Estimation of Respiratory Rate from Smartphone's Acceleration Data

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Outline

- » Motivation
- » Related work
- » Our method
- » Algorithm
- » Data set
- » Experiment
- » Result
- » Summary

Motivation (1)

- Vital signs
  - Temperature
  - **Respiratory rate (RP)**
  - Heart rate (pulse)
  - Blood pressure

Motivation (2)

RP Estimation

Direct Method

- IP
- RIP
- **accelerometer**
- laser-based
- ultrasound
- audio processing
- video processing

Indirect Method

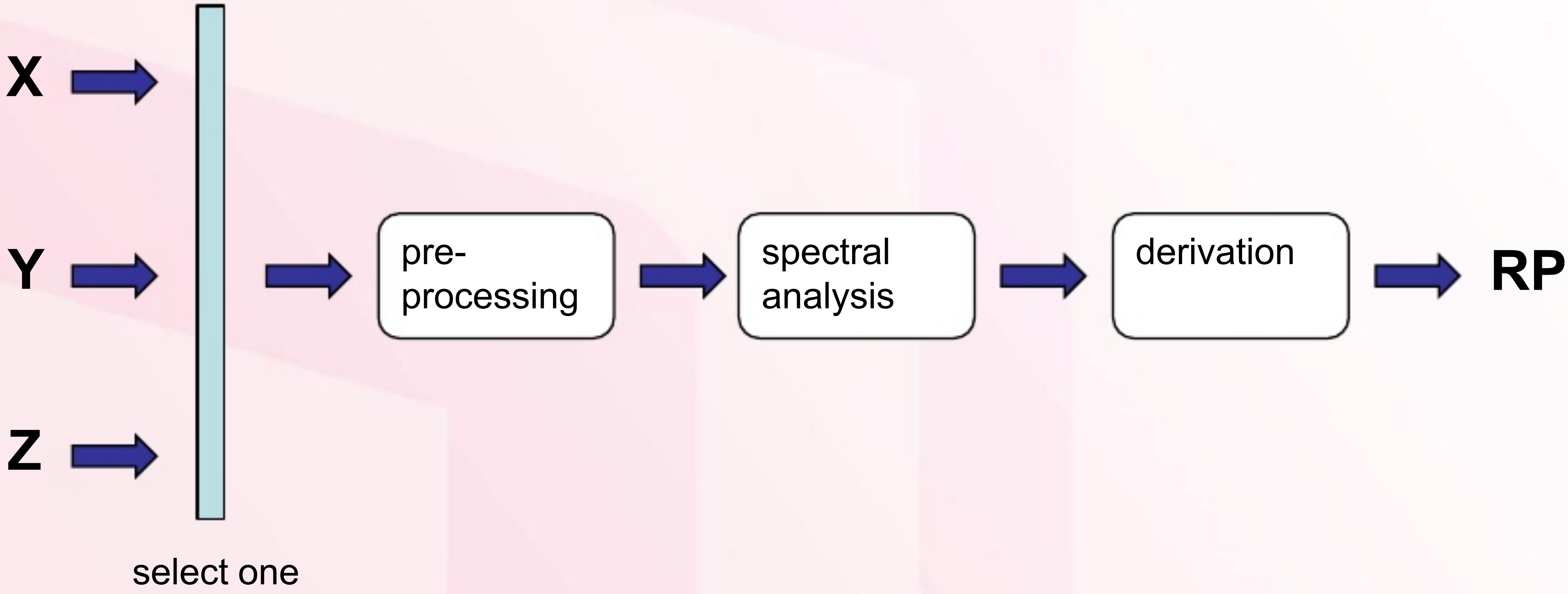
- ECG
- PPG
- ABP
- PAT

Related Work (accelerometer approach)

- 2008 – Hung et al. band-pass filter
- 2009 – Jin et al. PCA
- 2010 – Bates et al. rotation and movement
- 2011 – Dehkordi et al. evaluated RP signal
- 2011 – Liu et al. adaptive filter with BSN
- 2012 – Dehkordi et al. models with ensemble learning

Our Method

Algorithm (1)


X
Y
Z
select one
pre-processing
spectral analysis
derivation
RP

Algorithm (2)

1. Pre-processing
   - » Smoothing
   - » Detrending
2. Spectral analysis
   - » Fast Fourier transform (FFT)
3. RP derivation

$$\boxed{RP = f * 60}$$

Algorithm (3)

- Time series:

$$y_t = T_t + S_t + I_t$$

  - T_t = trend component
  - S_t = seasonal component
  - I_t = irregular component

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Algorithm (3)

- Time series:

$$y_t = T_t + S_t + I_t$$

estimated with moving average (MA)

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Algorithm (3)

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- For smoothing, $y_t^* = T_t$

Algorithm (3)

estimated with moving average (MA)

- Time series:

$$y_t = T_t + S_t + I_t$$

  - T_t = trend component
  - S_t = seasonal component
  - I_t = irregular component

- For smoothing, $y_t^* = T_t$
- For detreding, $y_t^{**} = y_t^* - T_t^*$

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Data Set

Data Set	Breathing
RP12	slow
RP18	normal
RP30	fast

RP unit = breaths per minute

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Experiment

- Each data set is labeled according to the counting done by practitioner referred as **HCRP**
- Introduce another RP estimate called **WCRP** by counting the waves in the actual acceleration data

$$RP = count/time * 60$$

HCRP, WCRP

Human Count (HCRP)	Wave Count (WCRP)
12	12
18	18
30	40

Result

Data Set	Respiratory Rate (BPM)	
	WCRP	ALRP
RP12	12	11.72
RP18	18	18.75
RP30	40	37.50
bed	N/A	0.00
table	N/A	0.00

Summary

- Propose a method to estimate respiratory rate using only smartphone

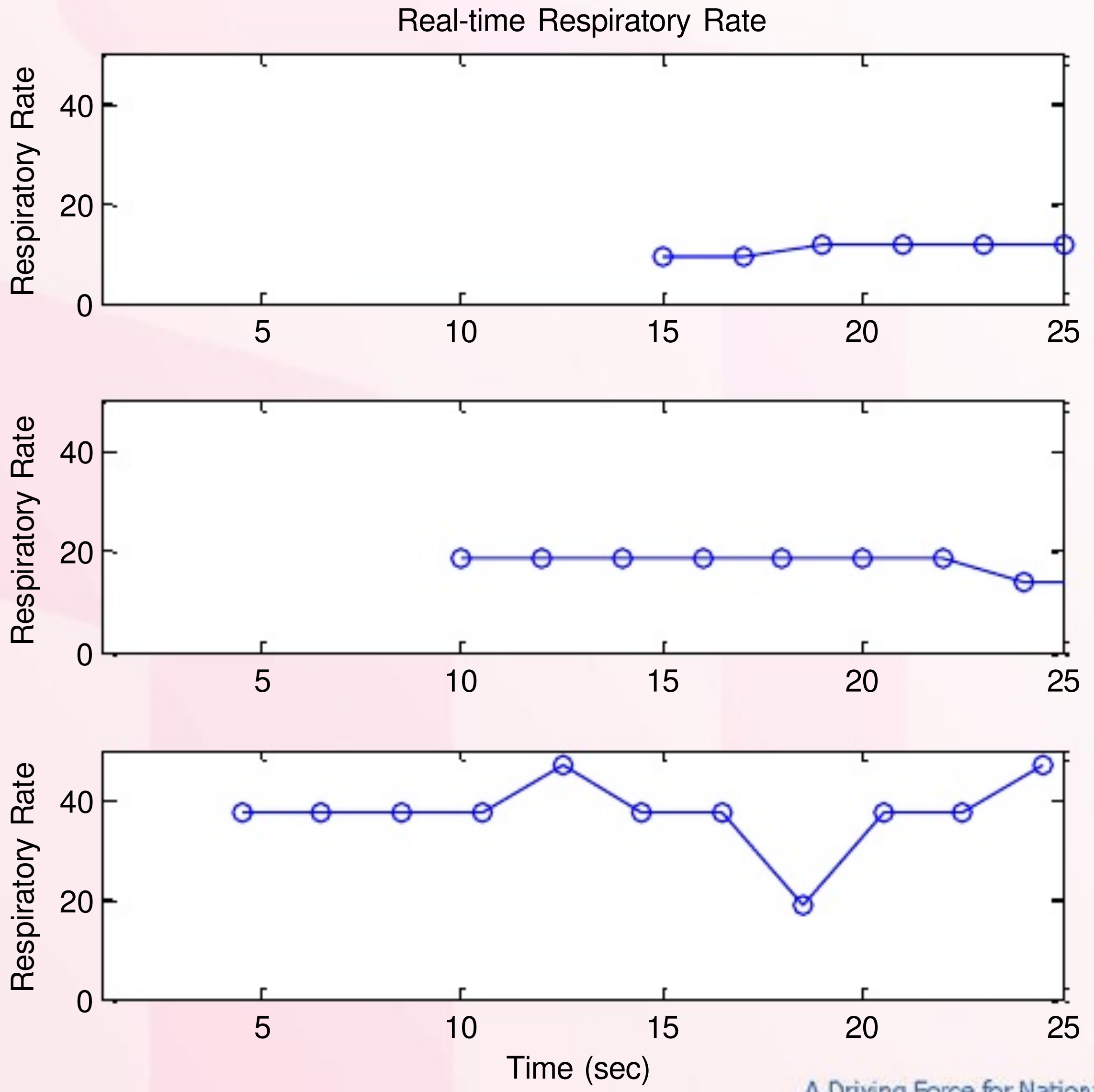
Future Work

- Experiment with more data
- Compare with existing methods
- Improve on the algorithm such as automatic selection of 1D from 3D data

$WCRP_{all}$, $WCRP_{range}$

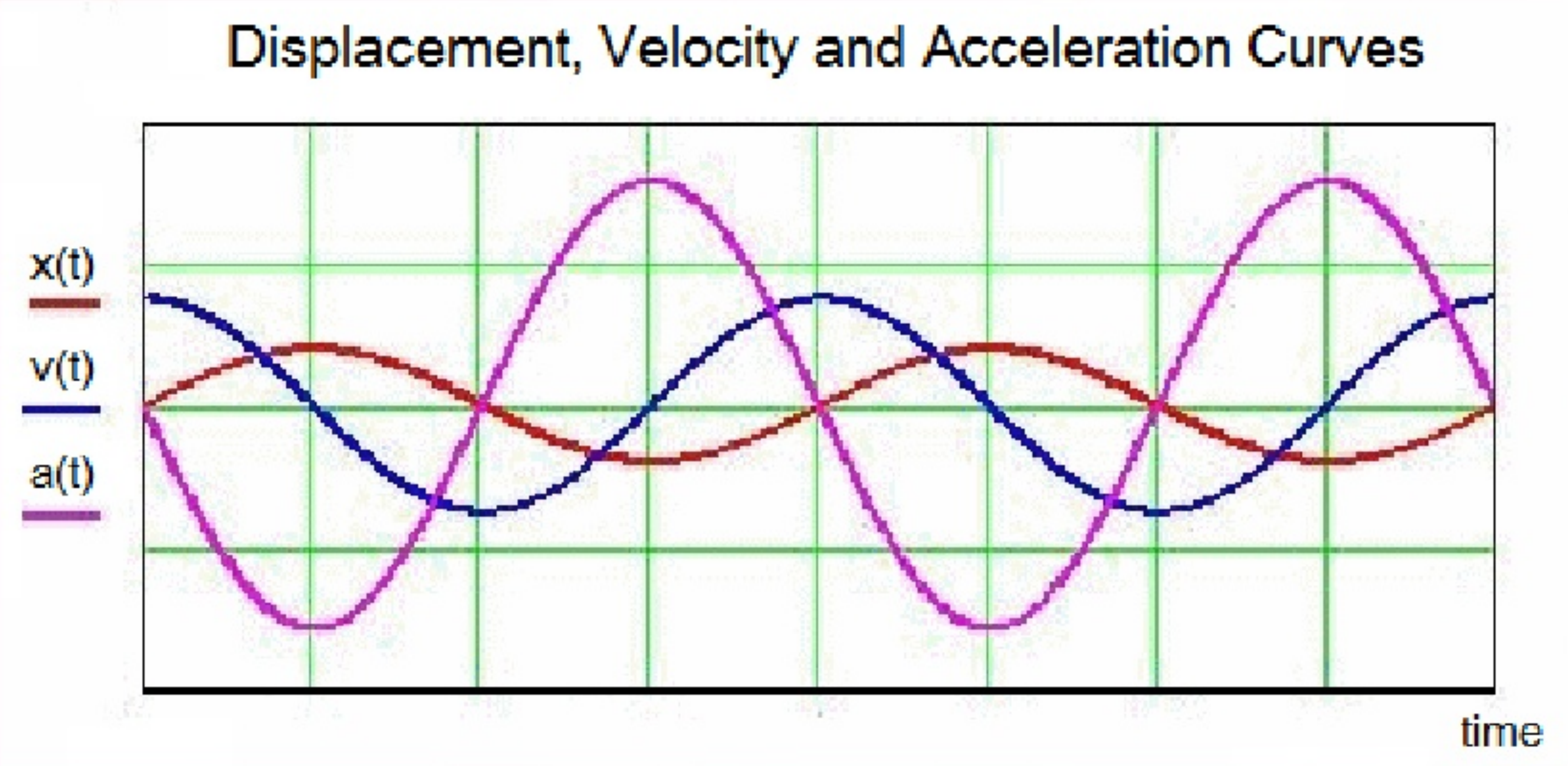
Data Set	WCRP	f_{WCRP}	T_{WCRP}	$3*T_{WCRP}$
RP12	12	0.20	5.00	15
RP18	18	0.30	3.33	10
RP30	40	0.67	1.50	4.5

Real-time Plot

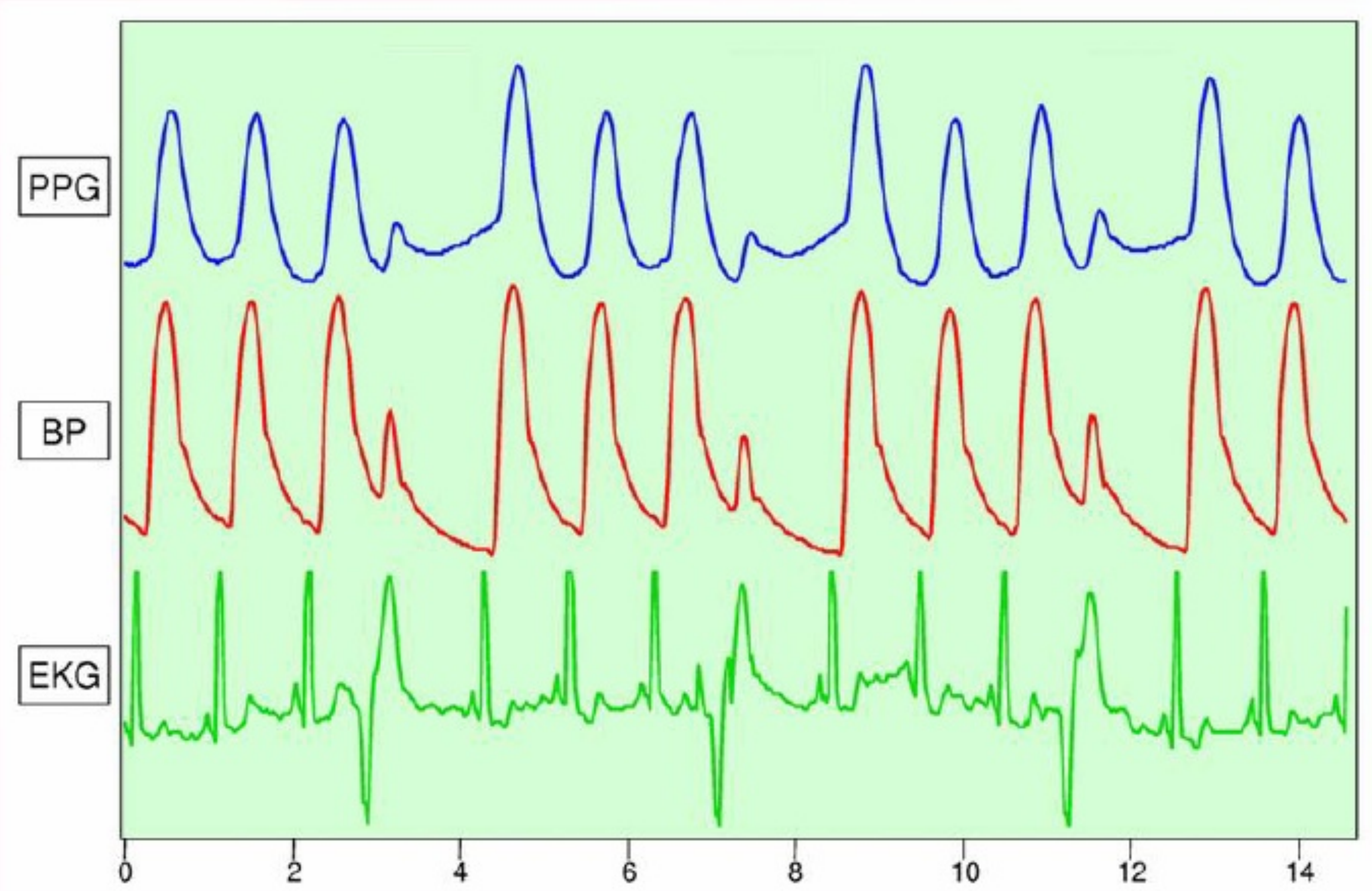


Work	HW	Sampling Frequency	Placement	Orientation	Target RP	Gold Standard
Hung	ADXL204 (2D acc) with belt, power supply	1 kHz (14-bit DAQ-6024E)	chest	sit, stand, lie down	normal, apnea, deep	RIP
Jin	3D acc	10 Hz	diaphragm muscle	sit, stand, lean, lie down *simulated	5 breathing cycles	IP
Bates	MMA7260QT (3D acc), Orient-3 (wireless), ADXRS300 (gyro)	64 Hz (12-bit dsPIC30F3014)	left lower costal margin, below the ribs		normal, irregular	nasal cannula pressure transducers
Dehkordi	ADXL335z (3D acc)	2 kHz (8-bit NI9205)	suprasternal notch	lie down (supine, prone, left side)	deep, normal, shallow	pressure spirometry and SGR
Liu	SCA3000 (3D acc), BSN	25 Hz	waist-worn			airflow CO_2 analysis with BIOPAC CO2100C
Dehkordi	ADXL335z (3D acc)	500 Hz (8-bit NI9205)	suprasternal notch, the thorax and the abdomen	lie down (supine, prone, left side)	apnea	nasal/oral airflow

Acceleration Waveform



PPG vs ABP vs ECG



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Reference

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- A. Bates, et al. "**Respiratory rate and flow waveform estimation from tri-axial accelerometer data.**" In *Body Sensor Networks (BSN), 2010 International Conference* on, pp. 144-150. IEEE, 2010.
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- G. Z. Liu, et al. "**Estimation of Respiration Rate from Three-Dimensional Acceleration Data Based on Body Sensor Network.**" *Telemedicine and e-Health* 17, no. 9 (2011): 705-711.
- P. Dehkordi, et al. "**Monitoring torso acceleration for estimating the respiratory flow and efforts for sleep apnea detection.**" In *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, pp. 6345-6348. IEEE, 2012.

Round-off Error

- In case of **HCRP** and **WCRP**, counting actually introduces round-off error as it can only accept integer.
- On the other hand, **ALRP** produces real value, which would eliminate round-off error.

Device (1)

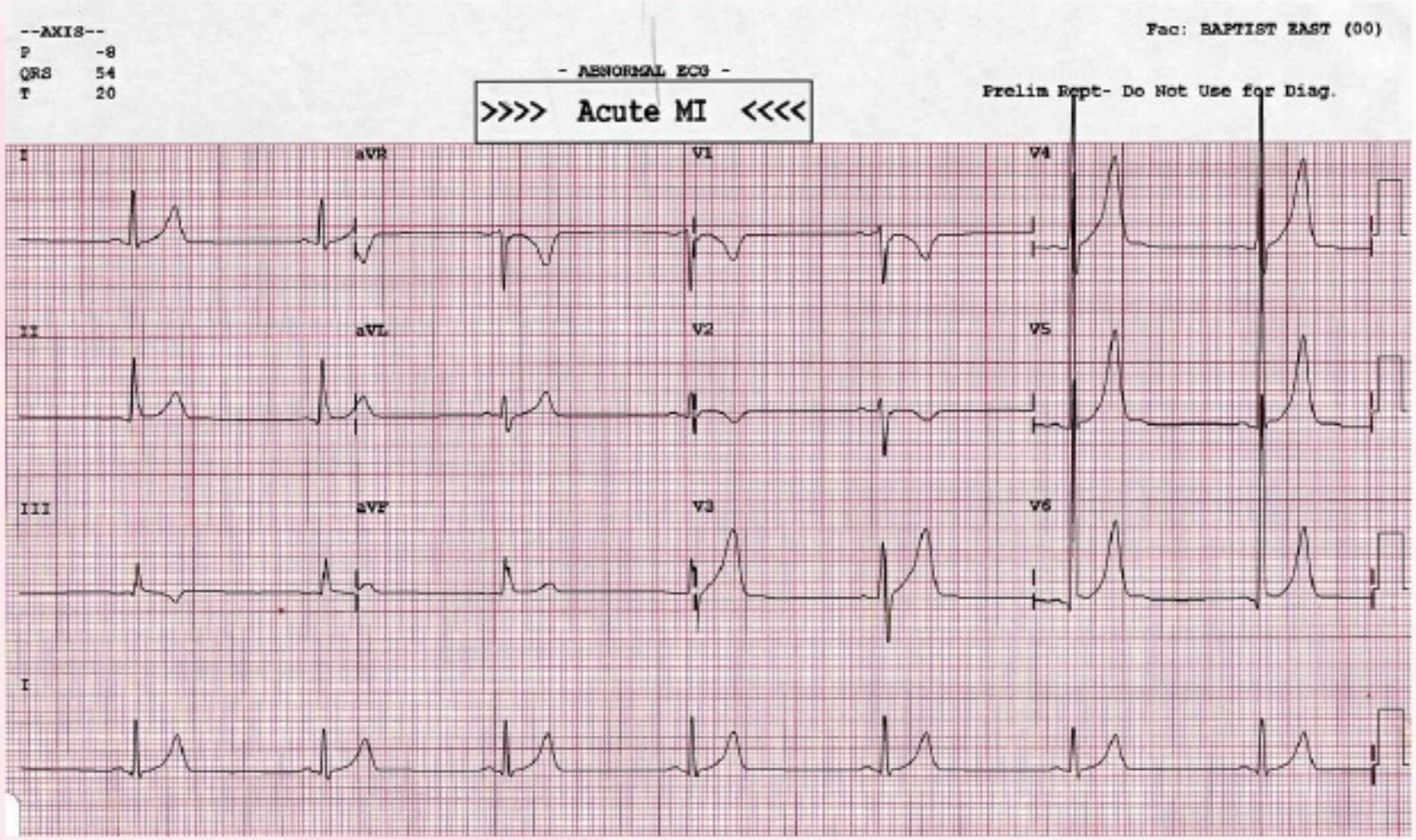
- Impedance pneumography (IP)

Device (2)

- Respiratory inductive plethysmography (RIP)

Device (3)

» Electrocardiogram (ECG, EKG)



Device (4)

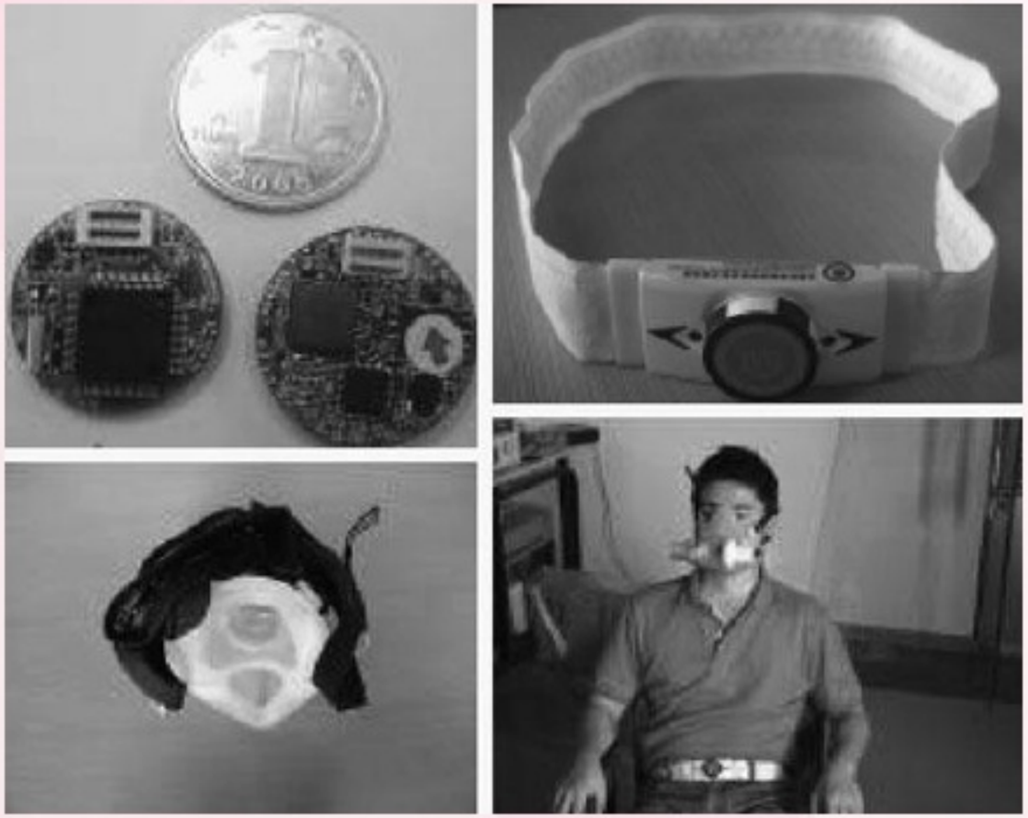
- Photoplethysmogram (PPG)

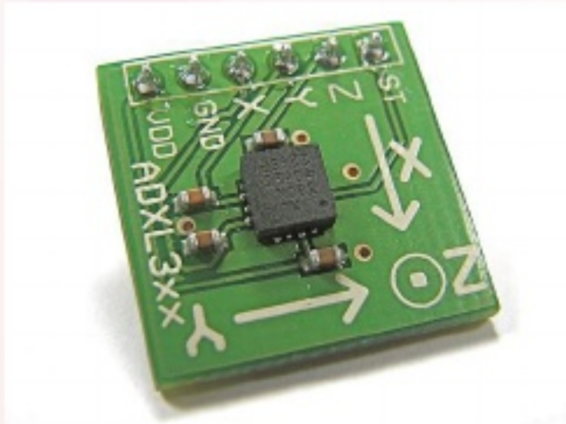
Device (5)

» Arterial blood pressure (ABP)

Device (6)

- Accelerometer





Data Collection

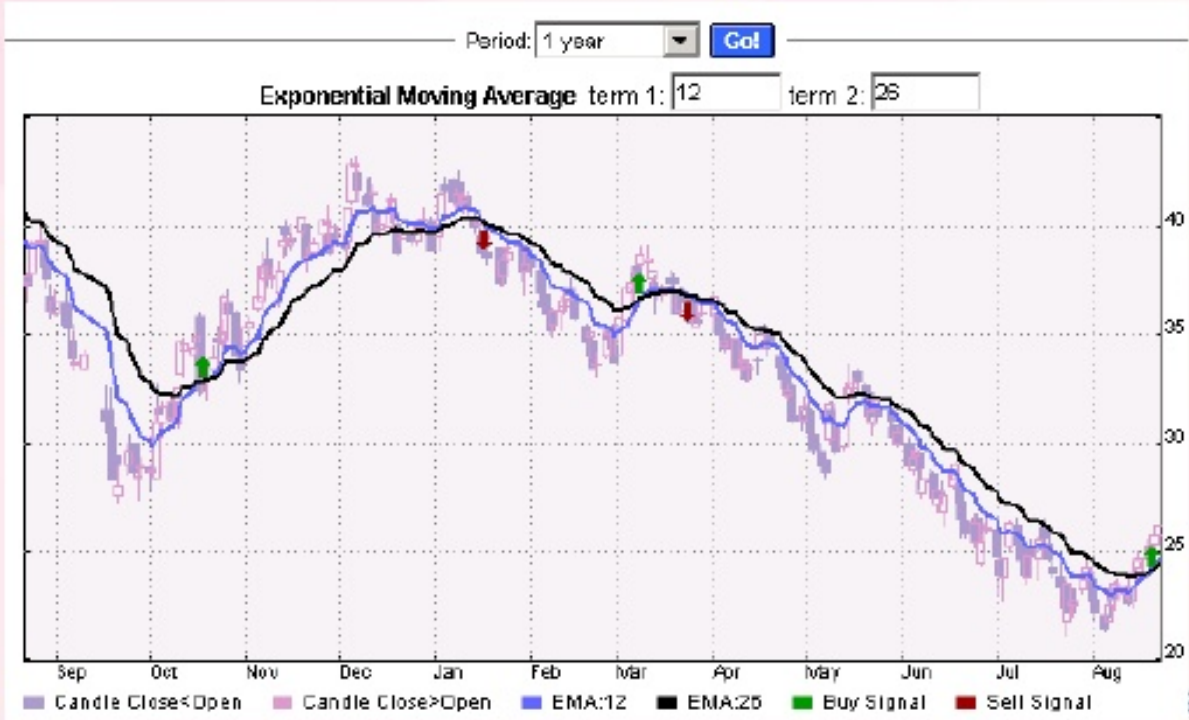
- We use “SensorLog” and iOS app to help collect the acceleration data
- With a sampling rate ($f_{sampling}$) of 10 Hz
- The actual smartphone is iPhone 4

https://itunes.apple.com/us/app/sensorlog/id388014573?mt=8

Moving Average

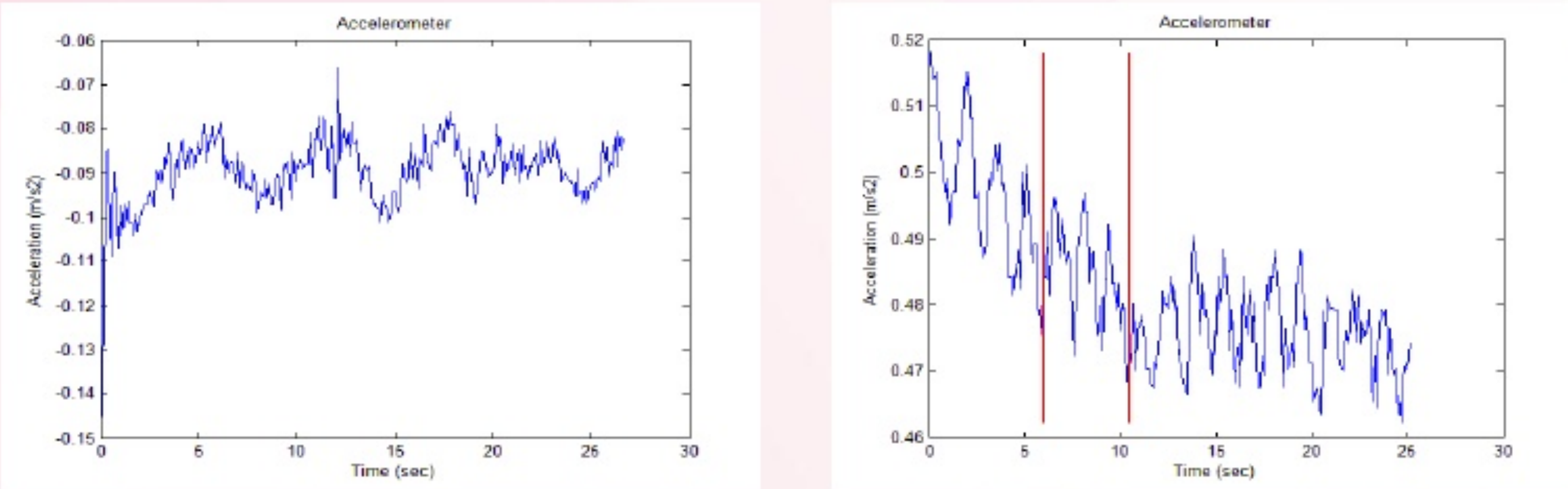
- MA is a common technique in drawing a trend line for time series data.

MA = average of nearby terms



Signal

- Cope with noisy, shifts in frequency, a trend found in some data sets



3D-axis Accelerometer

Reasons for Detrending Subtask

1. The signal occasionally contains a trend which corrupt FFT
2. Average value of zero, non-zero average (constant factor) will contribute to the final frequency of FFT