COMPARISON OF HEART-RATE VARIABILITY (HRV) BETWEEN ECG AND PPG

Aim:

To compare the Heart-Rate Variability (HRV) of the subject recorded using ECG and PPG

Objective:

- To record synchronized ECG and PPG signals from the subjects during sitting, supine and standing posture
- To estimate heart rate variability from both ECG and PPG measurement
- To compare the measurements of heart rate variability for both modalities

Apparatus required:

1. ECG - PPG sensor (pc max86150, Company: Protocentral)
2. Genuine Arduino Uno R3
3. MATLAB

Introduction:

Heart rate is the number of heart beats per minute. Heart rate variability (HRV) consists of changes in the time intervals between consecutive heartbeats called inter-beat intervals (IBIs). Even a healthy heart does not have constant IBI. The oscillations of a healthy heart are complex and constantly changing, which allows the cardiovascular system to rapidly adjust to sudden physical and psychological challenges to homeostasis.

HRV is the fluctuation in time intervals between adjacent heartbeats, it indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system (ANS) processes.

Theory:

HRV is an emergent property of interdependent regulatory systems which operate on different time scales to help us adapt to environmental and psychological challenges by stimulating and regulating some vascular component of the allostasis: HRV reflects regulation of autonomic balance, blood pressure (BP), gas exchange, gut, heart, and vascular tone, which refers to the diameter of the blood vessels that regulate BP, and possibly facial muscles.

Higher HRV is not always associated to better state of health of the subjects, numerous diseases affect the HRV and have the potential to increase this value. When cardiac conduction abnormalities cause an increase in the HRV, this is strongly linked to increased risk of mortality, particularly among the elderly (e.g. causing atrial fibrillation).

Faster HRs reduce the time between successive beats and the opportunity for the IBIs to vary. This lowers HRV. Conversely, slower HRs increase the time between adjacent heartbeats and the chance for IBIs to vary. This raises HRV. This phenomenon is called cycle length dependence. Resting HRs that exceed 90 bpm are associated with elevated risk of mortality.

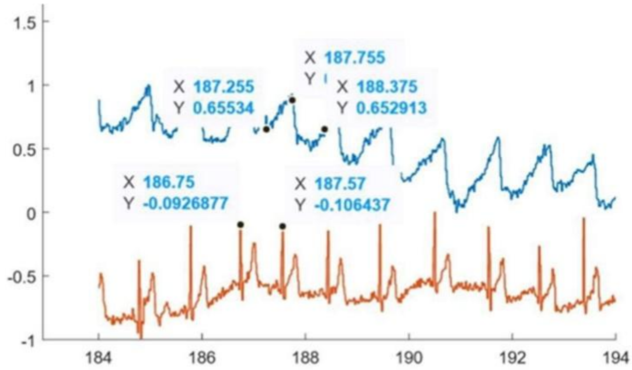

Figure 1: Representation of ECG (Orange) and PPG (Blue) Waveforms

Method:

For ECG and PPG measurement

1. The MAX86150 from Maxim rolls three devices into one for easy measurement of vital signs: an ECG frontend, an optical pulse oximeter, and an optical heart rate sensor
2. Clean the skin surface of the left-hand fingers
3. Put one finger on the PPG sensor. Put one finger from the right and left hand on the ECG electrode, as shown in the figure

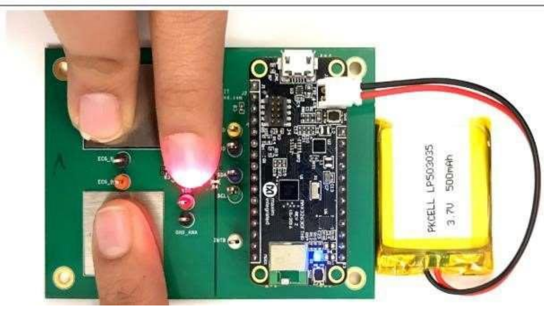

Figure 2. Finger Placement for ECG and PPG Measurement

4. Record the data using Arduino IDE
5. Keep sample rate on 200 ms and analyze the data using MATLAB
6. Record signal for 5-minute period

Standard Deviation of the Normal-to Normal (SDNN):

The SDNN is the standard deviation of the normal (NN) sinus-initiated IBI measured in milliseconds. This measure reflects the ebb and flow of all the factors that contribute to heart rate variability (HRV).

Root Mean Square of Successive Differences (RMSSD):

The root mean square of successive differences between normal heartbeats (RMSSD) is obtained by first calculating each successive time difference between heartbeats in ms. Then, each of the values is squared and the result is averaged before the square root of the total is obtained. The RMSSD reflects the beat-to-beat variance in HR and is the primary time-domain measure used to estimate the vagally mediated changes reflected in HRV.

pNN50:

pNN50 is defined as the proportion of differences of successive inter-pulse intervals exceeding 50 ms. This was derived by dividing the number of pulse duration exceeding 50 ms by the total number of inter-pulse intervals in the recorded signal.

Results:

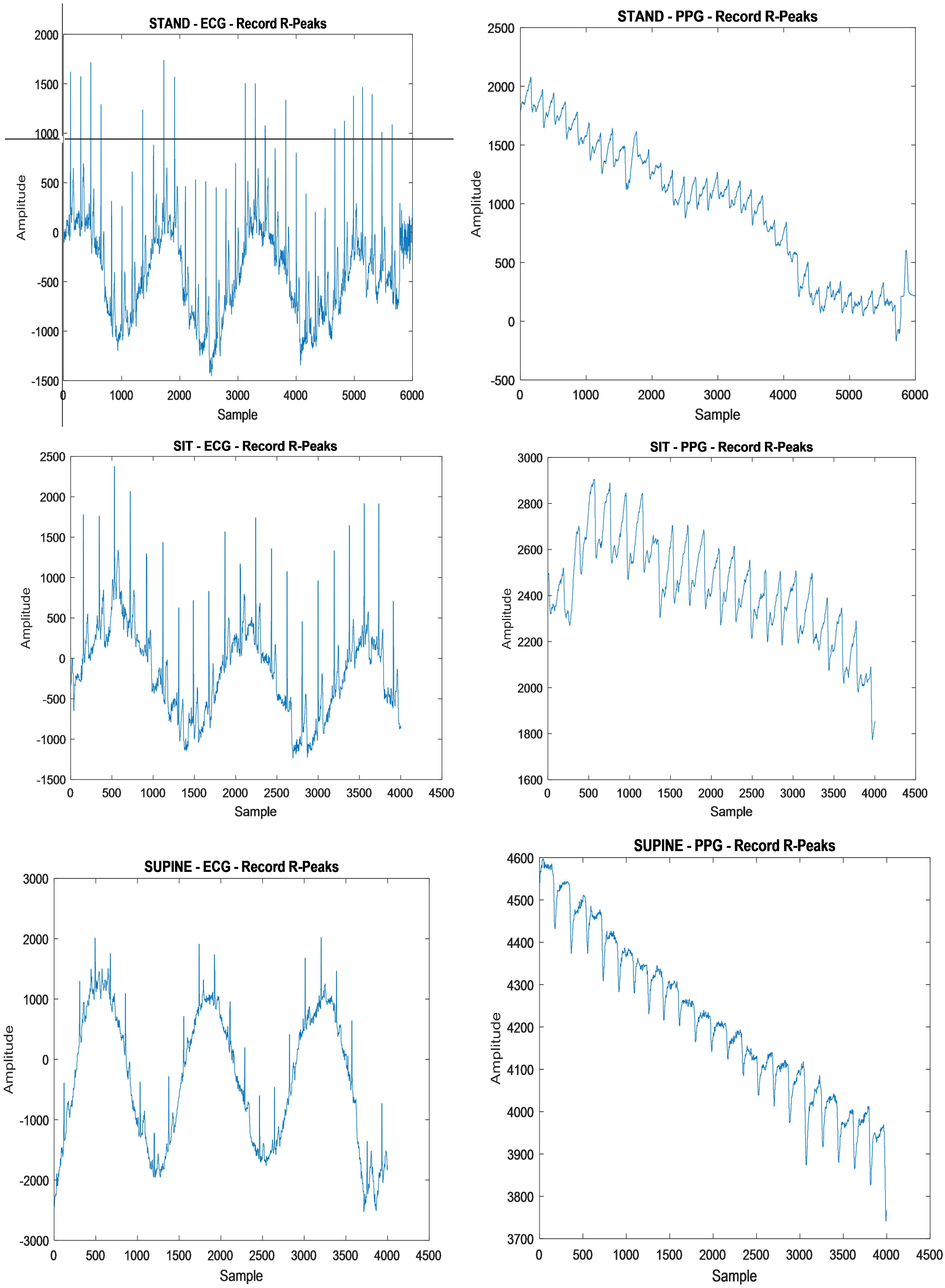

Figure 3: Data recorded plotted from MATLAB.

Activity	Features	Measurement from ECG		Measurement from PPG	
		Heart Rate	Heart Rate Variability	Pulse Rate	Pulse Rate Variability
Sitting	SDNN	60	56.02	60	79.02
	RMSSD		95.19		108.0
	pNN50		0.684		0.6315
Supine	SDNN	60	65.02	60	94.36
	RMSSD		94.8		164.5
	pNN50		0.526		0.6316
Standing	SDNN	64	138.5	46	94.89
	RMSSD		189.84		166.13
	pNN50		0.774		0.864

- Detection of change in heart rate variability with postural change
- Comparison between heart rate variability and pulse rate variability in all the postures outcomes
- The heart rate variability is sensitive to postural change
- The measurement of heart rate variability from ECG and PPG are comparable

Conclusion:

Heart Rate Variability can be estimated using both ECG and PPG, with different measurement indices. However, there is variability in the measurements from these two modalities.

Code for getting output:

```
% Clear workspace and command window
clear;
clc;

% Read data from CSV files
STAND = readmatrix('e(' E:\AM23M022_SEM2\FINAL_ADVANCED_BM_LAB\DATA\ppg&ecg_11-03-2024\dinesh-stand.csv');
SIT = readmatrix('e(' E:\AM23M022_SEM2\FINAL_ADVANCED_BM_LAB\DATA\ppg&ecg_11-03-2024\dinesh-sit.csv'');
SUPINE = readmatrix('e(' E:\AM23M022_SEM2\FINAL_ADVANCED_BM_LAB\DATA\ppg&ecg_11-03-2024\dinesh-sup.csv');

% Crop data to the first 6000 samples
STAND = STAND(1:6000, :);
SIT = SIT(7000:11000, :);
SUPINE = SUPINE(7000:11000, :);

% Plot data and record R-peaks for each posture
ECG_R_Times_STAND = plot_and_record(STAND(:,2), 'STAND - ECG');
PPG_R_Times_STAND = plot_and_record(STAND(:,3), 'STAND - PPG');

ECG_R_Times_SIT = plot_and_record(SIT(:,2), 'SIT - ECG');
PPG_R_Times_SIT = plot_and_record(SIT(:,3), 'SIT - PPG');

ECG_R_Times_SUPINE = plot_and_record(SUPINE(:,2), 'SUPINE - ECG');
PPG_R_Times_SUPINE = plot_and_record(SUPINE(:,3), 'SUPINE - PPG');
```

```
% Process data for each posture and signal type
[HR_ECG_STAND, SDNN_ECG_STAND, RMSSD_ECG_STAND, pNN50_ECG_STAND] =
process_data(STAND, ECG_R_Times_STAND, 200);
[HR_PPG_STAND, SDNN_PPG_STAND, RMSSD_PPG_STAND, pNN50_PPG_STAND] = process_data(STAND,
PPG_R_Times_STAND, 200);

[HR_ECG_SIT, SDNN_ECG_SIT, RMSSD_ECG_SIT, pNN50_ECG_SIT] = process_data(SIT, ECG_R_Times_SIT,
200);
[HR_PPG_SIT, SDNN_PPG_SIT, RMSSD_PPG_SIT, pNN50_PPG_SIT] = process_data(SIT, PPG_R_Times_SIT,
200);

[HR_ECG_SUPINE, SDNN_ECG_SUPINE, RMSSD_ECG_SUPINE, pNN50_ECG_SUPINE] =
process_data(SUPINE, ECG_R_Times_SUPINE, 200);
[HR_PPG_SUPINE, SDNN_PPG_SUPINE, RMSSD_PPG_SUPINE, pNN50_PPG_SUPINE] =
process_data(SUPINE, PPG_R_Times_SUPINE, 200);

% Display HRV metrics
disp('HRV Metrics for STAND - ECG:');
disp(['HR: ', num2str(HR_ECG_STAND), ' bpm']);
disp(['SDNN: ', num2str(SDNN_ECG_STAND), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_ECG_STAND), ' ms']);
disp(['pNN50: ', num2str(pNN50_ECG_STAND)]);

disp('HRV Metrics for STAND - PPG:');
disp(['HR: ', num2str(HR_PPG_STAND), ' bpm']);
disp(['SDNN: ', num2str(SDNN_PPG_STAND), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_PPG_STAND), ' ms']);
disp(['pNN50: ', num2str(pNN50_PPG_STAND)]);

disp('HRV Metrics for SIT - ECG:');
disp(['HR: ', num2str(HR_ECG_SIT), ' bpm']);
disp(['SDNN: ', num2str(SDNN_ECG_SIT), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_ECG_SIT), ' ms']);
disp(['pNN50: ', num2str(pNN50_ECG_SIT)]);

disp('HRV Metrics for SIT - PPG:');
disp(['HR: ', num2str(HR_PPG_SIT), ' bpm']);
disp(['SDNN: ', num2str(SDNN_PPG_SIT), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_PPG_SIT), ' ms']);
disp(['pNN50: ', num2str(pNN50_PPG_SIT)]);

disp('HRV Metrics for SUPINE - ECG:');
disp(['HR: ', num2str(HR_ECG_SUPINE), ' bpm']);
disp(['SDNN: ', num2str(SDNN_ECG_SUPINE), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_ECG_SUPINE), ' ms']);
disp(['pNN50: ', num2str(pNN50_ECG_SUPINE)]);

disp('HRV Metrics for SUPINE - PPG:');
disp(['HR: ', num2str(HR_PPG_SUPINE), ' bpm']);
disp(['SDNN: ', num2str(SDNN_PPG_SUPINE), ' ms']);
disp(['RMSSD: ', num2str(RMSSD_PPG_SUPINE), ' ms']);
disp(['pNN50: ', num2str(pNN50_PPG_SUPINE)]);

% Function to calculate HRV metrics
function [SDNN, RMSSD, pNN50] = calculate_hrv(IBI)
   SDNN = std(IBI * 1000); % Standard deviation of NN intervals in ms
   RMSSD = sqrt(mean(diff(IBI).^2)) * 1000; % Root mean square of successive differences in ms
   pNN50 = sum(abs(diff(IBI)) > 0.05) / length(IBI); % Proportion of NN50 intervals
end
```

```matlab
% Function to process ECG or PPG data
function [HR, SDNN, RMSSD, pNN50] = process_data(data, R_times, sample_rate)
    % Calculate IBI
    IBI = diff(R_times) / sample_rate; % Inter-beat interval (in seconds)
    % Calculate HRV metrics
    [SDNN, RMSSD, pNN50] = calculate_hrv(IBI);
    % Calculate Heart Rate
    HR = length(R_times) * 60 / (length(data) / sample_rate);
end

% Function to plot data and record R-peaks
function R_times = plot_and_record(signal, title_str)
    figure;
    plot(signal);
    title([title_str ' - Record R-Peaks']);
    xlabel('Sample');
    ylabel('Amplitude');
    [x, ~] = ginput(); % Use ginput to manually select R-peaks
    R_times = round(x); % Round to nearest sample point
end
```