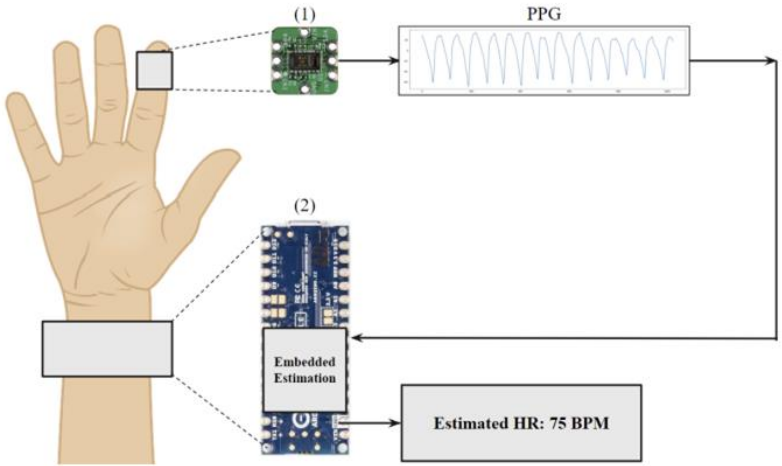
SKM 2023

Day-to-day Heart Rate Estimation with PPG for Embedded Sensor Systems

Jacob Sindorf

Table of Contents



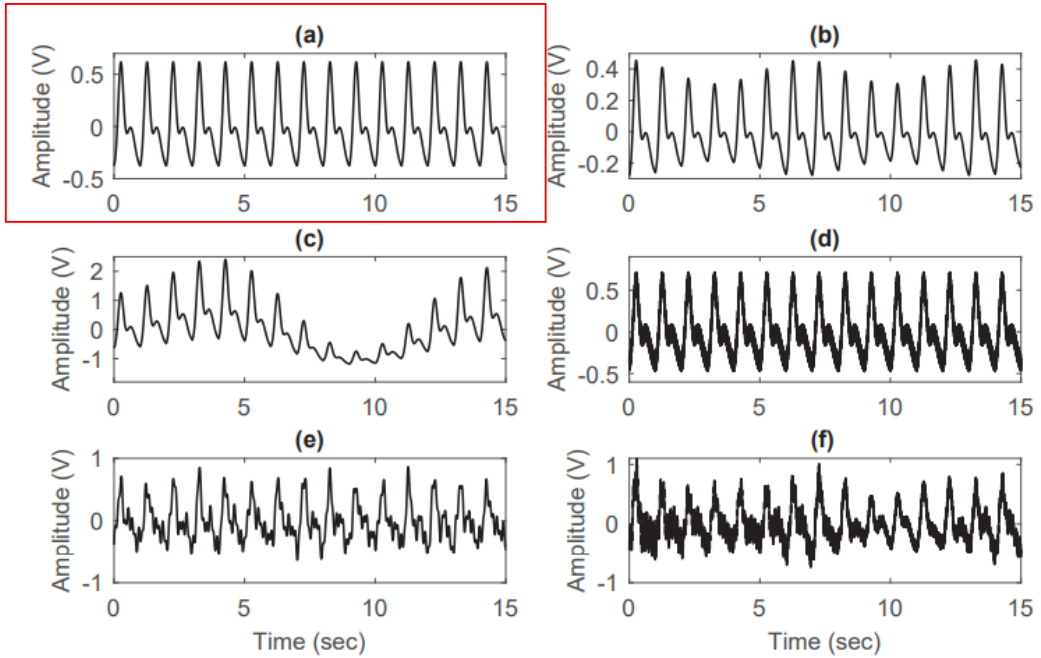
1.0

Introduction

The PPG Signal and Noise

Noise Sources:
(a) clean, *(b)* respiratory modulated, *(c)* baseline modulated, *(d)* power-line affected, *(e)* motion affected, *(f)* affected by all of the above

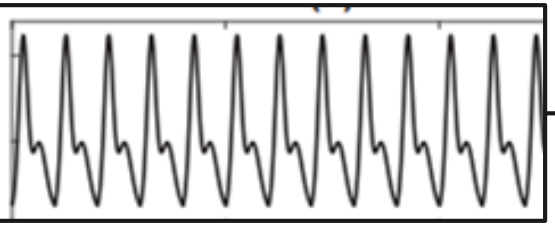
- Noise alters the signal, limiting interpretation



1. Allen et al. 2021, Photoplethysmography

HR Estimation Equations

Clean PPG



HR Equations

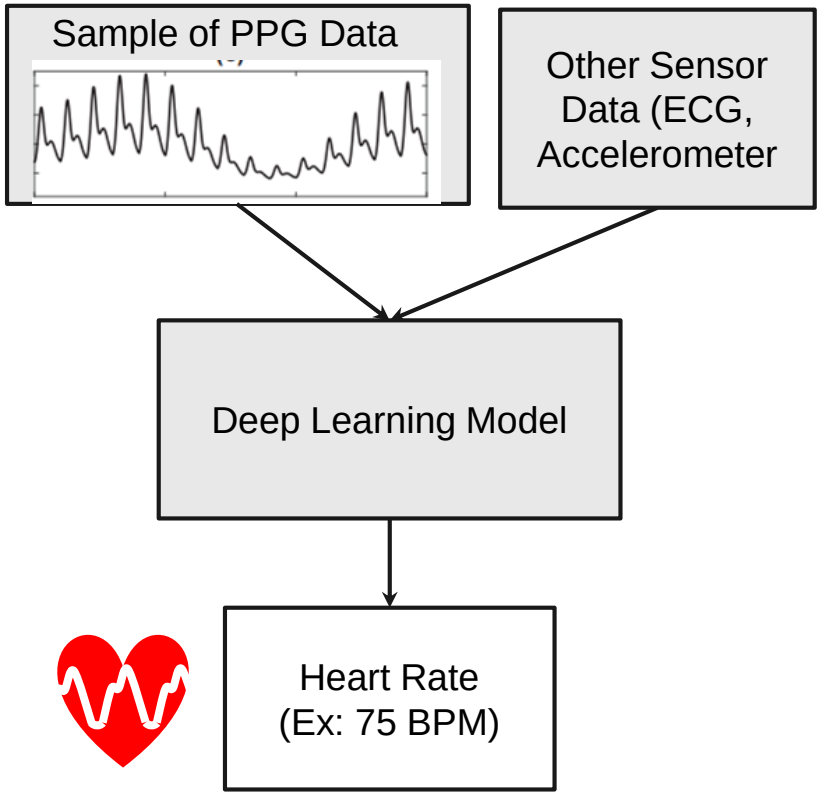
$$BPM = \frac{1 \text{ minute}}{\text{Current Peak - Previous Peak}}$$

$$BPM = f_{maxamp} \times 60$$

Derived Heart Rate

Heart Rate
(Ex: 75 BPM)

Cons of a Deep Learning Approach

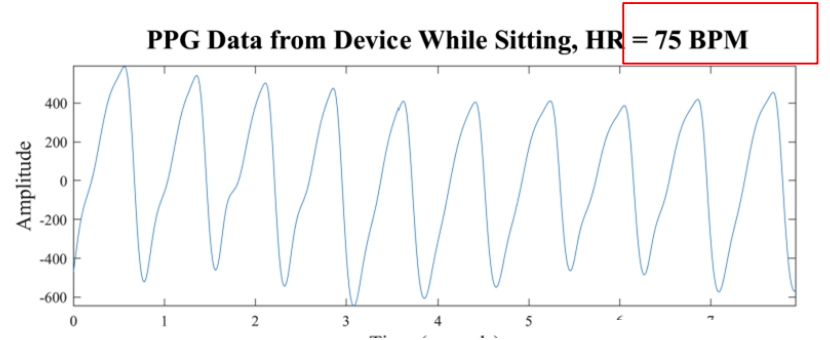


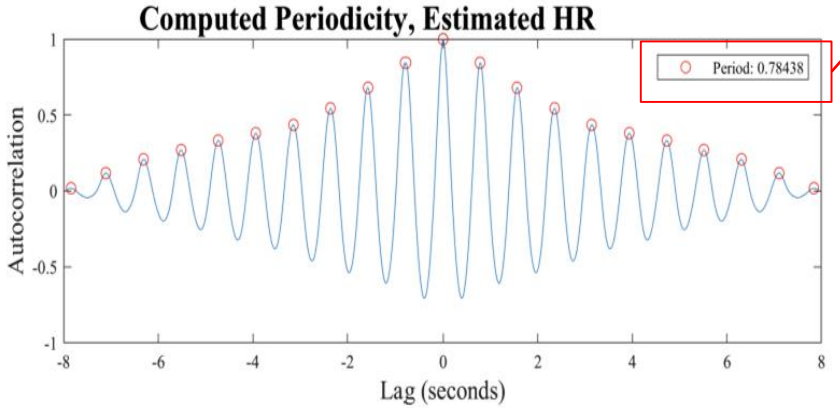
- Black box approach
- Requires large amounts of descriptive data
- Hardware constraints
- Usually require additional sensors

2.0

Methodology

HR Estimation





1

Time-based

$$BPM = \frac{1 \text{ minute}}{\text{Current Peak - Previous Peak}}$$

Autocorr periodicity: 0.78438
(average peak to peak)

$$BPM = \frac{60 \text{ seconds}}{0.78438} = 76.5 \text{ BPM}$$

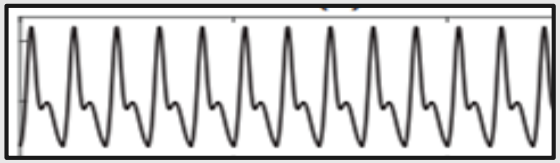
2

Frequency-based

$$BPM = f_{maxamp} \times 60$$

HR Estimation Pipeline

Window PPG Data (Sample)



2nd Order Butterworth (cut off <30BPM, and >240BPM)

Z-Normalization (0 mean, 1 standard deviation)

1

Time-based

$$BPM = \frac{1 \text{ minute}}{\text{Current Peak - Previous Peak}}$$

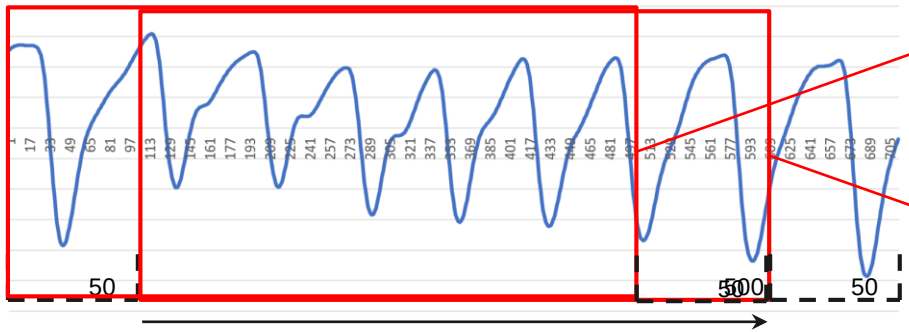
2

Frequency-based

$$BPM = f_{maxamp} \times 60$$

Heart Rate (Ex: 75 BPM)

HR Estimation Sliding Window Average



Heart Rate 1

Heart Rate 2

AVG

[HR 1, HR 2, …. , HR 10]

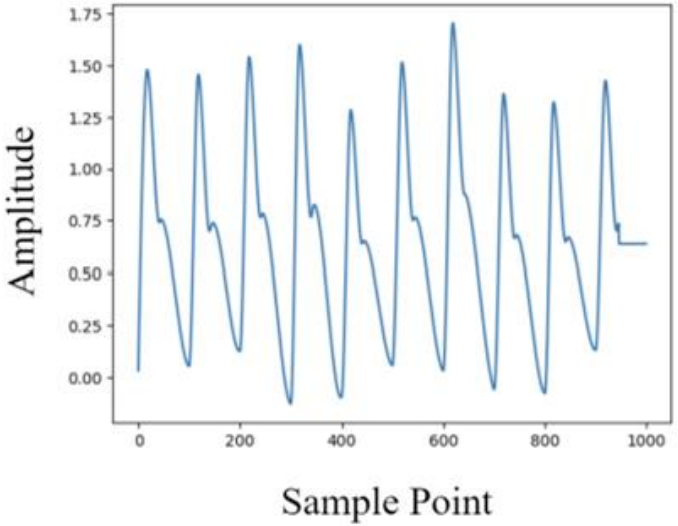
Final Averaged Heart Rate

2.1

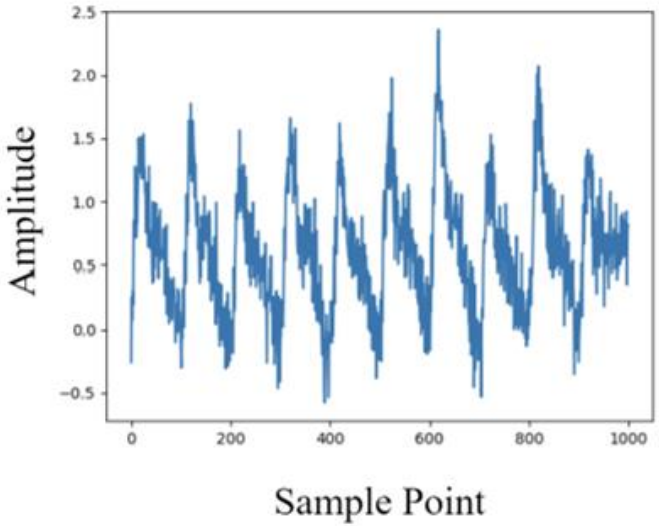
PPG Collection

Simulated PPG

Simulated 60 BPM PPG from Neurokit2 at 100Hz



* Respiratory modulation noise.

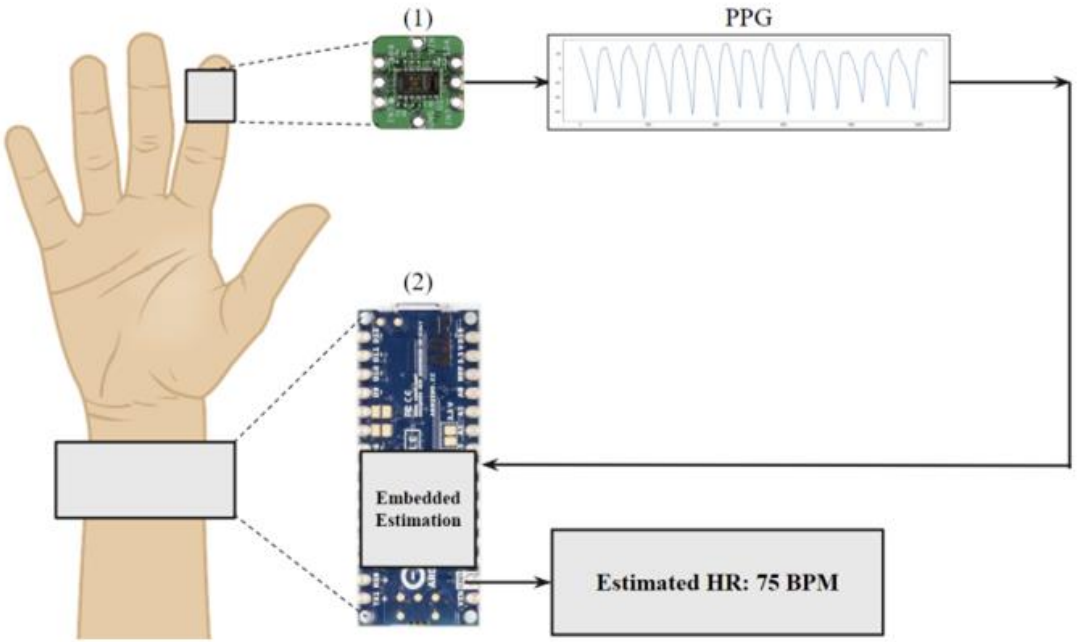


* Respiratory modulation and Powerline Interference (random white noise)

Final Simulated Signals Created:

- 60,80,100,120,140, 160,180 (BPM)
  - With varying amounts of noise
- 60 BPM
  - with varying powerline noise

Real Day-to-Day PPG



Components

(1) MAXREFDES117
(2) Arduino Nano 33 BLE Sense

Data Collected On:

- 3 subjects
- 4 activities (10 min each)

3.0

Results

Simulated PPG Results

	Neurokit2 MAE						
HR	*60*	*80*	*100*	*120*	*140*	*160*	*180*
Autocorr	2.02	1.92	0.95	1.10	1.77	0.82	1.46
FFT	0.00	4.00	4.00	0.00	4.00	4.00	0.00

Real PPG Results

	Windowed Autocorr		
Activity	*MAE (BPM)*	*MSE (BPM^2)*	*|Difference| (BPM)*
Sitting	1.93	17.00	0.68
Walking	2.43	23.32	0.88
Stepper	3.12	24.13	0.39
Working	2.81	23.60	0.35

	Windowed FFT		
Activity	*MAE (BPM)*	*MSE (BPM^2)*	*|Difference| (BPM)*
Sitting	2.43	23.97	0.45
Walking	2.76	27.10	0.17
Stepper	3.68	31.59	1.54
Working	3.77	62.91	1.48

4.0

Discussion

Discussion

	Neurokit2 MAE						
HR	*60*	*80*	*100*	*120*	*140*	*160*	*180*
Autocorr	2.02	1.92	0.95	1.10	1.77	0.82	1.46
FFT	0.00	4.00	4.00	0.00	4.00	4.00	0.00

MAE~1.2

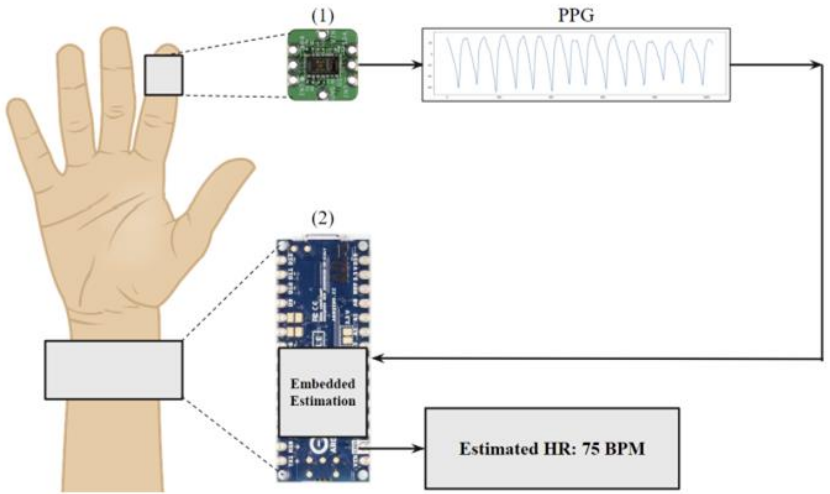
	Windowed Autocorr		
Activity	*MAE (BPM)*	*MSE (BPM^2)*	*|Difference| (BPM)*
Sitting	1.93	17.00	0.68
Walking	2.43	23.32	0.88
Stepper	3.12	24.13	0.39
Working	2.81	23.60	0.35

	Windowed FFT		
Activity	*MAE (BPM)*	*MSE (BPM^2)*	*|Difference| (BPM)*
Sitting	2.43	23.97	0.45
Walking	2.76	27.10	0.17
Stepper	3.68	31.59	1.54
Working	3.77	62.91	1.48

5.0

Conclusion

Conclusion



1

Time-based

$$BPM = \frac{1 \text{ minute}}{\text{Current Peak - Previous Peak}}$$

2

Frequency-based

$$BPM = f_{maxamp} \times 60$$