Measuring Heart and Respiratory Rate with IMU Sensors and ICA

Biomedical Signal Processing
22/23

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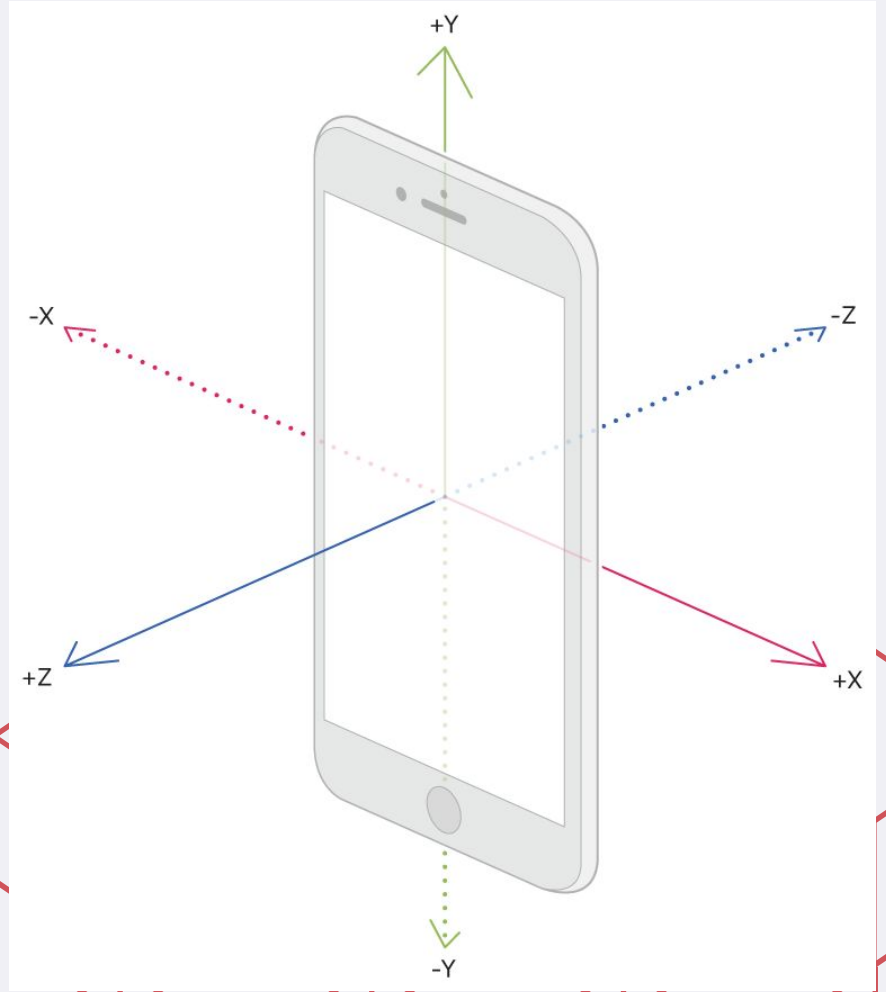
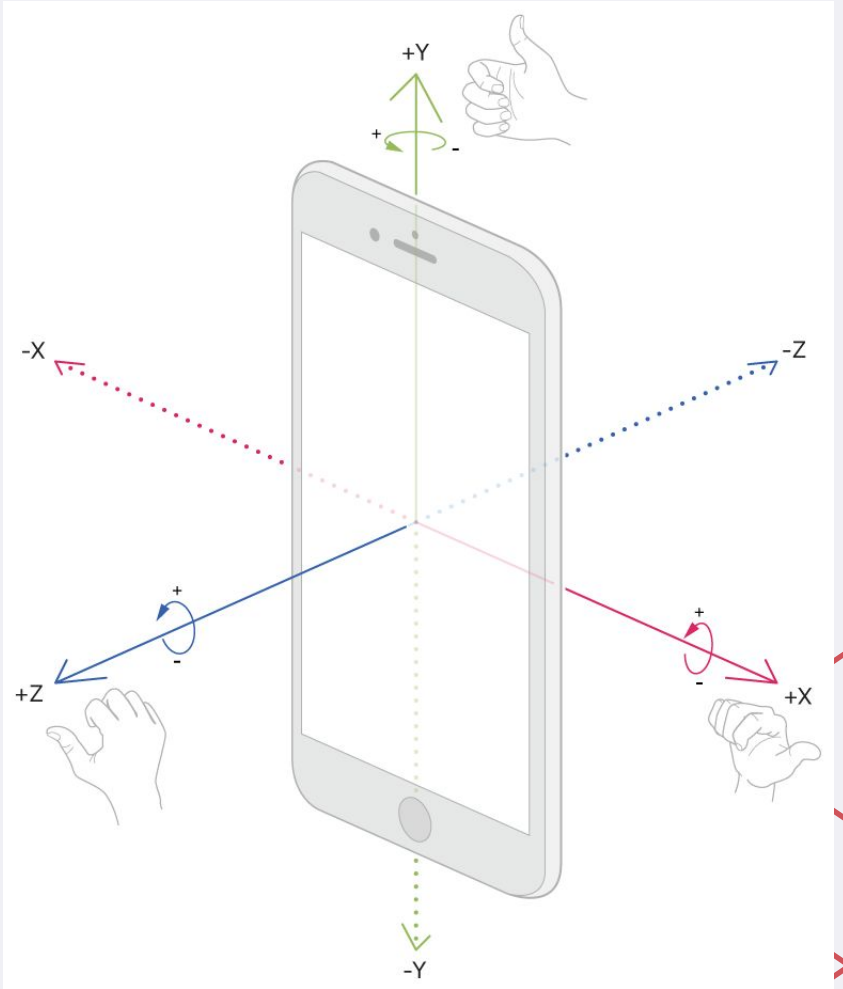
Basic Concepts

- Measuring **Heart** and **Respiratory** rates may be:
  - **Obtrusive**
  - **Not available**
  - **Impractical**
- Smartphone **Inertial Measurement Unit (IMU)**
  - Accelerometer & Gyroscope

Phone IMU Sensor





01

Related Work

Related Work Features and Methods

	Heart Rate	Respiratory Rate	Accel	Gyro	Multiple Axis	Fs	Signal Filter	Method
[1] Bates 2010						64 Hz	Low-pass 1Hz	PCA
[2] Lapi 2014						128 Hz	Lowpass 2Hz	Visual Analysis of Waveform
[3] Jia 2015						80 Hz	Hilbert & Butterworth 0.67 to 3.33Hz	L2 Norm & 6th Order AR Model
[4] Lahdenoja 2015						800 Hz	Bandpass	Autocorrelation Analysis
[5] Hernandez 2018						250 Hz	Bandpass 0.8 to 5 Hz	Distance Between Peaks
Proposed Solution						500Hz	Butterworth and Bandpass	ICA, L2 Norm and FFT

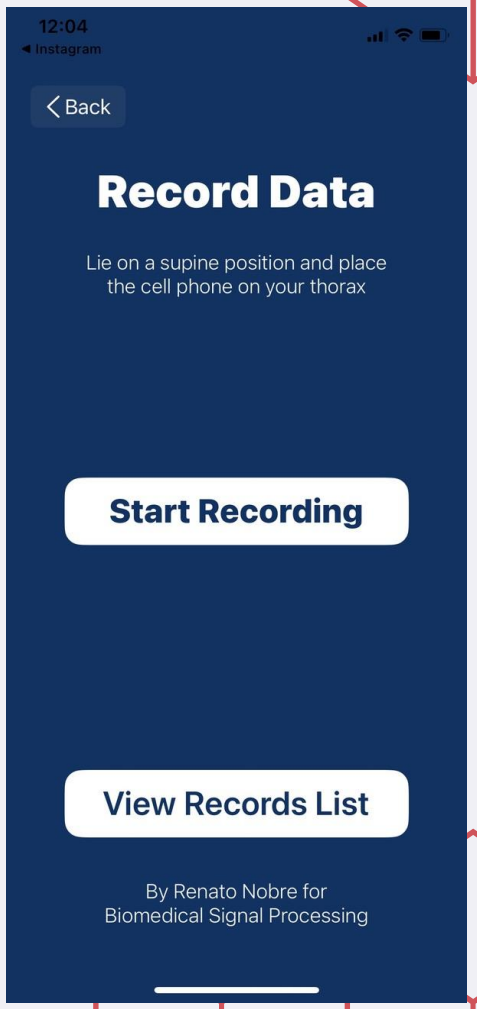
02

Data Collection & Dataset

.1

Statale Vital Signs iOS App


12:04
Instagram
Statale's Vital Signs
Monitor Signs
Record Data
UNIVERSITÀ DEGLI STUDI DI MILANO
LA STATALE
By Renato Nobre for Biomedical Signal Processing


12:04
Instagram
Back
Record Data
Lie on a supine position and place the cell phone on your thorax
Start Recording
View Records List
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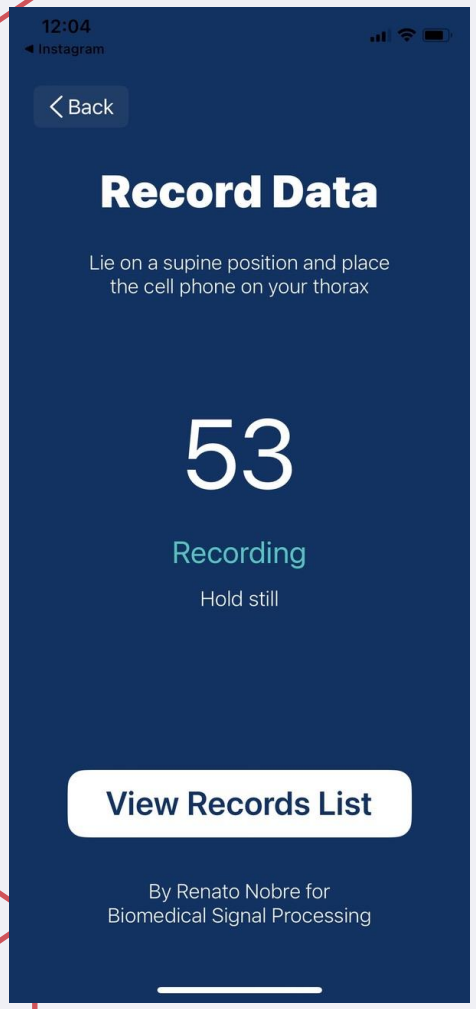
12:04
Instagram
Back
Record Data
Lie on a supine position and place the cell phone on your thorax
53
Recording
Hold still
View Records List
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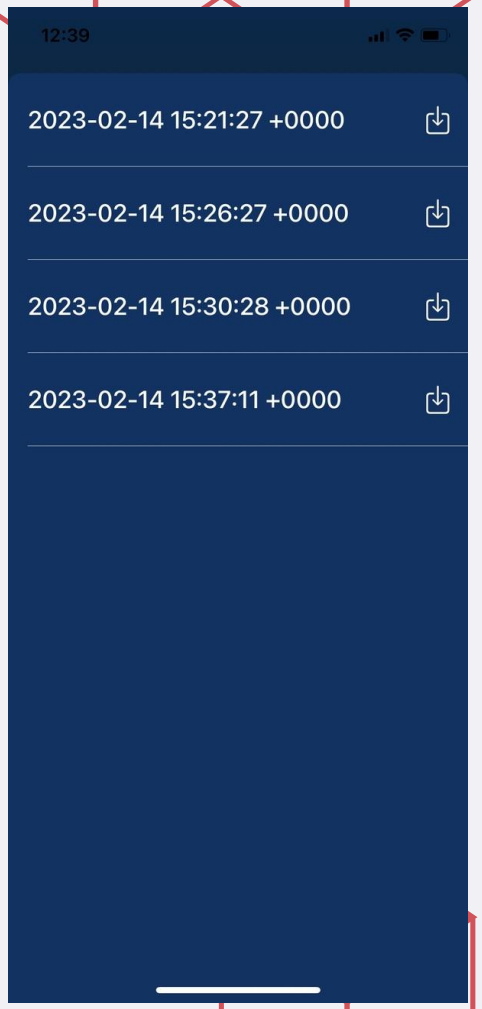

12:39
2023-02-14 15:21:27 +0000
2023-02-14 15:26:27 +0000
2023-02-14 15:30:28 +0000
2023-02-14 15:37:11 +0000

.2

Dataset

Collected Dataset Composition

- 30 Samples (of 60 second)
- Sampling Frequency of 500Hz
- Respiratory Rate Range 12 - 30 (Breaths per Minute)
- Heart Rate Range 55 - 102 (Beats per Minute)

Collected Dataset Composition

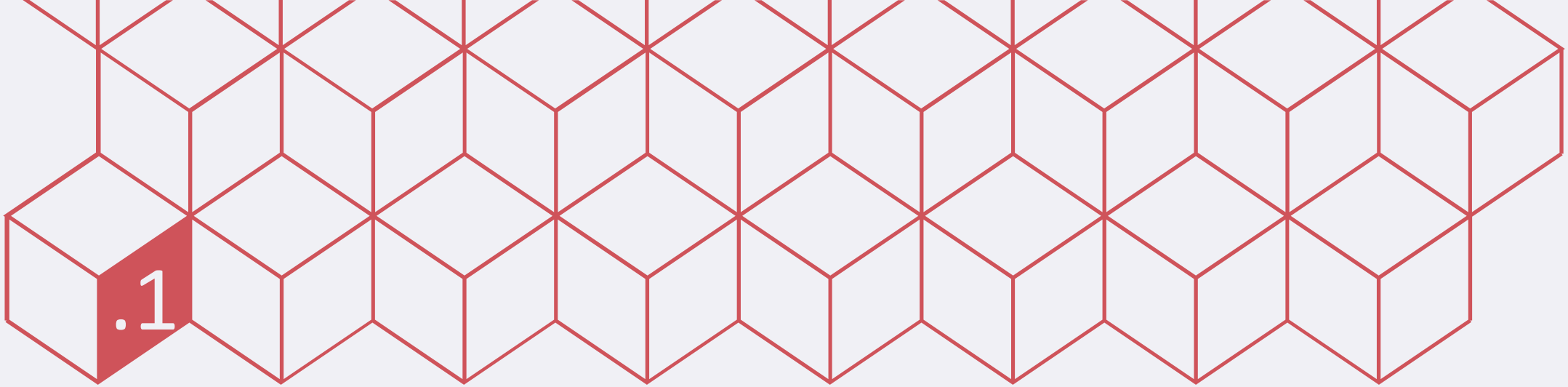
- 5 Healthy Subjects
- 4 Women
  - Age 27, 51, 54, 88
- 1 Men
  - Age 67

Collected Sample Example

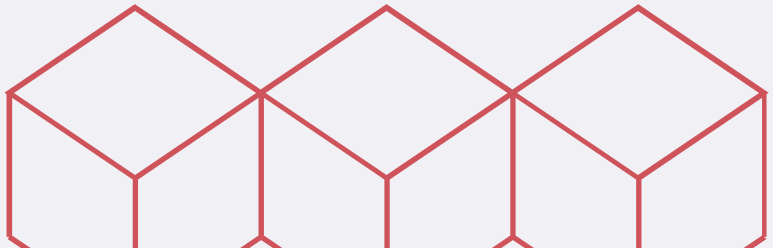
- NAME00RR00-00BPM.csv
- "True" Respiratory Rate collected through metronome controlled respiration
- "True" Heart Rate collected through oximeter

03

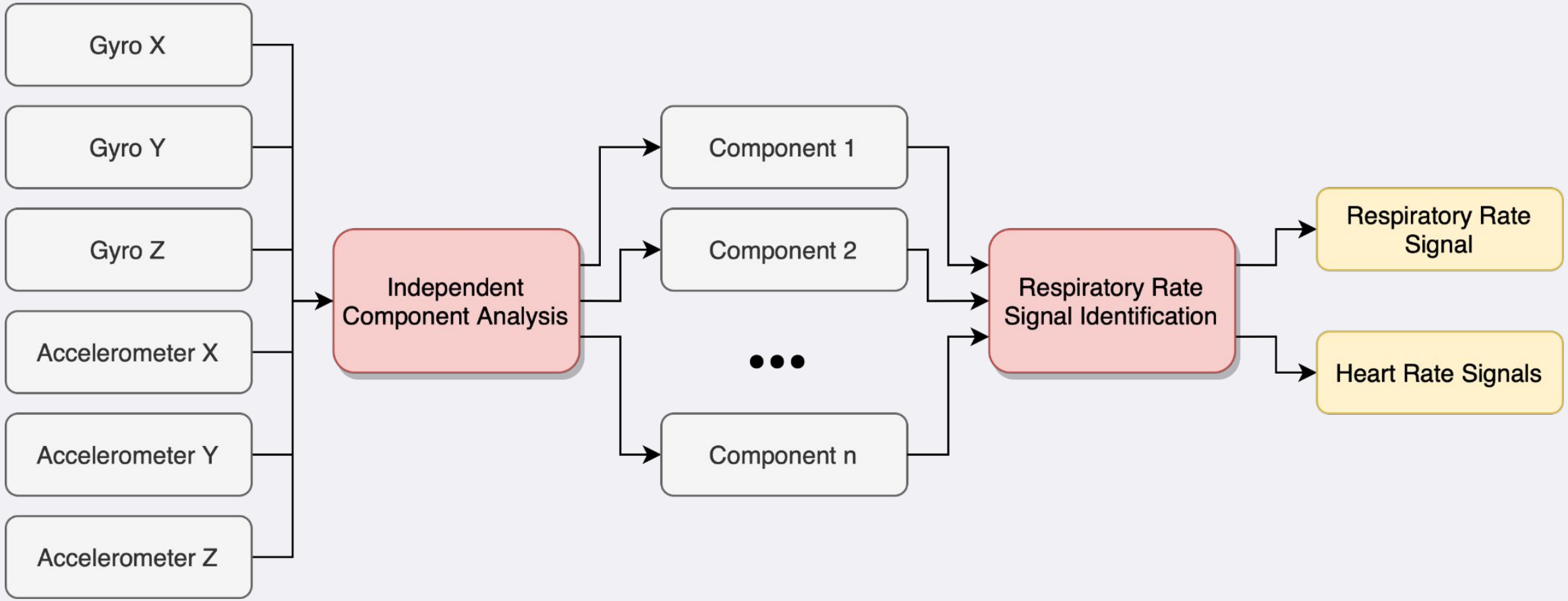
Methodology



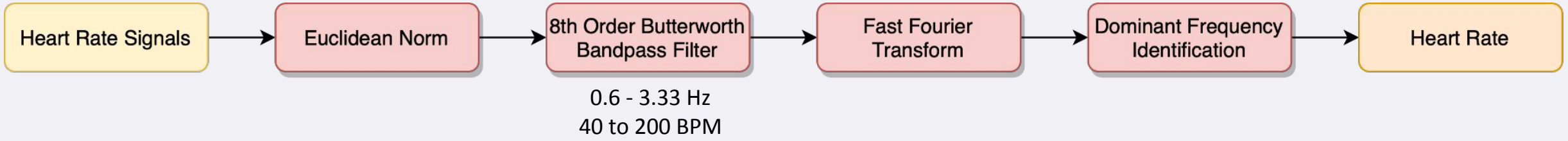
Overview



Model Overview - Signal Separation



Model Overview - Frequency Identification



Independent Component Analysis

- Blind source separation technique
- Assume HR and RR to be statistically independent and non-gaussian
- **Problems:**
  - Generation of components not guaranteed
  - Identification not straightforward

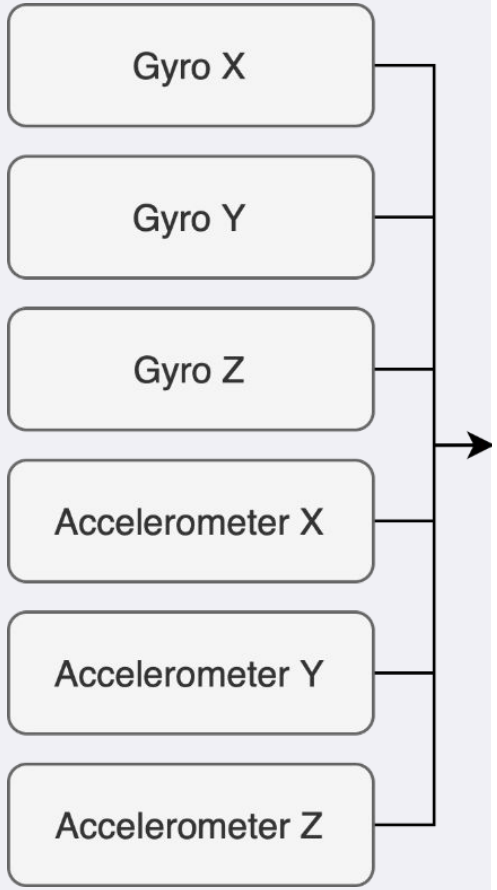
RR Signal Identification

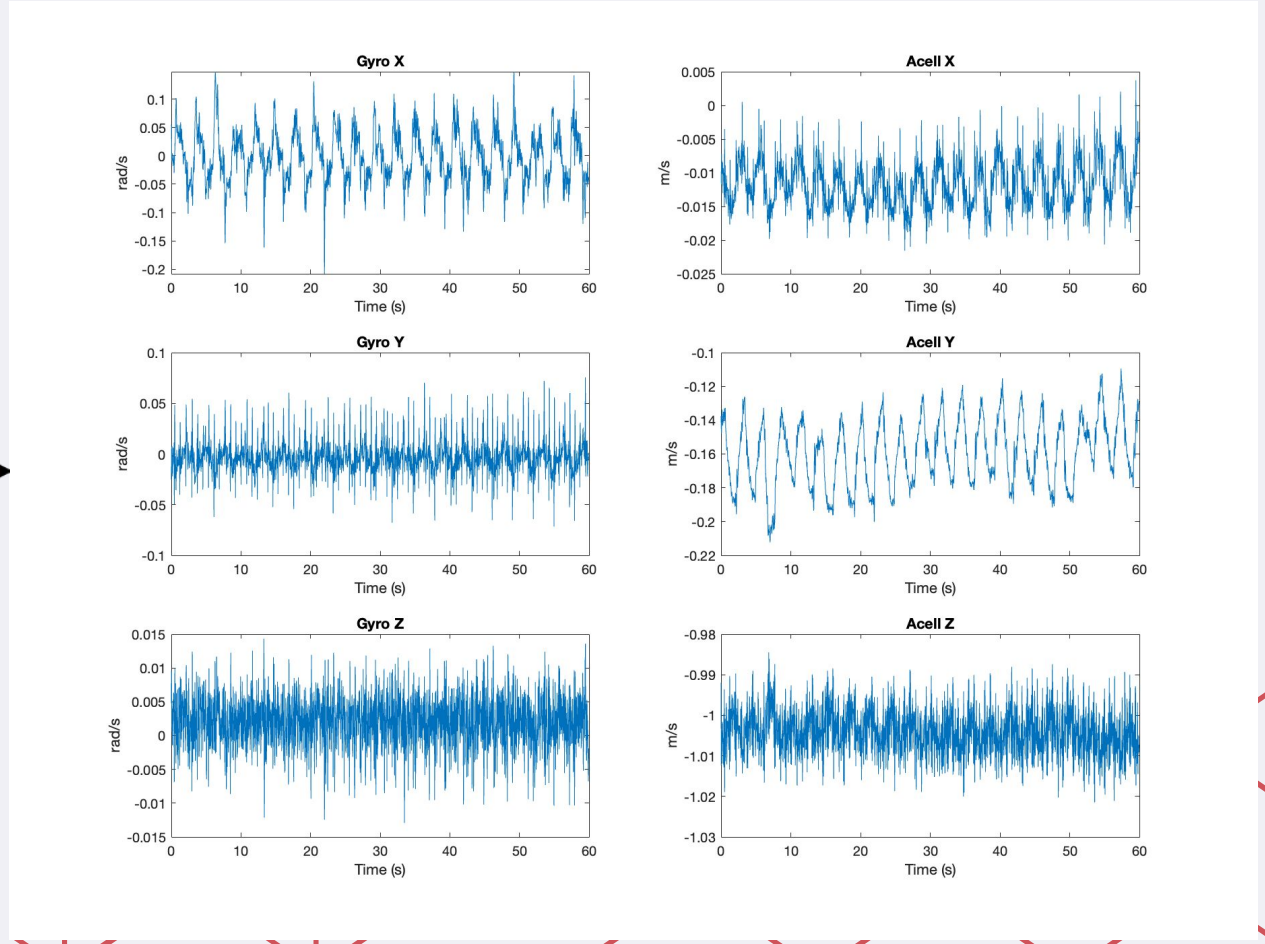
- Respiratory Rate Signal resembles a simple sine wave.
- Correlation of each component to a sine wave
- Select most similar component

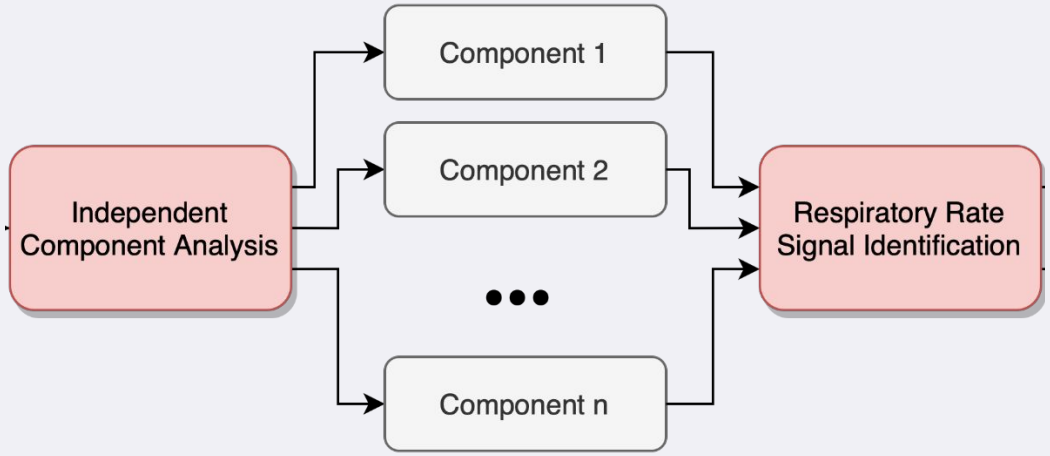
.2

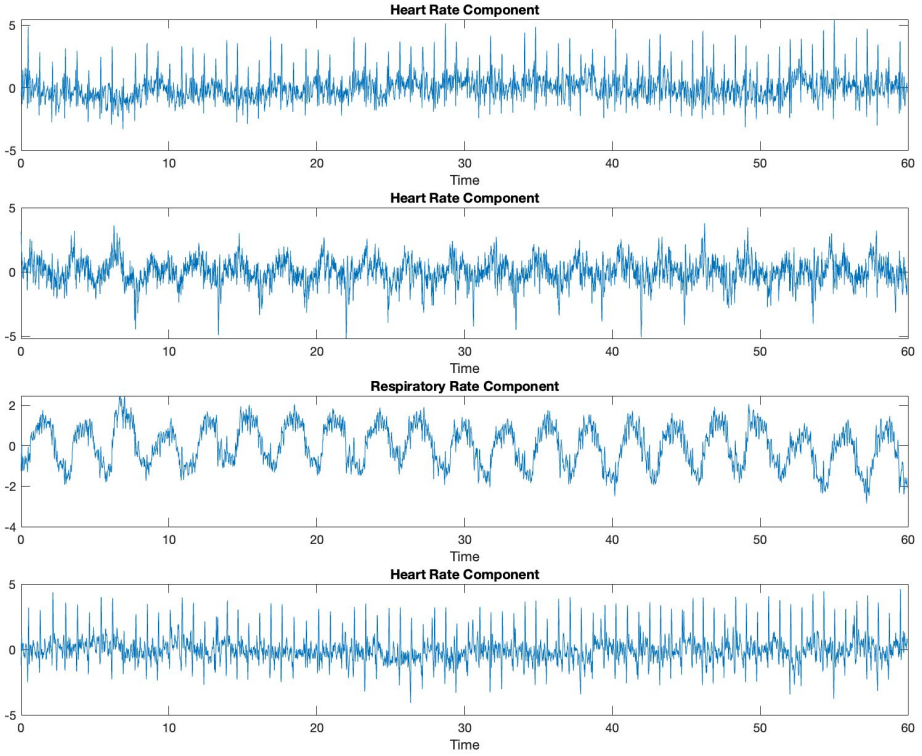
Sample Execution
Subject 21 RR 80 BMP

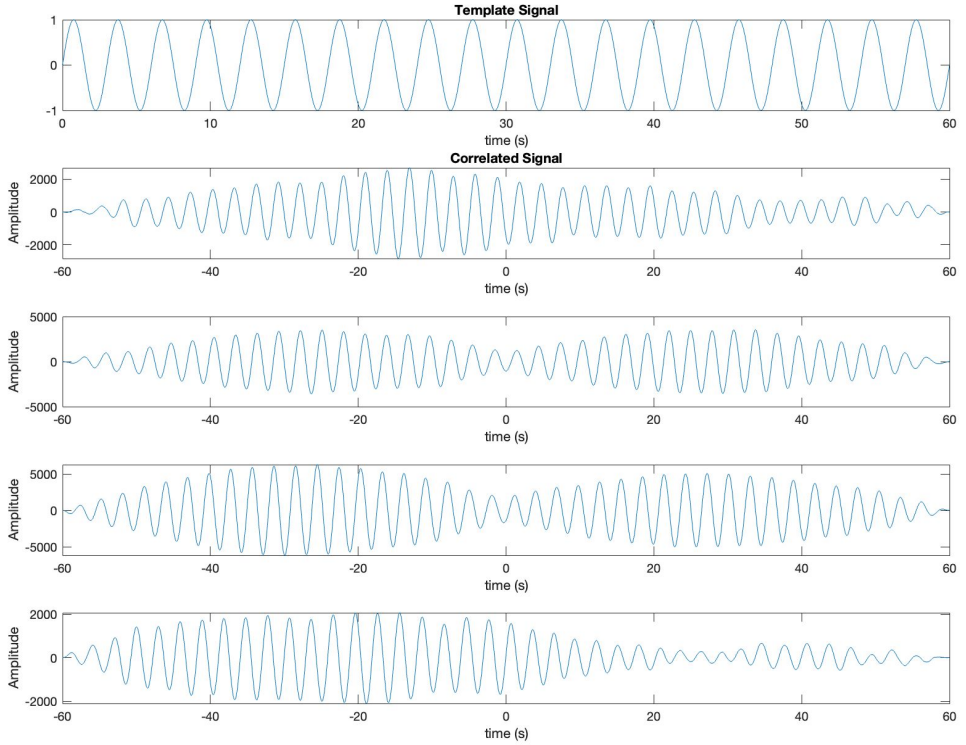
Sample Execution - Subject 21 **RR** 80 **BPM**

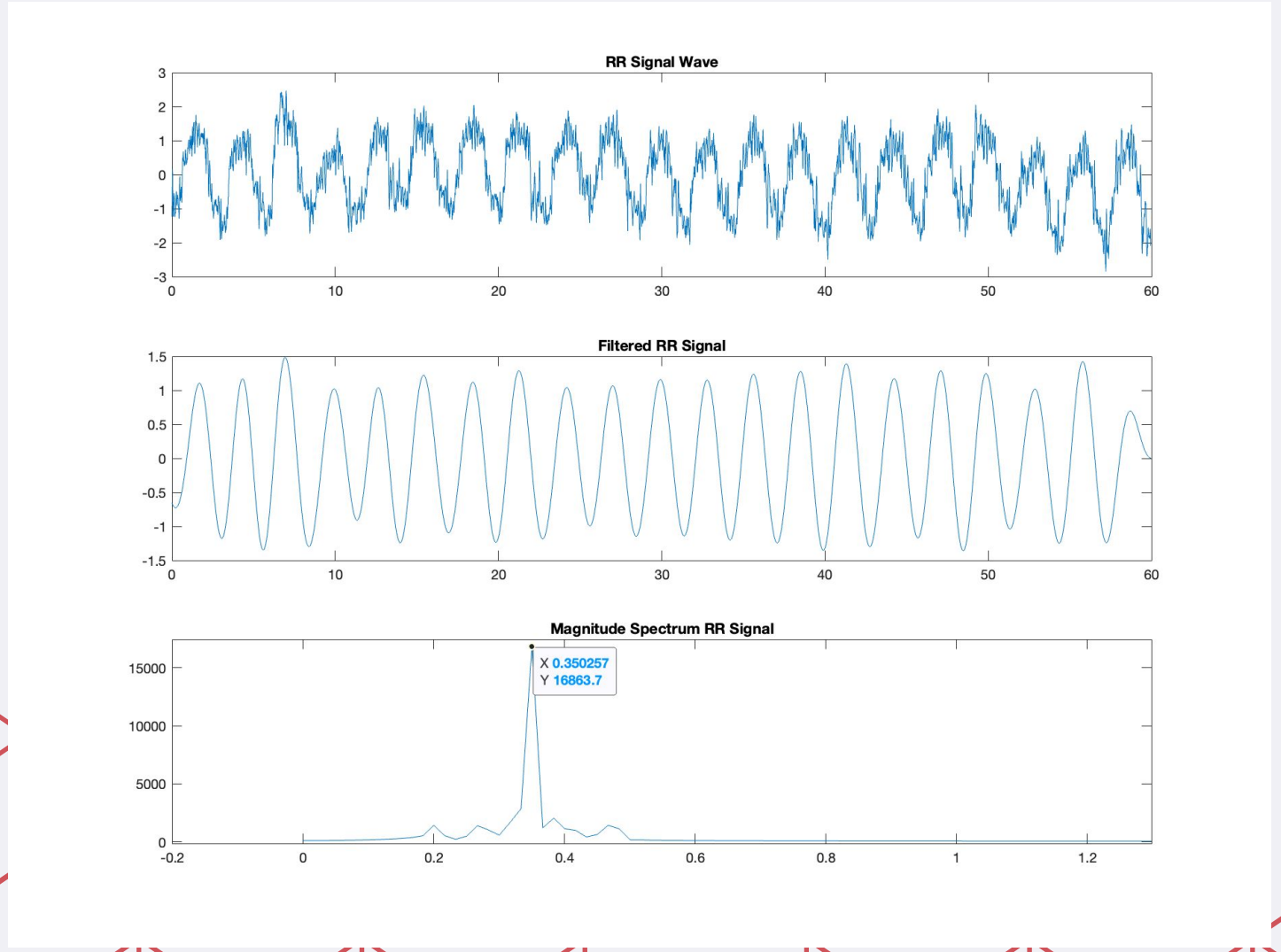




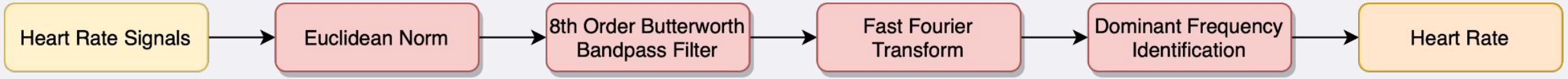

Component 1
Component 2
Component n
Independent Component Analysis
Respiratory Rate Signal Identification

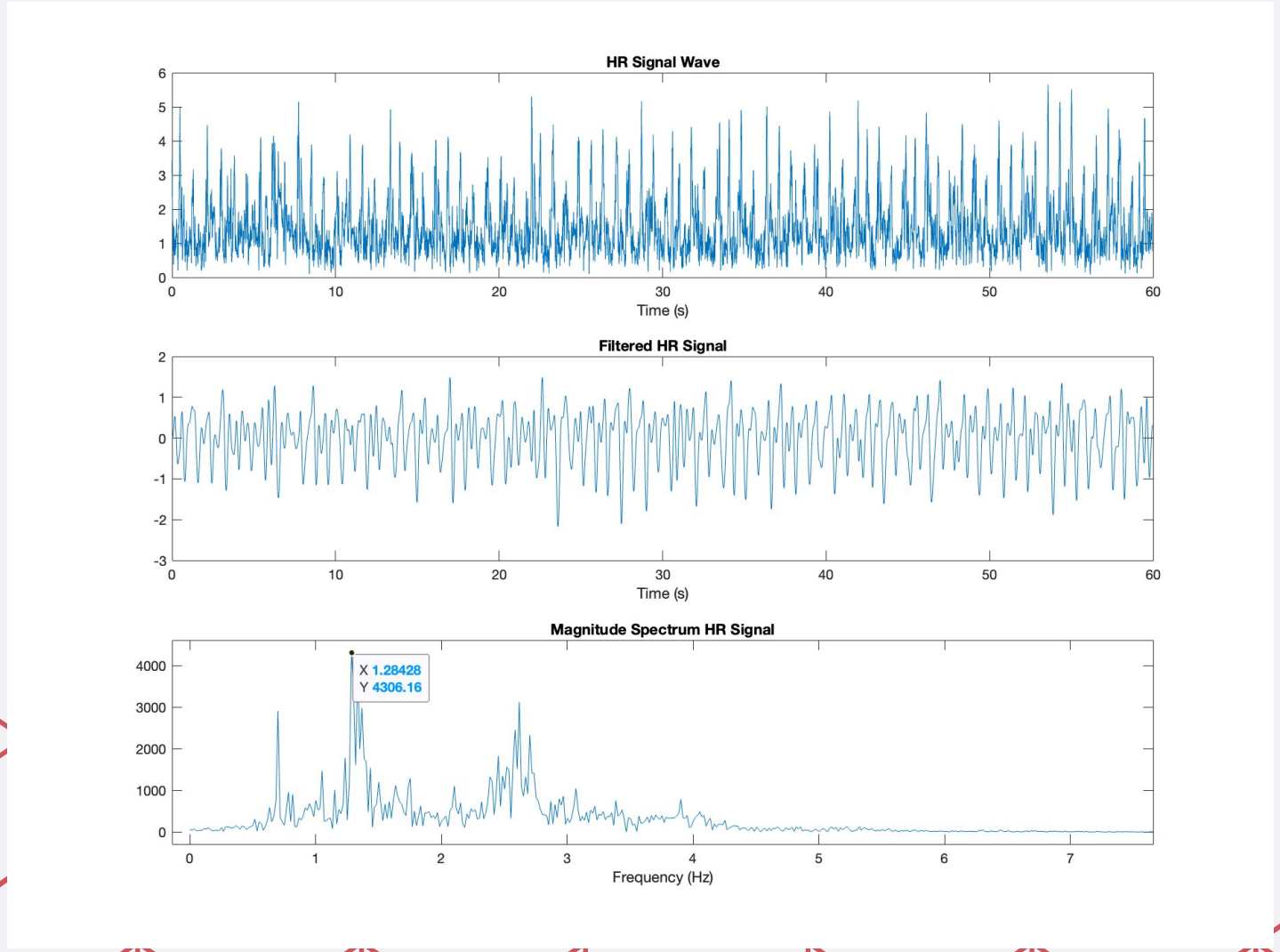

Heart Rate Component
Time
Heart Rate Component
Time
Respiratory Rate Component
Time
Heart Rate Component
Time


Template Signal
time (s)
Correlated Signal
Amplitude
time (s)
Amplitude
time (s)
Amplitude
time (s)
Amplitude
time (s)



0.350257*60
=
~21 RR





1.28428*60
=
~77 BPM

03

Experimental Setup & Validation

Experimental Setup

- 30 Repetitions on the 30 samples dataset
- 4 Components
- Metrics
  - Mean Absolute Error
  - Root Mean Squared Error
  - Accuracy

Final Results

	Mean Absolute Error	Root Mean Squared Error	Accuracy
Respiratory Rate	0.71	2.69	0.82
Heart Rate	6.84	14.57	

04

Conclusions and Future Work

Conclusions

- Results were favorable and consistent for the respiratory rate
- The heart rate provides an good initial estimate but error could be reduced
- The heart rate error can be also higher due to the oximeter error

Future Work

- Implement iOS App for Monitoring Signals
- Improve sensor fusion by Kalman Filters
- Apply PCA before performing ICA
- Design an identification method of heart rate signal

References

1. Bates, Andrew, et al. “Respiratory rate and flow waveform estimation from tri-axial accelerometer data.” *International Conference on Body Sensor Networks*. IEEE, 2010.
2. Lapi, Sara, et al. “Respiratory rate assessments using a dual-accelerometer device.” *Respiratory physiology & neurobiology* 191 (2014): 60-66.
3. Jia, Wenyan, et al. “Estimation of heart rate from a chest-worn inertial measurement unit.” *International Symposium on Bioelectronics and Bioinformatics (ISBB).* IEEE, 2015.
4. Lahdenoja, Olli, et al. “Heart rate variability estimation with joint accelerometer and gyroscope sensing.” *Computing in Cardiology Conference (CinC)*. IEEE, 2016.
5. Hernandez, Joel Ezequiel, and Edmond Cretu. “Simple heart rate monitoring system with a MEMS gyroscope for sleep studies.” *IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON).* IEEE, 2018.

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Thank You! Questions?