SKM 2023

Embedded Machine Learning for Heart Rate Estimation with Arduino

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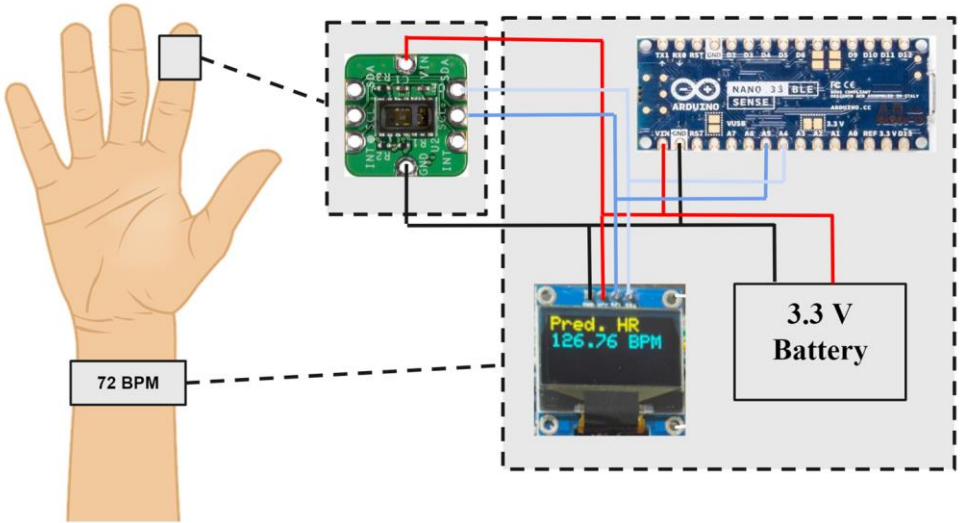


1.0

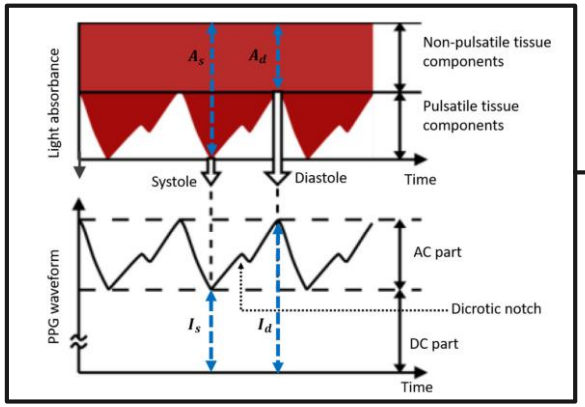
Introduction

The PPG Signal

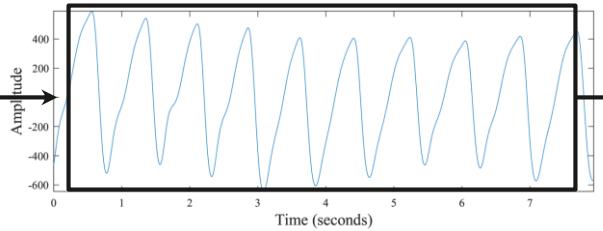
Photoplethysmography (PPG):
Noninvasive(extracutaneous), optical based, interpreted to HR (and other biometrics)

→ **Wearable HR Monitoring**

PPG Waveform Components[1]



Processed PPG Signal



Derived Heart Rate

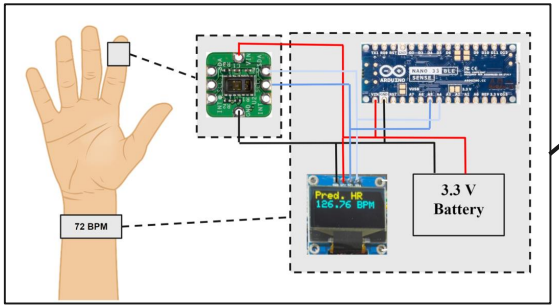
Heart Rate
75 BPM

1. Kyriacou et al. 2022, Photoplethysmography

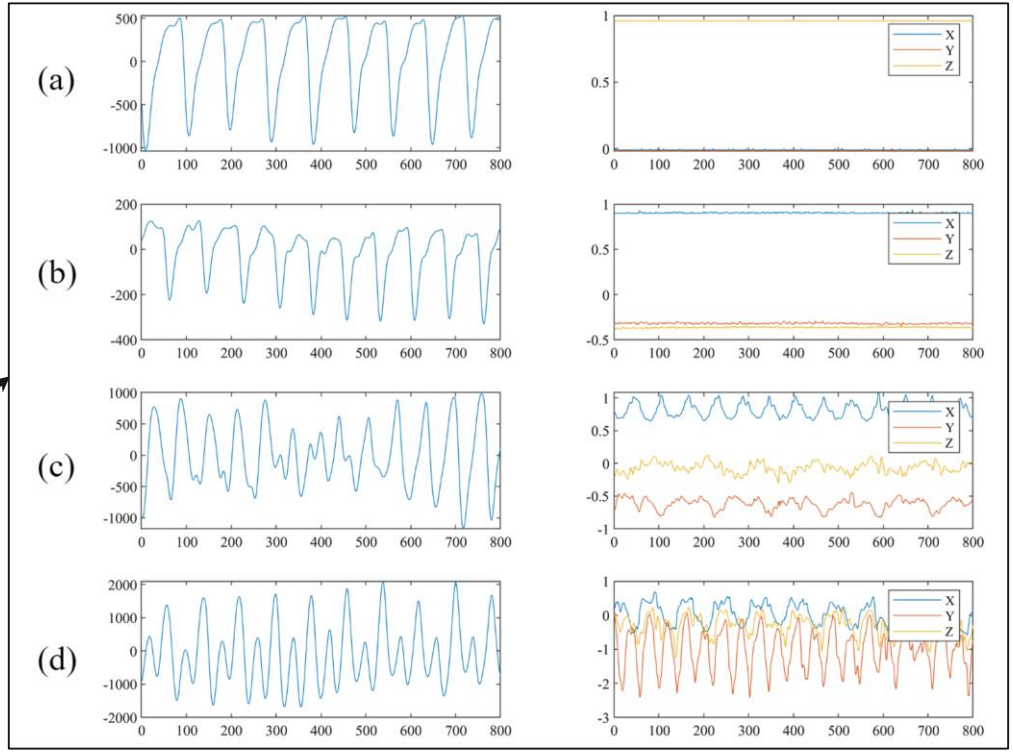
PPG Singnal and Noise

Motion Artifact (MA):

The degree of motion strongly alters the PPG signal obscuring the overall wave-form. (a) Sitting (b) Standing (c) Walking (d) Running

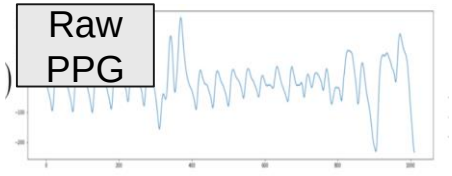


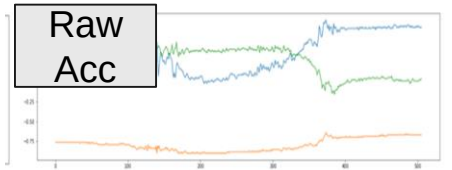
Raw PPG and Accelerometer Data from Proposed Device



PPG-DaLiA and HR Estimation

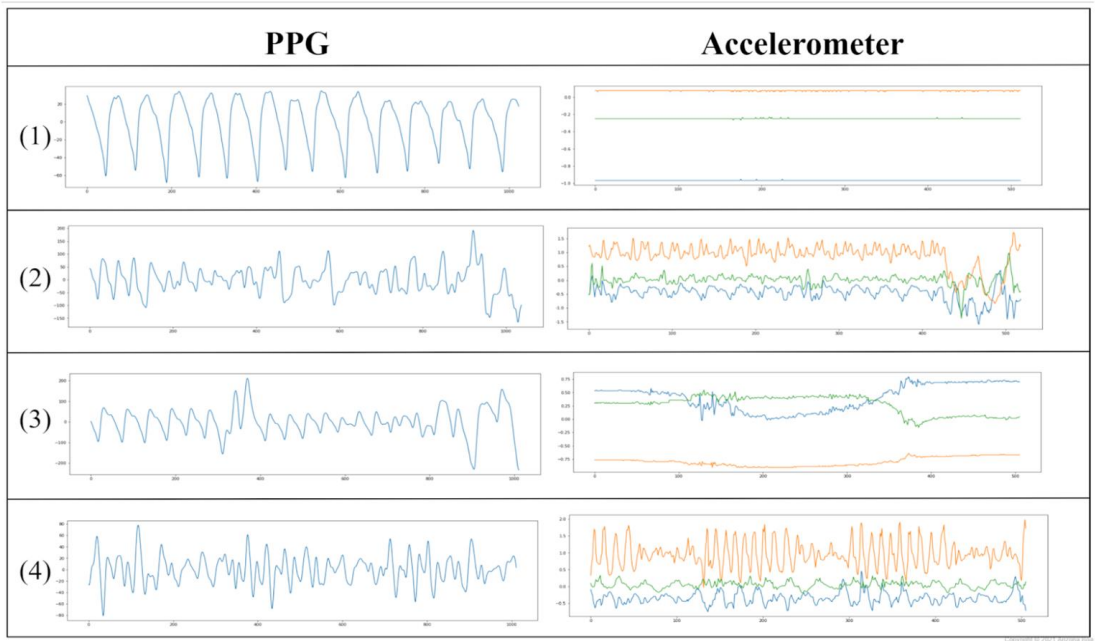
PPG-DaLiA Dataset





- ***15*** *Subjects*
- ***Continuous*** *PPG and accelerometer readings*
- ***Ground truth*** *HR*

Raw PPG and Accelerometer Data from PPG-DaLiA (S7)



(1) Sitting (2) Walking (3) Working (4) Stairs

2.0

Methodology

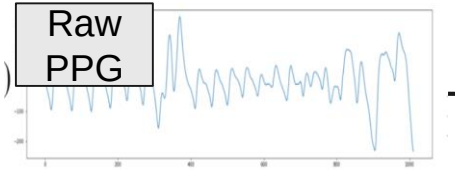
2.1

Edge Impulse

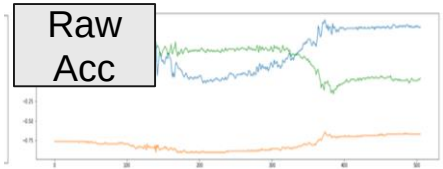
Edge Impulse: Data Preparation

PPG-DaLiA Dataset

Raw PPG



Raw Acc



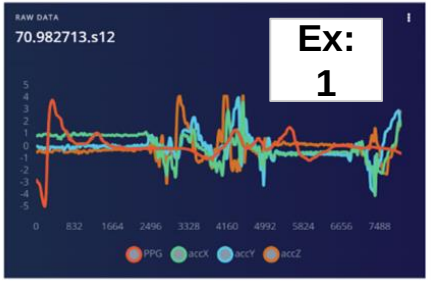
- ***15*** *Subjects*
- ***Continuous*** *PPG and accelerometer readings*
- ***Ground truth*** *HR*

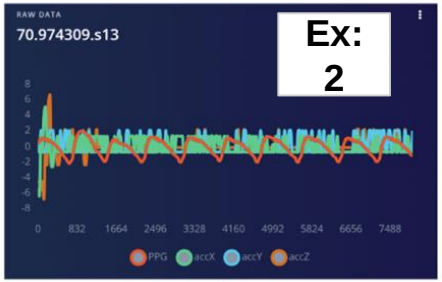
Sliding Window and Znorm

Data Sample (512x4)

- **PPG (512)**
- **X(acc) (512)**
- **Y(acc) (512)**
- **Z(acc)(512)**

Data Sample Examples





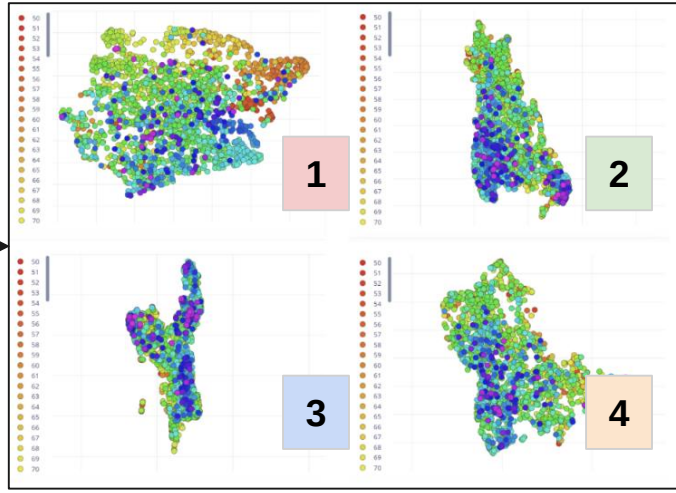
Edge Impulse: Feature Extraction

Data Sample (512x4)

- PPG (512)
- X(acc) (512)
- Y(acc) (512)
- Z(acc)(512)

Spectrogram Settings	
Frame Length	4
Frame Stride	1
Frequency Bands	256
Noise Floor (dB)	-110

Feature Maps per HR



Final Features (2580)

Edge Impulse: Model Building and Training

Final Features (2580)

Edge Impulse CNN Model
Training Cycles: 200
Validation set size: 20%
Learning rate 0.001.
Input: 2580, Reshape Layer (645 columns)
for (i = 1 to 6)
2D Conv / pool layer (2^{2+i} filter, 3 kernel size, 1 layer)
Dropout(.5)
2D Conv / pool layer (16 filter, 3 kernel size, 1 layer)
Dropout(.5)
Flatten Layer
Dense (1024)
Dropout(.5)
Dense(512)
Dropout(.5)
Output Layer (1 class)

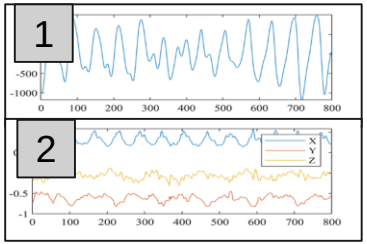
Heart Rate
(Ex: 75 BPM)

2.2

Embedded Hardware and Model Deployment

Embedded Hardware

DC Bias, 2nd Order Butterworth

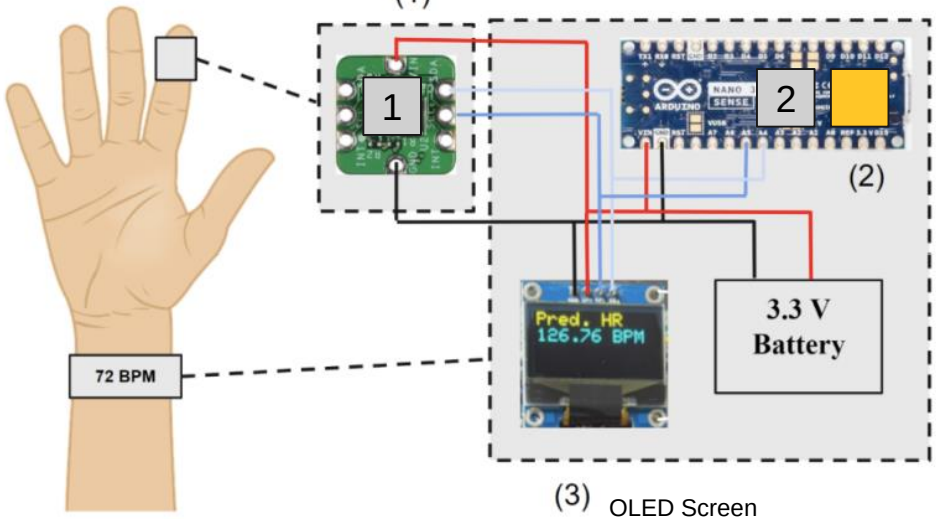


Data Sample (512x4)

- PPG (512)
- X(acc) (512)
- Y(acc) (512)
- Z(acc)(512)

Trained Embedded Model

Heart Rate (Ex: 75 BPM)



Arduino Nano 33 BLE Sense

2.3

Validation Testing

Validation Testing

Activity Label	Description	Duration (min)
Sitting	*Sitting still with arms resting on a table.*	~10
Walking	*Walking on a treadmill at subject specified walking pace (between 2 and 3 mph)*	~10
Stepper	*Exercising on the Gold's Gym Stamina Mini Stepper*	~10
Working	*Repeatedly performing three tasks in random order:* ***Typing, Reaching, Standing*** ***Typing:*** *while sitting, subject types on a keyboard* ***Reaching*** *: while sitting, subject reaches towards a set point, then returns their arm* ***Standing:*** *From a seated position, the subject stands up, waits, then sits back down*	~10

Subject ID	Gender	Age (years)	Height (inches)	Weight (lbs)	Skin Type	Fitness
Sub1	M	25	74	200	2	4
Sub2	M	25	70	175	2	4
Sub3	M	50	68	195	1	2

3.0

Results

Results

	Embedded CNN Results		
Activity	*|Avg HR Diff| (BPM)*	*MAE (BPM)*	*MSE (BPM^2)*
Sitting	0.85	4.48	32.06
Walking	0.75	4.18	24.89
Stepper	11.41	12.11	204.66
Working	10.12	11.30	166.26

	MAE Comparison	
Activity	*PPG-DaLiA (BPM)*	*Embedded CNN (BPM)*
Sitting	4.93	4.48
Walking	9.21	4.18
Stepper	6.00*	12.11
Working	12.11**	11.30

* Average of Walking and Stairs activities
** Average of Lunch, Working, and Transition activities

4.0

Discussion and Conclusion

Discussion and Conclusion

Activity	Embedded CNN Results		
	|Avg HR Diff| (BPM)	*MAE (BPM)*	*MSE (BPM^2)*
Sitting	0.85	4.48	32.06
Walking	0.75	4.18	24.89
Stepper	11.41	12.11	204.66
Working	10.12	11.30	166.26

- Good performance on low noise activities
- Decreased performance on high motion activities

Activity	MAE Comparison	
	PPG-DaLiA (BPM)	*Embedded CNN (BPM)*
Sitting	4.93	4.48
Walking	9.21	4.18
Stepper	6.00*	12.11
Working	12.11**	11.30

- Comparable or better performance than the results proposed by Reiss et al.