to obtain HR through monitoring from an estimated rPPG signal.

Such application was first proposed in 2008, nearly more than a decade and still the observation finds to attract attention and help many. To my dismay, earlier research papers did not discuss every aspect in detail. The basic pipeline which was used for the execution deals with the same approach. As stated earlier, our contribution to this topic- 1. Is to provide an overview of the conducted research in this field; 2. Is to classify studies by our choice of algorithm and contributions to the field. We chose to use this method- rPPG because it is by far the most frequently used (~50%) and more approachable to novice accomplices.

The review studies on rPPG that used low-cost face video, are only targeted because, much of the work is related to the above-mentioned scenario. Recording equipment is of commercial grade. Included only those studies whose goal was to obtain HRM using videos or live capture of subject faces. And from there, proceeding towards the details regarding the implementation of our research.

The rest of the paper id divided into various sections which briefly describe the pipeline of our project. As the research is mostly based on few prior papers. Extensive developments are not listed and considered but will surely be acknowledged in the future for the development of the paper. Section II details the methodology, section III deals with approach, section IV discusses the setup and equipment used. Finally, section V is dealt with conclusion of the paper.

II. Methodology

The method exploited in the research regarding the rPPG is closely related to the cardiac cycle. Each cycle being periodic will show affects both on the facial skin and mechanical head movement, which enables researchers to calculate HR.

The connection between the light and human tissue on the foreskin of a person's head is complex. When the application is all about low-cost and easy accessibility, certain aspects of the experiment should hold viable for a proper conduct of the research. This has shown that the reflection of light is dependent on many other factors and among them, blood volume change and blood vessel [5][6] movement. Present day studies have shown that ambient light is sufficient to obtain a plethysmographic [7] signal. All the above-mentioned changes in the region of the face, are not easy to track and difficult to be visible by a naked human eye. So, to detect such phenomena the implementation of the image processing algorithms is necessary. These are used for selecting the region of interest and observing the change in intensities of the pixels located in the region. By calculating the mean of the intensities of the pixel and extracting the frequencies using FFT would provide us with a clear peak of values which the represent the heart beats. To achieve the primary goal of this project, the implementation of the ROI was carried in Jupyter notebook and other related python libraries- mainly OpenCV.

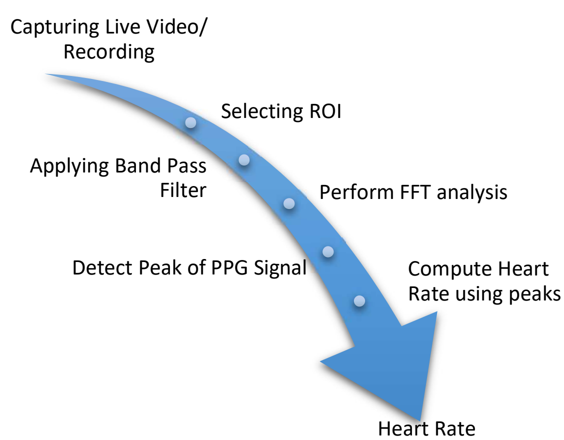

Figure 1. Process of Determining Heart Rate

A. *Detecting Faces*

Face detection is not the important aspect of the research, so we are not choosing the best method available but one that is readily available and is implemented on the hardware and mobile devices for convenience's sake. The method for face detection is using Haar cascades, which has been proven effective and proposed by Paul Viola and Michael Jones in their [4] paper. Creating a haar cascade filter is complex but effective in the later end. Various objects can be focused and detected by training the machine learning model with two sets of images- positive and negative images. The positive set contains the features we want our filter to detect and focus while the negative contains all the unwanted data which makes the model distinguishable and helps in identifying the object. As Viola-Jones detector has several key-features, as:

1. *Converting pixel intensity values into an Integral Image*.
2. *Haar Features*: Different rectangular images.
3. *The AdaBoost learning algorithm*: it is used for selecting the best features out of the entire set.
4. *The Cascade Filter*: it discards the negative set of windows in order to focus the computational process on the positive ones as much as possible.

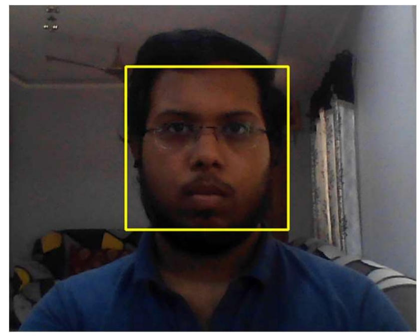

Figure 2. ROI Selection

B. *Selecting ROI*

The intermediary part of the process of determining heart rate. The region of interest (ROI) is an area of image, selected on specific criteria, which is to be used during the computational process. As discussed earlier, to observe the skin color variation, the forehead region is the best and optimal place to observe this phenomenon. Thus, a rectangular box enclosing on the ROI adapts to the size changes depending on the distance between the camera and the subject. The ROI is applied only to the frames where haar cascade filter detects the face of the subject. The enclosing is a significant way of making the observers understand the working of the process. Now, to calculate the mean or the average of the pixels in the region and select the maximum of generated values to obtain a clear signal.

Figure 3. Phenomenon explained in rPPG [1]

C. *Object Tracking*

To identify the face of the subject, two options can be implemented:

1. Applying the face detection algorithm for each frame.
2. Applying the face detection algorithm for certain frames, between which only face tracking is implemented.

Applied the first method for the subject's face. Turns out there is another way which is quite [3] faster. The reason being at the time of implementation, the method followed varied and to the best of my knowledge performed the research.

D. Heart Rate Measurement

Most vital process of the research is studying heart rate. From the information we learned in the above sections, we start by applying the Fast Fourier Transform (FFT) by the last 150 frames of the signal obtained from the previous point. Heart beats are in the range of 35 to 195 beats per minute. The heart rate translates this to a frequency between 1 and 3 Hz.

Frequency filtering is applied to the false readings. The filter specifically used is a bandpass filter, where it is used to transmit signals in a certain band of frequencies and block signals of lower and higher frequencies. Same is observed in a television or radio by tuning for a desired frequency. The desired band is centered around a frequency. And finally narrow it down to finding out the heart rate of the subject.

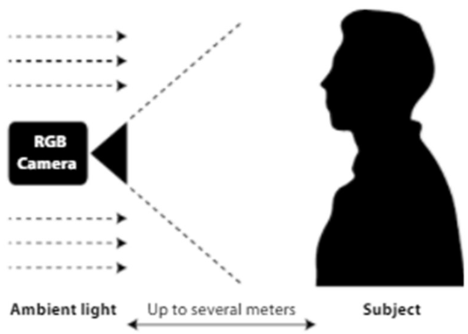

Fig. 4. Setup during rPPG application in HR measurement [1]

III. APPROACH

A lot of various sources define the process of calculating the heart rate. After studying different opinions on such study has opened many possibilities and areas to explore. To start with, the programming mainly involved building a gaussian like surface around the frame, just like in physics where different surfaces are built around objects. Every picture, live video or recordings are all read in the form of arrays in python.

1. During the gaussian phase, the frames are reduced in dimension and stored away for later use.
2. Define the parameters for the dimensions of the frame.
3. Define color magnification parameters.
4. Now, we define the parameters such as the thickness, font-color, font-scale and few others.
5. Initialize this gaussian frame we have built for the specified frequencies we are targeting.
6. The band pass filter is applied to the frequencies are targeted.
7. Most important parameters are for the heart rate for determining the frequency.
8. Reconstructing the frame by increasing the dimension of the frame, this is mainly done to aid with the computational process of the research.
9. Another helping hand function in this process would be to detect faces using haar cascade.

The above mentioned are to clarify the process we established for the research. A profound knowledge of different areas of interest will surely make all the change. In addition to the points above, with keeping in mind that it is low-cost and home-made computational process, we are very much limited by the equipment. But, to the best of our abilities we were able to design a process which soon be developed and adapted in industries.

It is fascinating to know from the previous studies that there exist many ideas, methods to execute such process. With focusing on the idea, we had at the beginning, were able to learn and maintain the integrity for which the research stands.

Then, as stated earlier, convert the color image to grayscale mainly to decrease the computational process for various reasons and select the ROI based on the rectangle enclosing our face. Remember the ROI is less and based on the position of our forehead. Somewhat live tracking of motion of the face to aid us in determining the signal.

The Fast Fourier Transform (FFT) is commonly used for frequent analysis as FFT analysis converts the time domain of signal into frequency domain. Being better version of Discrete Fourier Transform (DFT), it can be applied when the number of samples is of power two [8].

$$x_n = \frac{1}{N}\sum_{1=1}^{N-1} X_k \cdot e^{2i\Pi kn/N}, n \in Z$$

Where x_n is the discrete-time signal with a period N. For the PPG signal determination, FFT is computed and analyzed. One the frequency of the signal was obtained from the spectrum, heart rate can be measured from,

$$\textit{Heart Rate} = \textit{frequency } (f_h) * 60$$

Peak Detection

Using individual peaks, extracting more information such heart rate variability from the inter-beat intervals is possible. To obtain a refined signal for peak detection, the signal is usually interploated using a cubic spline function [9,10,11]. The points can then be identified using a moving window, as they are the maxima within the signal.

$$\textit{Heart Rate} = f_h * [(\textit{Number of peaks/Time})]\ \textit{bpm}$$

More elobrated formula for the understanding of measuring heart rate. This approach is selected to provide calirty in determining the signal.

IV. SETUP

During development, the process and tests were run on the following hardware:

- Processor: Intel^R Core^{TM} i5 7200U CPU @2.50GHz
- RAM: 16.00 GB
- 720p FHD webcam

Now, after calculating the mean or average of the pixels in the ROI. By comparing the results obtained for people having a visible difference between skin tone.

All the observations are noted in the morning and in a well-lit environment for better result. No make-up and none of them suffered from any form of skin condition, which are optimal for the observation to be noted.

TABLE I. EXPERIMENT DETAILS

Subject	**Features**		
	Age	***Skin Tone***	***Gender***
Person 1	21	Brown Medium	Male
Person 2	21	Brown Medium	Male

Fig. 5. Shows the Person 1 and Person 2 while running the test:

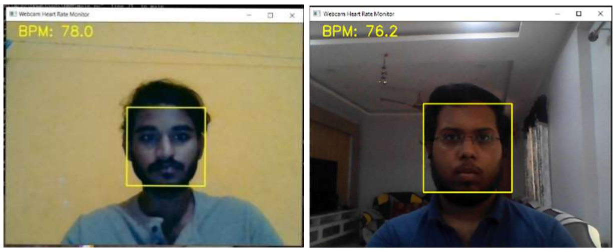

Figure Labels: Running tests on Person 1 and Person 2 having same skin tone.

In calculating the HR, tests are done later in parallel with another application to ensure the accuracy of the measurement. Error variation detected from 1.0 – 5.0 %, but it is hard to detect errors in this process, as these can be a result of the intrinsic ones. The tests performed on the subjects belong to the Indian subcontinent. One more study suggests that the heart rate can be affected by fitness. The more obese a person is, the higher the chances of heart rate rising. Because the cardiac cycle maintained by the veins in our forehead upholds more stress in flowing the blood. When the mean is observed between the two subjects, they vary. And this variation is to be note on the fitness levels and no other factors.

TABLE II. Heart Rate Tests

Number	**Experiment Results**		
	Subject	***Observations (5)***	***Error (%)***
1	Person A	76.2	~ 1.2
		75.6	
		73.8	
		77.4	
		78.0	
2	Person B	85.2	~ 4.2
		77.4	
		85.8	
		80.4	
		76.2	

V. CONCLUSION

A real time noncontact-based heart rate method is described in this paper using facial video of a subject, which is easy to implement, cost effective and comfortable in real time applications. The main idea is to determine heart rate using from the color variation in the foreskin of a subject who is completely still or slightly moving, though any of those factors will not affect the process. With sufficient ambient light, the experiment works. Comparison of our experiment is done with other applications to strengthen our case of using rPPG. Though many variations observed in the procedure, the results are similar, precise and notable. The noncontact technology in the last two decades has been noted by many scholars and many improvements had taken place. The most promising sector for such applications to work would be medical, road safety, security. Also, to increase the accuracy of the application would involve only making more observation in different scenarios and other verifying systems. Creating a real-time, multi parameter application with different technological improvements will be the subject of future work.

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