Assignment 2: Performing Heart Rate and Blood Pressure Sensing Using Smartphone Data

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Cardiovascular diseases (CVDs) such as ischaemic heart disease account for 17.7 million deaths in India. Regular monitoring of physiological indices such as heart rate, haemoglobin, oxygen saturation, and blood pressure can lead to early intervention and more effective treatments. This assignment demonstrates how smartphones can measure pulse rate and show the challenges obtained in estimating the relative blood pressure measurement. A total of eight participants volunteered to participate in the pulse rate measurement experiment. The Mean Absolute Error (MAE) for pulse rate measurement was 1.95 beats per minute.

Additional Key Words and Phrases: ppg, heart rate, optical mouse

ACM Reference Format:
Rishiraj Adhikary. 2021. Assignment 2: Performing Heart Rate and Blood Pressure Sensing Using Smartphone Data. In . ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/1122445.1122456

1 INTRODUCTION

Cardiovascular diseases (CVDs) such as ischaemic heart disease account for 17.7 million deaths in India. The Global Burden of Disease study results states an age-standardized CVD death rate of 272 per 100000 population in India, which is much higher than that of the global average of 235 [4]. Frequent monitoring of physiological parameters such as heart rate at home has been shown to improve the management of CVDs effectiveness of treatments [6]. The combination of a smartphone camera and flash LED to measure the blood pulses from the fingertip, known as photoplethysmograph (PPG), is a well-established technology. A PPG is often obtained by illuminating the skin and measuring changes in light absorption. Various research projects [2, 3, 5] have also explored the use of smartphone cameras with their IR filter removed to perform pulse oximetry, using a custom set of red and infrared LEDs to illuminate the fingertip of a patient and the camera to measure the pulse at the finger under different illuminations.

In this assignment, I demonstrate how we can use the smartphone camera and flash to monitor pulse rate by deriving the PPG waveform. Furthermore, I investigated how accelerometer data can be synced with the PPG waveform to deduce relative changes in diastolic blood pressure.

2 APPROACH

In this assignment, I started with two objectives; the First was to estimate the pulse rate from the PPG waveform recorded via a smartphone camera. The second was to estimate the blood pressure by combing the accelerometer data with the PPG waveform.

2.1 Estimating Pulse Rate

The steps in estimating pulse rate are as follows.

Ubicomp Class '21, Semester 1, 2021, Gandhinagar, India

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM. . . $15.00
https://doi.org/10.1145/1122445.1122456

(1) I used the Samsung Galaxy M10 smartphone to record a 10s to a 15-second video clip with flash on. As shown in Figure 1, I asked the participants to place their index finger in such a way so that the finger covers the camera and the flash.

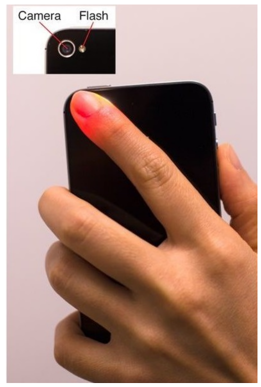

Fig. 1. A representational image [1] demonstrating how the video clips were recorded.

(2) While recording the video, the other hand's index finger was put inside a Pulse Oximeter (Dr Trust Professional Series Finger Tip Pulse Oximeter). I noted the pulse rate as reported by the pulse oximeter. Here, I assumed that the pulse rate obtained from the oximeter was the ground truth.
(3) I used OpenCV in Python to convert the video clip into a 4-dimensional Numpy Array. The first dimension represents the number of frames in the video clip. A 10second video clip consisted of a little more (due to milliseconds) than 300 frames. The second and the third dimension represents the height and width of the frame. The last dimension, which equals 3, represents the three-channel, i.e. Red, Blue and Green.
(4) cropped each frame of the video. The objective of cropping the video was to reduce computational complexity.
(5) According to prior literature, the red channel of a frame has the highest amplitude difference when blood leaves and enters an arterial site (index finger). I decided to use only the red channel information for further analysis. At this point, the 4-dimensional matrix was reduced to 3 dimensions.
(6) I took the average sum of all pixels for each frame and stored it in a list. This step reduced the 3-dimensional matrix into a one-dimensional vector. The one-dimensional vector, when plotted, represents the PPG waveform.
(7) To denoise the PPG waveform, I further applied a gaussian filter. Experimental results showed that the Gaussian filter gives a better result compared to a low pass filter.
(8) A standard peak detection algorithm was applied to the filtered PPG waveform. The number of peaks in a minute gave us the estimated pulse rate.

2.2 Estimating Blood Pressure [7]

Blood pressure can be estimated by deducing the Pulse Transit Time (PTT). Prior research has shown that the diastolic Blood Pressure is inversely related to the PTT. Although it is impossible to obtain the absolute value of pressure, a relative pressure difference can be estimated from the PTT.

Pulse transit time is the time the heart's pulse takes to propagate between two arterial sites, which is inversely related to BP. PTT can only estimate relative changes in blood pressure (diastolic), i.e., an absolute measure of

PTT cannot be extrapolated to an absolute measure of BP.

Seismocardiogram (SCG) is the recording of body vibrations induced by the heartbeat. As the blood leaves the heart, the valve opening in the heart causes the muscle to vibrate. An accelerometer can capture this vibration below the pectoral muscles on the sternum or above the pectoral muscles and below the clavicles. The SCG is measured using the accelerometer Y-axis data (along with the height of the phone), and the PPG is measured using the camera data. Figure 2 shows how PTT can be estimated from SCG and PPG.

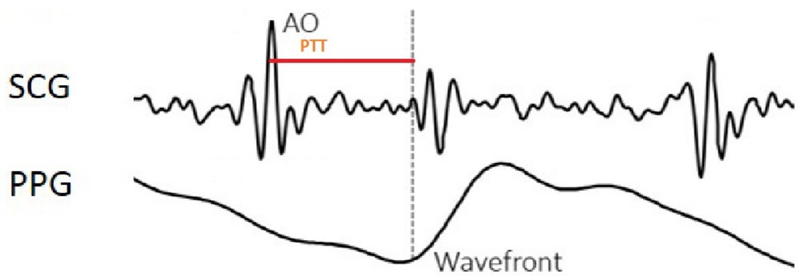

Fig. 2. PTT is measured as the time taken between aortic valve opening (AO) and the trough of the PPG waveform. The figure is modified and the actual figure is taken from prior literature [7]

The following points describe the steps followed to obtain the estimated BP measure.

(1) I configured the MATLAB mobile application to collect accelerometer data at a 100Hz sampling rate.
(2) While the application started recording accelerometer data (to obtain SCG), I switched the camera in video mode with flash on to record simultaneous video data to obtain the PPG.
(3) Both the data were time synched manually in Python by matching the start time.

3 EVALUATION AND RESULT

3.1 Estimating Pulse Rate

Eight participants consented to record their PPG and underwent a ground truth oximeter test. Table 1 shows the error in pulse rate obtained for all the participants. Figure 3 shows the PPG waveform for all the participants. The Mean Absolute Error (MAE) was 1.95. I observed that whenever some participants (Participants 5 and 6) press too hard on the camera and the flash, the resultant PPG waveform diminishes in amplitude. The low amplitude can be attributed to a change in blood flow due to physical stress on the finger.

3.2 Estimating Pressure

I could not obtain any relative pressure as the aortic valve opening (AO part of the SCG) was not visually evident. Figure 4 shows one of five attempts to obtain SCG and PPG. Holding the phone into the chest and performing an SCG manoeuvre is challenging as any participant would tend to tilt the phone along. There could be multiple reasons why a proper SCG waveform was not observed.

(1) **Lower Sampling Rate:** MATLAB mobile sampled the accelerometer data at 100Hz, whereas in prior literature, the accelerometer was sampled at 400Hz.
(2) **Wrong Placement:** Prior literature states that muscle and fat tissue will result in noise in the SCG waveform. Coupled with a lower sampling rate, the SCG waveform could appear as noise even for lower fat

Participant ID	Sex	Predicted Pulse Rate (Per Minute)	Oximeter Reported Heart Rate (Pulse Minute)	Absolute Difference
0	M	69.86	68	0.96
1	M	68.30	68	0.3
2	F	70.51	72	1.49
3	M	73.97	72	1.97
4	M	71.92	72	0.08
5	M	78.78	74	4.78
6	F	77.77	73	4.77
7	M	78.25	77	1.25
			Mean Absolute Error	**1.95**

Table 1. Demographic of participants who underwent user-study. The ground truth was first taken using a Oximeter, followed by PPG test via a smartphone.

tissue participants. It is not trivial to identify pectoral muscles on the sternum or pectoral muscles below the clavicles.

It is thus important to experiment with an accelerometer of a higher sampling rate. A trained medical professional can only make identification of right placement which corresponds to the aortic valve.

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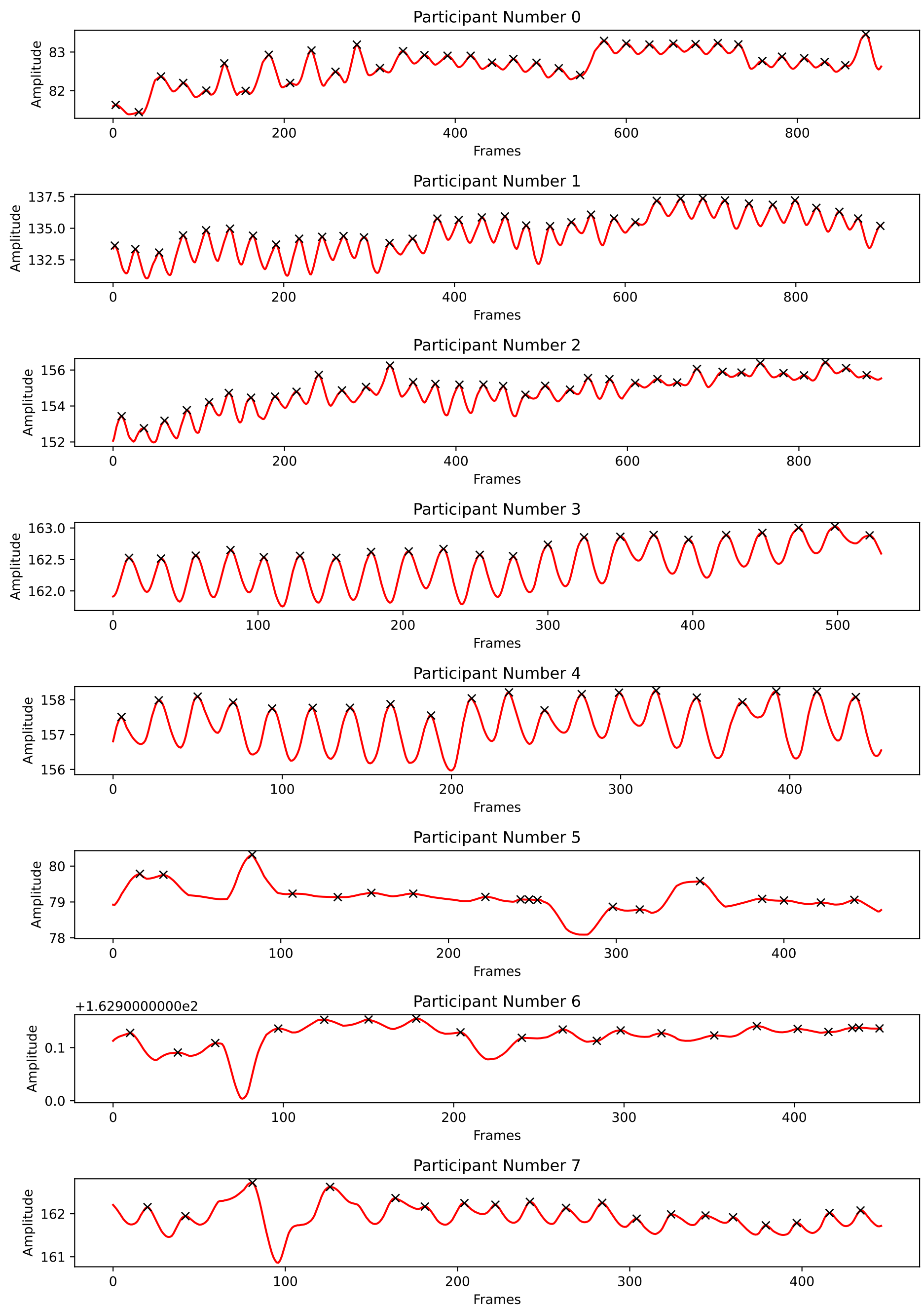

Fig. 3. PPG waveform obtained across different participant. Observe that the PPG waveform is low in amplitude for participant 5 and 6 as the amplitude depends on the pressure put the camera. The amplitude varies per person and hence it was not normalised across each participants.

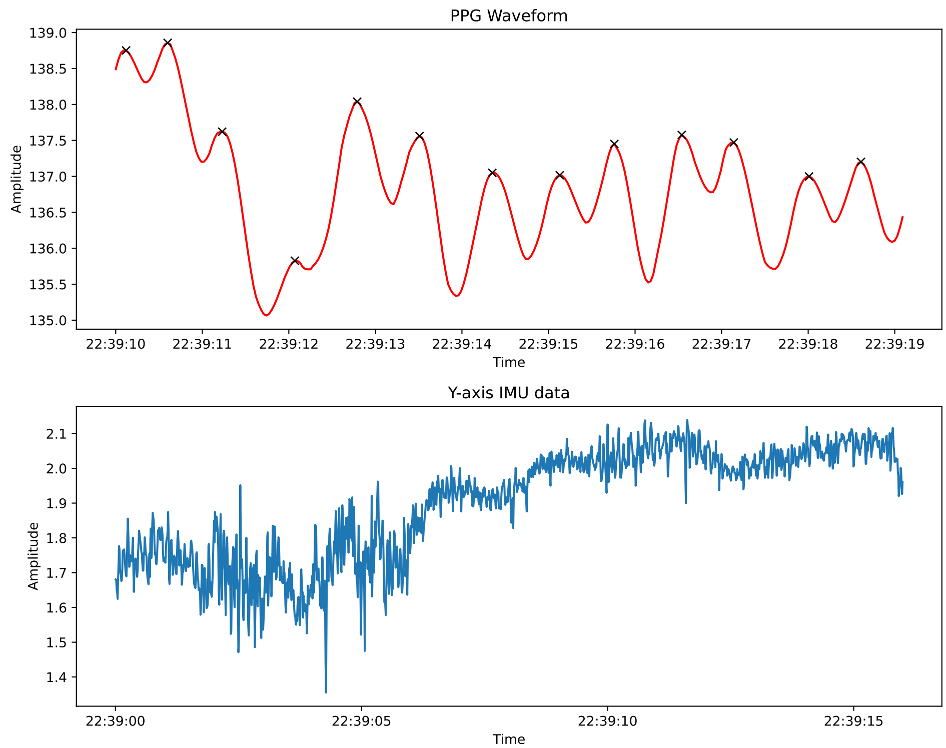

Fig. 4. The red curve shows the PPG and the blue curve shows the accelereomter data obtained. The accelerometer data does not corresponf to a SCG waveform and is nowhere close to what was shown in Figure 2. Even the PPG waveform is impacted due to the difficulty in holding the phone in a certain manner.