Photoplethysmography based Heart Rate Calculation using Fingertip Video Captured by Smartphone

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Chapter 1

Introduction

1.1 Overview and Motivation

Vital signs such as heart rate, respiratory rate, blood pressure, body temperature etc. are group of $4-6$ most important physiological measurements that indicate the persons health condition. So, monitoring of vital signs is essential for timely detection of diseases. Heart Rate (HR) is the speed at which heart makes contraction to pump the blood through the body. Heart rate varies from person to person depending on many factors such as age, fitness, health conditions, state of body i.e. whether they are relaxing, sleeping, exercising, working etc. According to National Institute of Health the average resting heart rate is for children 10 years or older and adults is $60-100$ bpm (Beats per minute) and for well trained athlete it is $40-60$ bpm [1]. Heart Rate indicates health and proper functioning of heart. Heart Rate measurement can be helpful for diagnosing tachycardia, bradycardia, cardiac arrest and many other heart diseases. Since, Heart Rate provides information about ones cardiovascular health and fitness, it is important to monitor heart rate during day to day life [2].

There are many different techniques and commercial products available for the Heart Rate measurement. Pulse oximeters, Wrist Bands, ECG machines etc. are commercially available products. These days, Smartphones are becoming quite popular, they have increased processing power, better wireless connectivity and many sensors. Smartphones cameras have become more powerful which has potential application for monitoring the heart rate. People have developed many Applications for smartphones for the measurement the Heart Rate for example, Instant Heart Rate, iCare health monitor, iHealth Monitor etc. These applications show the potential of smartphones as low cost, portable physiological measurement solution [3].

1.2 Photoplethysmograph

The smartphone camera uses the subtle color change of the skin during the cardiac pulse for measuring the heart rate which is similar to pulse oximeters. These technique is called the Photoplethysmograph (PPG). Photoplethysmography (PPG) is a non-invasive, low cost electro-optical technique for the detection of the blood volume changes during a cardiac cycle. For recording the PPG signal generally light is incident on body part under testing and change in the reflecting light is recorded. Because of cardiac pulse, blood volume changes and light absorbed by the skin also changes, which is reflected in PPG signal. Basically, PPG reflects the interaction of the photons and hemoglobin in the blood during the cardiac cycle.Figure 1.1 shows the typical PPG signal acquired from finger tip using pulse oximeter. Imaging PPG (iPPG) uses the high resolution digital cameras for the detecting change in skin color because of the blood volume change. Smartphones having high resolution camera and LED flash now a day, can be used for the Imaging PPG. Since, PPG or iPPG is related to Cardiovascular activity, it is possible to extract heart rate from the PPG signal. PPG measurement generally uses the red or infrared wavelengths light [4].

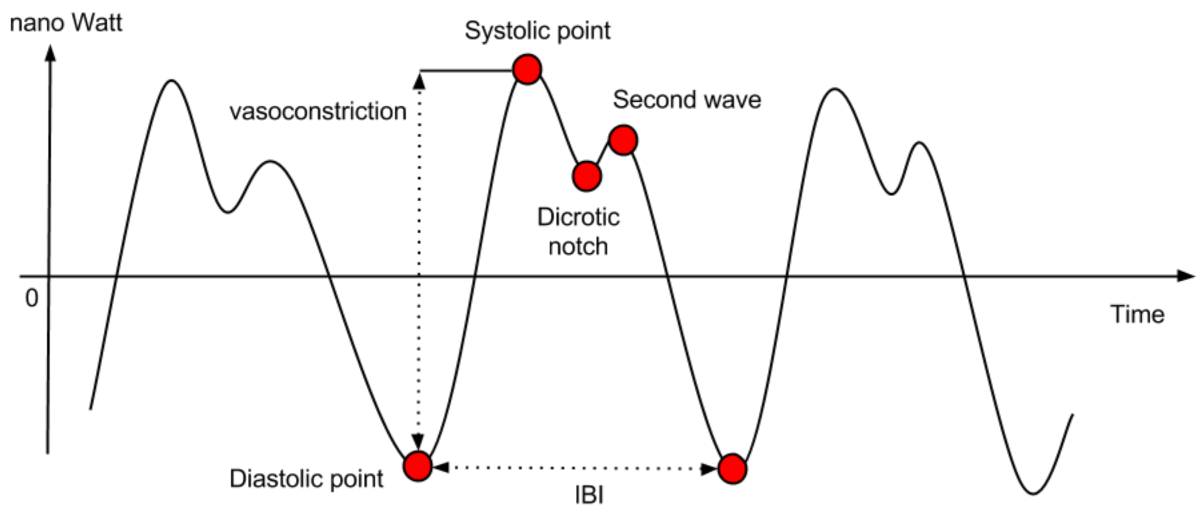


Figure 1.1: Sample PPG Signal [5]

There are two methods for the measuring the PPG signal i.e. transmission mode and reflective mode. As shown in Figure 1.2, In Transmission mode, light is passed through finger tip or ear lobe and response is recorded from the other side of the body part, hence named transmission mode. In reflection mode, Light is incident on tissue using LED and response is recorded with the Photo Diode from the same side.

1.3 Project Objectives and Challenges

In the light of the discussion above, the project will focus on investigating and developing program for the Heart Rate measurement using fingertip video recorded from smartphone camera. Processing of the video will be done in few steps using Histogram details and Thresholding on video frames. There are numerous challenges as listed below that needs to be addressed for the correct measurement.

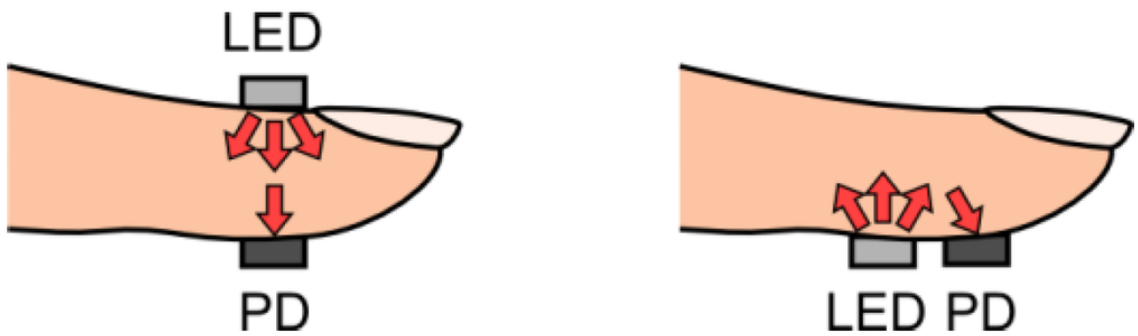


Figure 1.2: Transmission Mode PPG acquisition and Reflective mode PPG Acquisition [6]

1. PPG measurements are very sensitive to subjects tissue and/or movement artifacts. Making system resilient against these artifacts and variations is non trivial task [4].
2. Verifying correct usage of camera under good lighting conditions is difficult task.
3. Since, Every Smartphones have different Saturation and Sensitivity, making system invariable across different smartphone platforms is also challenging.

Chapter 2

Literature Review

There have been many developments in measuring heart rate measurement using different techniques. Many applications are available for smartphones commercially. Such as Instant Heart Rate, Heart Rate Tester, Pulse Rate monitor etc. But they only provide good results in certain conditions. In addition, there is no comparison available against medical devices. So, these applications should only be used as references not as medical tool [4].

Papon et.al. experimented with several top applications available in market did a survey on their accuracy [2].

Pelegris et.al. proposed a technique based on the gray scale intensities of every frames [7].

Jonathan and leahy shows that green channel provides better estimate than red one. They selected 10×10 pixels area as region of interest to compute mean intensity value and calculated Fourier transform to evaluate heart rate [4, 8].

Fu et.al. reported that 6-level multi resolution analysis obtained from wavelet transform can effectively extract HR with 97% accuracy [9].

Kwon et.al. developed program called FACEBeat to extract heart rate from facial video [3].

Scully et.al. developed a program calculating PPG values as average of 50×50 pixel window on green channel as region of interest [10].

Most of the research work dealt with testing specific smartphone mode and did not refer to problem of movement artifacts. Kurylyak et.al. reported that distribution of pixels in either green or blue channels is not uniform for different smartphones.Only the red channel distribution remains relatively invariant across all smartphones [11]. Many of the prior work, does not address the issue of invalid usage or improper alignment of finger on camera lens. So, the propose of this project is to address these two issues.

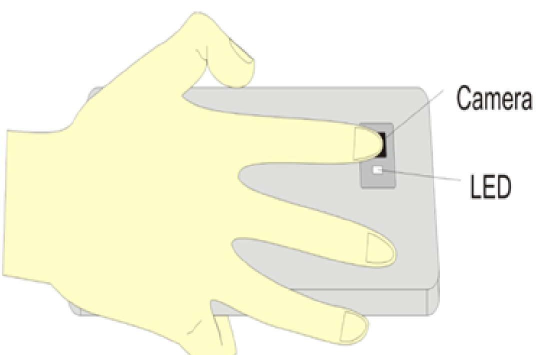
Chapter 3

System Overview

This section provides description of the algorithm, methods and data sets used.

3.1 Data

For this project 6 volunteers were asked to participate in data collection. They held their fingertip on camera lens and Video was recorded first without LED flash light for 10 seconds and then with LED flash light for 10 seconds. Volunteers were asked to keep their finger steady and pressing tip on camera lens without additional force. Video with LED flash light data was considered as Reflective mode PPG data and Video without LED flash light was considered as Transmission mode PPG data. Data was collected with 6 different smartphones i.e.̃iPhone 5, iPhone 6, Nexus6, Samsung Galaxy Grand, LeEco Le 2, Motorola G3. At the end, Volunteers were asked to measure their heart beats using their first two fingers from their wrist artery for 10 seconds for collecting actual Heart Rate Measurement for comparison.



(a) The Way Video was recorded from Smartphone

(b) How actual HR was measured

Figure 3.1: Data Collection [12]

3.2 System Flow

Figure 3.2 shows the flow chart of the system. As shown in flow chart for correct measurement, there are basically three steps i.e. 1. Correct usage verification, 2. Calibration stage, 3. Measurement. Following sections explains how these steps have been implemented.

3.2.1 Correct usage verification

Correct usage verification decides whether the data collected is using with LED or without using LED. It also checks whether the person has put his/her finger properly on camera lens or not. It also imposes certain lighting conditions for measurement. For the implementation of this step in this project, 9 different rules and fixed values for different parameters given by Lamonaca et. al. were used [12]. Table 3.1, lists these rules.

Table 3.1: Rules and Values for different parameters used for correct usage verification [12]

When LED is Used	When LED is not used	Fixed Values used in project
$mean(G) - \sigma_G \leq G_{LEDmin}$	$mean(G) + \sigma_G < G_{NOLEDmax}$	$G_{LEDmin} = 10$
$mean(R) - \sigma_R \geq R_{LEDmin}$	$mean(B) + \sigma_B < B_{max}$	$R_{LEDmin} = 128$
$mean(G) + \sigma_G \leq G_{max}$	$mean(R) > R_{NOLEDmax}$	$G_{max} = 128$
$\sigma_R, \sigma_G, \sigma_B < \sigma_{max}$	$\sigma_R, \sigma_G, \sigma_B < \sigma_{max}$	$B_{max} = 128$
$mean(B) + \sigma_B < B_{max}$		$\sigma_{max} = 40$
		$G_{NOLEDmax} = 10$
		$R_{NOLEDmin} = 10$

Here, $mean(G), mean(R), mean(B)$ are the mean value of the RGB color spaces for each frame. $\sigma_R, \sigma_G, \sigma_B$ are standard deviation of the intensity values for each color space. $_max$ is the maximum allowed deviation. $G_{NOLEDmax}$ is the maximum value of green channel allowed when LED is not used. $R_{NOLEDmin}$ is the minimum intensity value for red channel when LED is not used. R_{LEDmin} and G_{LEDmin} are minimum intensity values for each frame when LED is used. Similarly, G_{max} and B_{max} the maximum intensity values allowed for each frame.

These rules follow from Histogram analysis of each frame across different smartphones. According to [12] For most of the smartphones while recording data with fingertip on camera lens, if LED is on, then Green and Blue channel intensity values are lower half of the histogram i.e. less than 128. If LED is off, then Green and blue channel intensity values are close to zero in histogram. Hence, method of use, whether the LED is used or not can be detected with above rules. These rules also encapsulate typical range of value when finger is placed properly on camera lens. Hence, Verifies the proper alignment of finger. For the calculation of the PPG values red channel values will be used, because it remains significantly invariant across different smartphones [12].

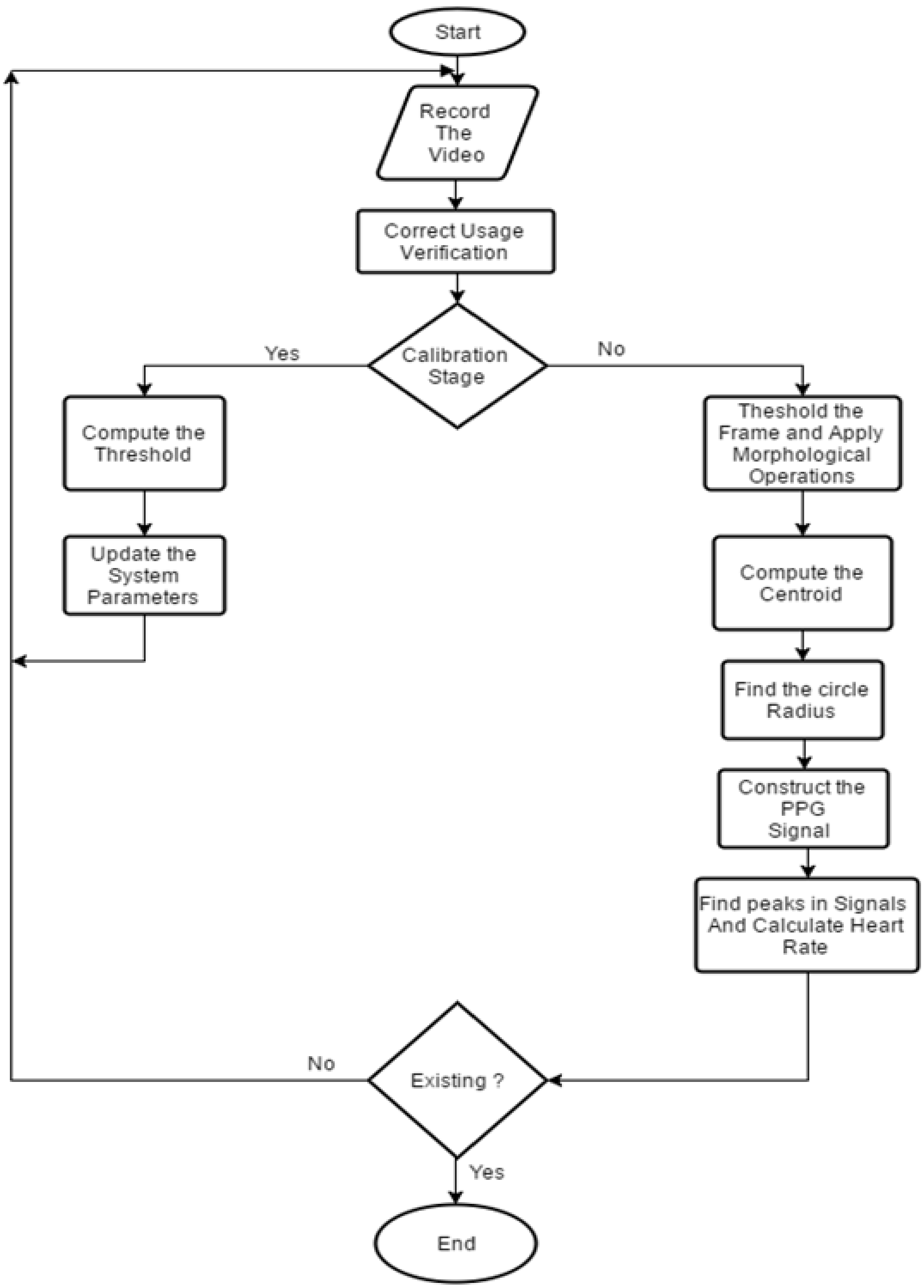


Figure 3.2: Flowchart of the system [4]

3.2.2 Calibration

This step calculates the Threshold for the Video Frames. Algorithm finds the 80% quartile of the intensity values of Red channel for first 10 seconds or 150 Video frames and takes its average to determine the threshold. Here, Algorithm basically decides the window for the PPG value computation based on the intensity values rather than fixed $A \times A$ window, which in effect helps to make system robust across different smartphone platforms. Threshold can be defined mathematically as follows,

$$T = mean(T_i), \quad where(T_i) : \frac{\| value(P_i) \leq T_i \|}{\| P_i \|} = 0.8 \tag{3.1}$$

Here, T_i is the computed threshold for the frame i, P_i is the array of red channel pixels for the frame i, $val(P_i)$ is the value of each pixel in P_i, $\| \cdots \|$ is the number pixels in the array [4].

3.2.3 Measurement

For the measurement of the PPG values, we can employ various methods. To calculate PPG values, for every captured red channel frame, they were passed through threshold mask, which creates the binary image based on whether the pixel value is above threshold or below threshold. In this binary image, non-zero pixels creates the Region of Interest (ROI). This ROI generally has the circular shape. We can find PPG value from this ROI using many methods. First is to calculate number of non-zero pixels, which will vary during cardiac cycle and from frame to frame. Second is we can find centroid of ROI and measure the radius of circle as distance from Centroid to nearest zero pixel. Centroid is defined as follow,

$$C_X = \frac{\Sigma X_n}{n}, \qquad C_Y = \frac{\Sigma Y_n}{n} \tag{3.2}$$

Where C_X and C_Y denotes the coordinates of the centroid in binary image, x_n, y_n are the coordinates of each pixel with value 1 binary image, and n is total number of such pixels [12]. Third method is to use Hough Transform for finding the radius of the ROI. Experiments were done with all three methods. Since, Boundary of ROI wasnt very definite, Hough transform did not give good results. Chapter 4, shows the results with other two methods. For the heart rate in BPM, Number of peaks in PPG signal were used to calculate HR. All these processing was done in MATLAB using its inbuilt functions.

Chapter 4

Results and Discussion

Steps for measuring the HR from fingertip video were outlined in previous Chapter. All those steps were implemented on MATLAB 2016a. Total, 22 Videos of different lengths from 6 different smartphones and 6 different people have been tested. Results are as follows.

4.1 Correct usage verification Results

Correct usage verification is required to check whether the LED was used or not when recording the Video. Correct usage verification program was implemented on MATLAB using 9 rules outlined in section 3.2.1. In Table 4.1, correct usage identification is marked as green while incorrect is in red.

4.2 Calibration

Threshold values were calculated as mean of the 80% quartile from the first 150 red channel frames for both LED and NON-LED part.

4.3 Measurement

For constructing the PPG signal and measurement of HR, two methods were followed, summing the Non Zero values in Binary Image After applying threshold and second method is to find the radius of the ROI. Though results in only includes results from Radius of ROI method. This was done using steps given in section 3.2.3 and was implemented using MATLAB. Figure 4.2, shows the variations in radius and PPG value for first few frames and corresponding Radius Values. Figure 4.3, shows the sample PPG signals constructed using radius method.

Table 4.1: Results of the correct usage verification rules

Subject	Phone	LED /NOLED	Duration (Seconds)	Totol Number of Frames	LED Frames Detected	NOLED Frames Detected	Incorrect Frames
1	Le 2	LED	10.24	245	245	0	0
1	Le 2	NOLED	10.09	241	0	241	0
1	Le 2	LED	30.91	741	741	0	0
1	Le 2	NOLED	31.53	754	294	454	6
2	Le 2	LED	10.30	246	246	0	0
2	Le 2	NOLED	10.83	259	259	0	0
3	Le 2	LED	10.56	252	252	0	0
3	Le 2	NOLED	10.7570	258	258	0	0
4	Le 2	LED	10.77	257	0	0	257
4	Le 2	NOLED	11.5410	276	0	0	276
5	Le 2	LED	10.8580	259	259	0	0
5	Le 2	NOLED	10.77	258	0	258	0
1	Le 2	LED	16.1920	386	386	0	0
1	Le 2	LED	11.050	265	265	0	0
6	iPhone 5	LED	11.3067	339	339	0	0
6	iPhone 5	NOLED	12.3067	369	139	0	230
3	Grand	LED	10.99	324	324	0	0
3	Grand	NOLED	11.200	331	331	0	0
4	G3	LED	10.1760	241	0	0	241
4	G3	LOLED	10.3900	247	0	247	0
5	Nexus 5	LED	10.3130	301	301	0	0
5	Nexus 5	NOLED	10.6030	310	4	0	306

Table 4.2: Accuracy of Correct Usage Rules/Algorithm

Total Number of Vidoes	20
Correct Identification	14
Incorrect Identification	8
Accuracy	64%

Table 4.3: True/False Detection Accuracy

LED is used	Number of Videos with LED used = 12	Detected as LED True Detection	10	84%
		False Detection as NO LED	0	0.00%
		Rejected as incorrect	2	16.67%
NO LED	Number of NOLED Videos= 10	Detected as NO LED: True Detection	4	40.00%
		False Detection as NO LED	3	30.00 %
		Rejected as Incorrect	3	30.00%

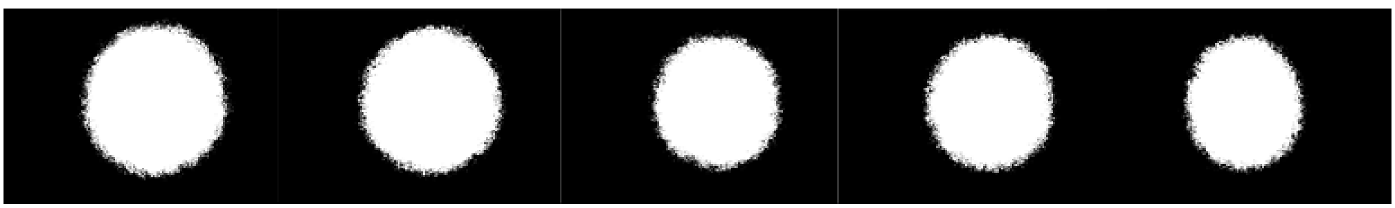


Figure 4.1: Variations in first Five frames after Thresholding

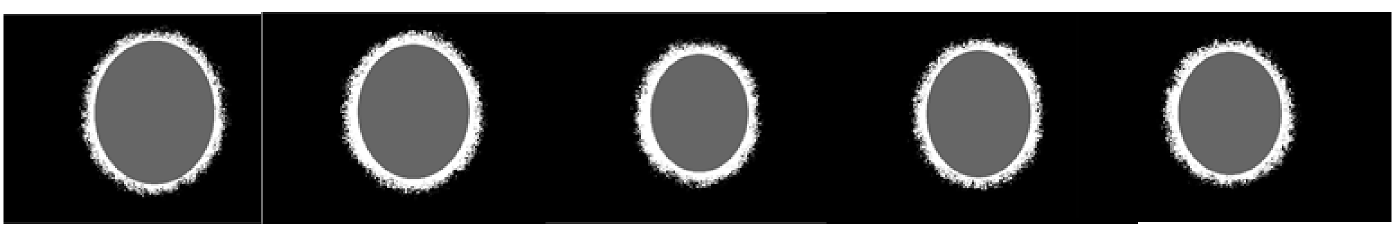


Figure 4.2: Circles and its radius used to compute PPG values

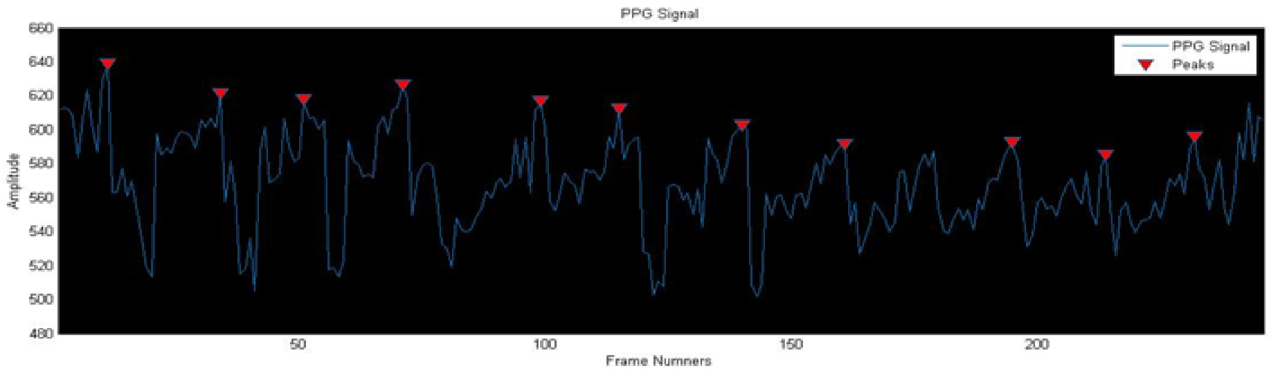


Figure 4.3: Sample PPG signals constructed using radius of ROI method and its peaks

Table 4.4: Heart Rate measured using Radius of ROI from videos of NO-LED Data from Le 2 phone and iPhone 5 for subject 6

Subject	Measured Heart Rate in BPM	Actual heartrate in BPM	Difference
2	66	65	1
4	78	72	6
3	54	78	24
1	72	80	8
6	72	76	4
5	60	75	15

Chapter 5

Conclusion

In this project, Various methods for constructing PPG signals i.e. Radius of ROI, Sum of all the non-zero values in binary image after Thresholding, Hough transform were implemented. We found that Hough transform cannot be used since, boundaries of the ROI were very indefinite and results obtained were false. Radius of ROI method can only be used on NO-LED data, since in LED data, Threshold was very high and binary image showed no significant variations in Radius of ROI. Sum of non-zero values can be used to calculate PPG Values in LED data, but it requires experimentation. Things need to be addressed in future,

- Motion Artifacts
- Smartphone platform invariability

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