A robust fetal ECG detection method for abdominal recordings

Porcelli Angelica – 78083A

Biomedical Signal Processing

Table of content

Fetal ECG Extraction Challenges

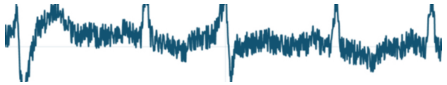
When recording **abdominal ECG** from a *pregnant woman*, the signal is a **mixture** of different physiological and non-physiological components:

1. **Maternal ECG (MECG)**

x10

2. **Fetal ECG (FECG)**

3. **Noise and artifacts**



What is the paper approach ?

The paper proposes a **sequential, physiologically-informed approach**.

The idea is:
instead of trying to separate everything at once (as ICA does), remove problems **one by one**, in a meaningful order.

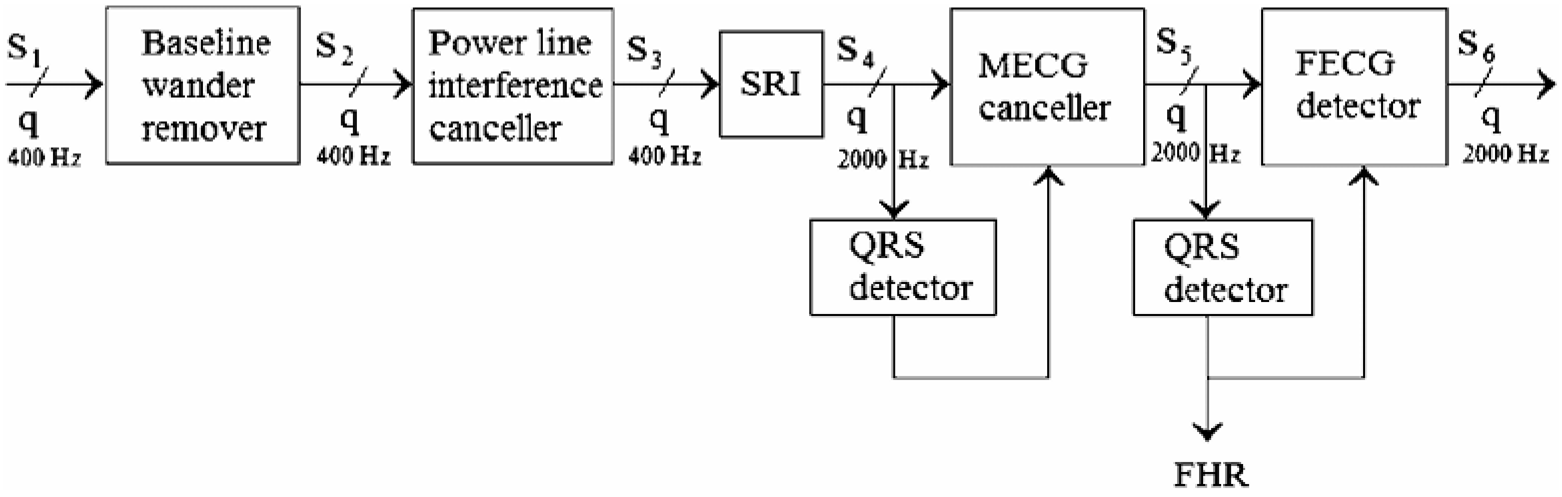
The algorithm:

7 step, and **each block removes a specific distortion.**

Table of content

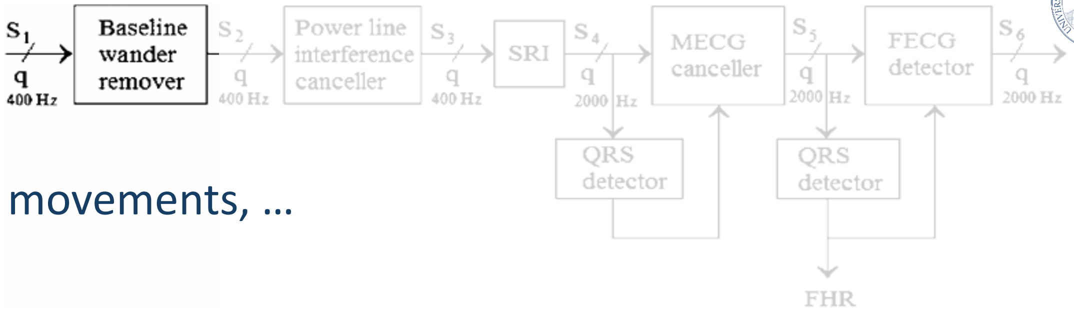
The Algorithm

1. Remove baseline
2. Remove powerline
3. Increase samplings
4. Maternal QRS detector
5. MECG Canceller
6. Fetal QRS detector
7. FECG detector



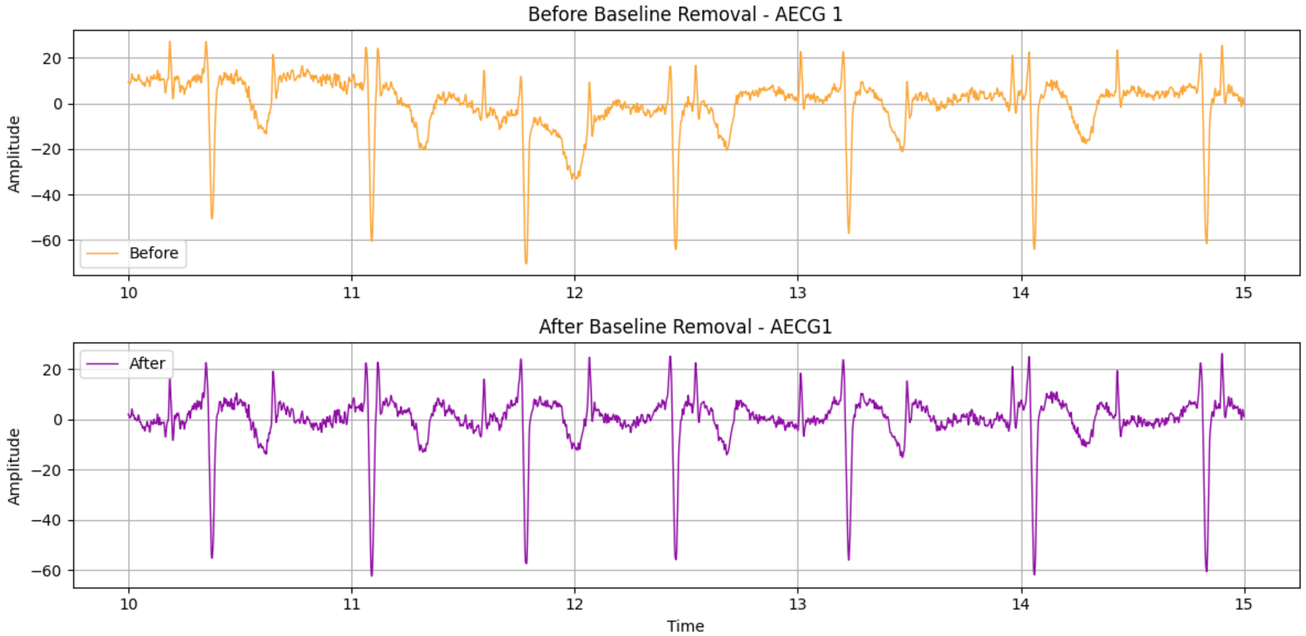
1. Remove Baseline

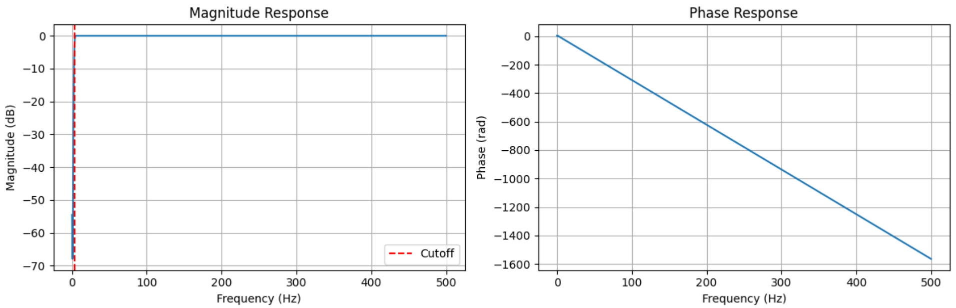
Objective: **remove slow oscillations** caused by breathing, body movements, …



High-pass FIR filter :

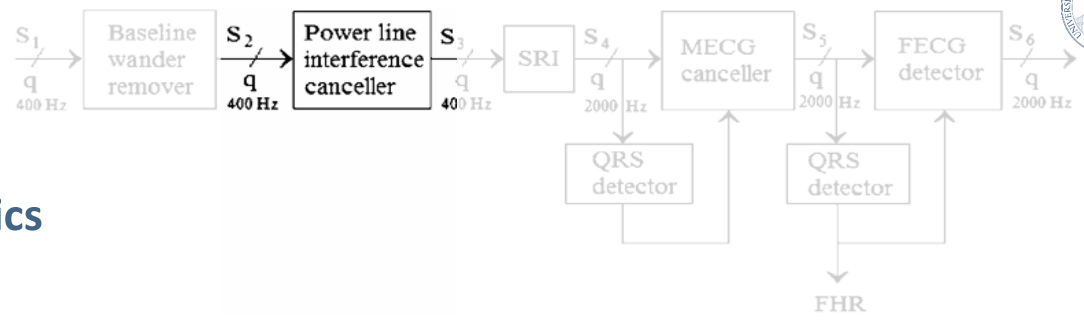
- 1000 + 1 coefficients
- 3 Hz cutoff frequency
- Window Hamming



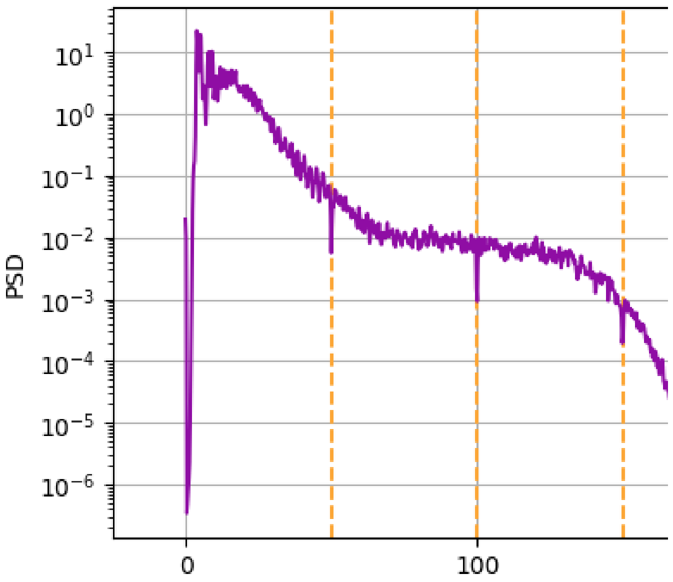


S1 → S2

2. Remove Powerline



Objective: **remove 50 Hz** electrical **interference** and its **harmonics**



Use of **adaptive noise cancelling** (ANC):

- Estimates the 50 Hz interference using *model*

$$\hat{d}(t) = A(t)\sin(\phi(t)) + B(t)\cos(\phi(t))$$

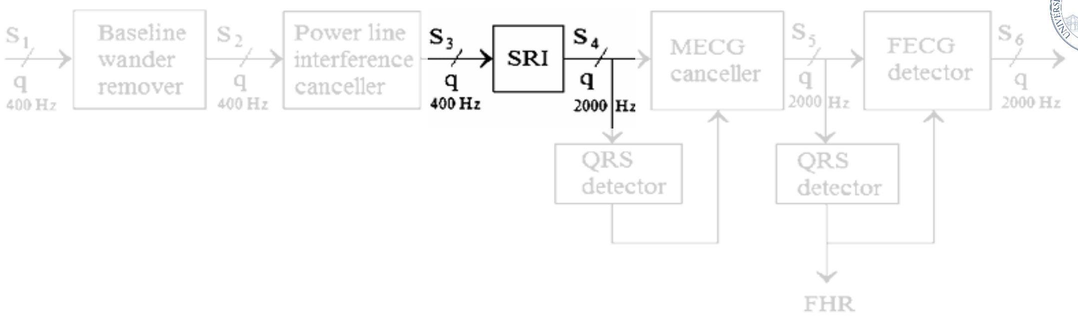
Clean Signal → Update of Coefficients → Phase Adaptation

using an LMS rule driven
by the residual error

S2 → S3

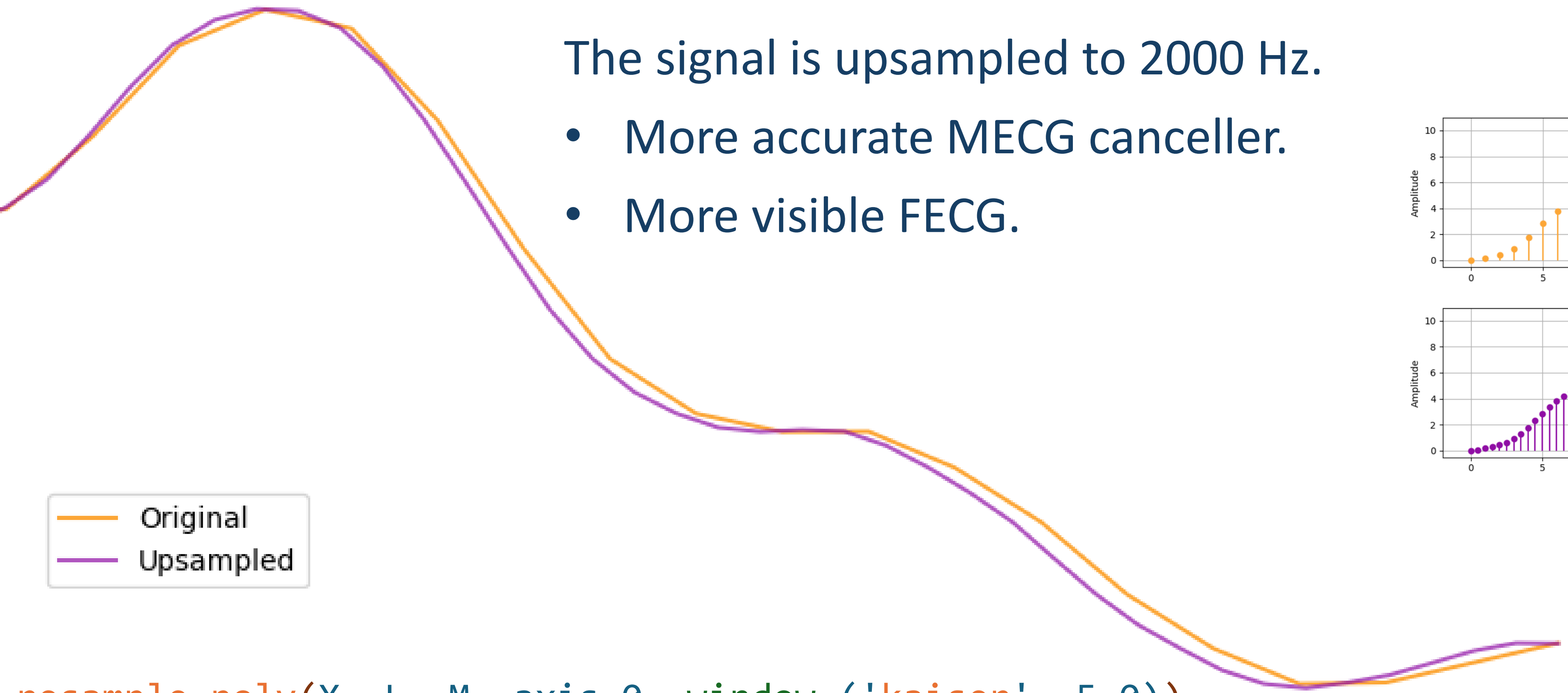
3. Increase samplings

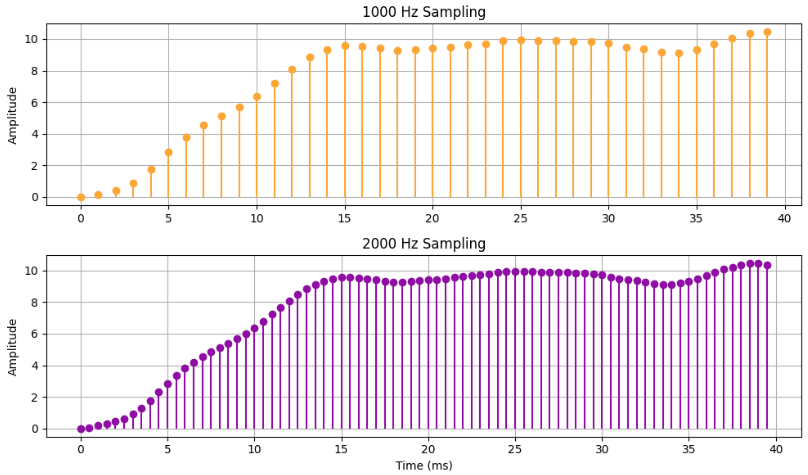
Objective: **improve temporal resolution** and QRS alignment



The signal is upsampled to 2000 Hz.

- More accurate MECG canceller.
- More visible FECG.

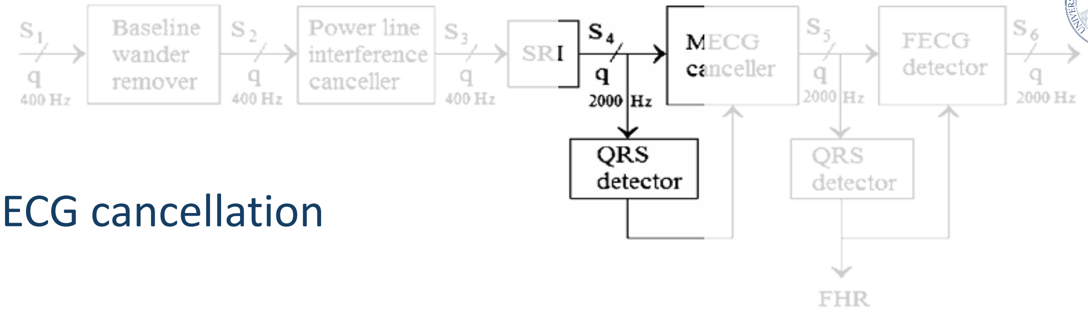





```
resample_poly(X, L, M, axis=0, window=('kaiser', 5.0))
```

S3 → S4

4. M-QRS Detection



Objective: **identify maternal QRS** complexes to enable correct ECG cancellation

1. PCA enhancement

PCA-based multichannel QRS enhancement

Extract PC1

2. Rough detection

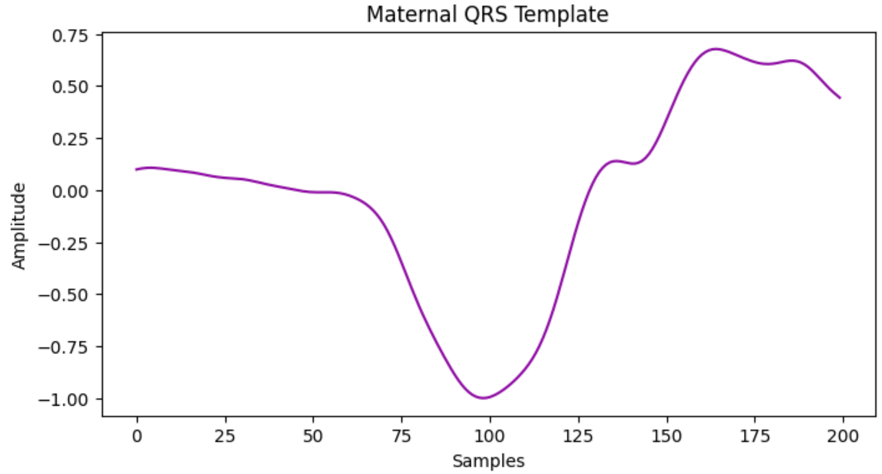
Cross-correlation with a synthetic QRS template

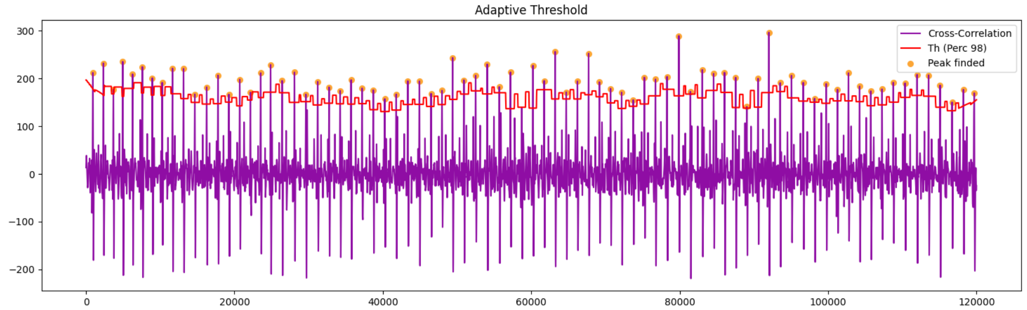
3. Real Template

Averaging of **±50 ms** segments around subset

4. Final detection

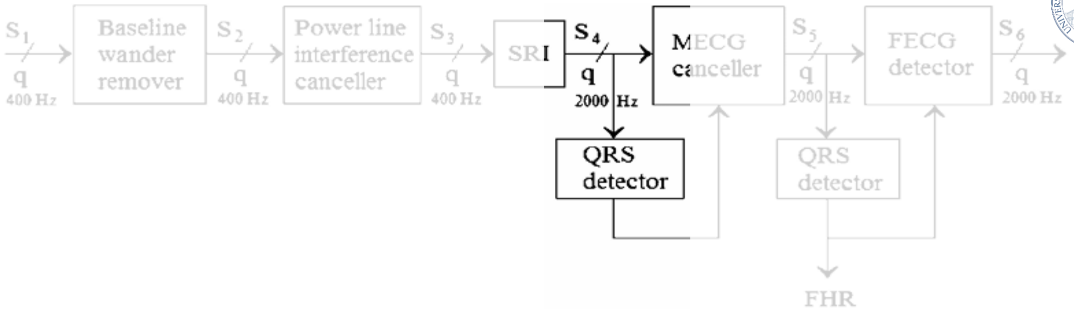
Cross-correlation with QRS template

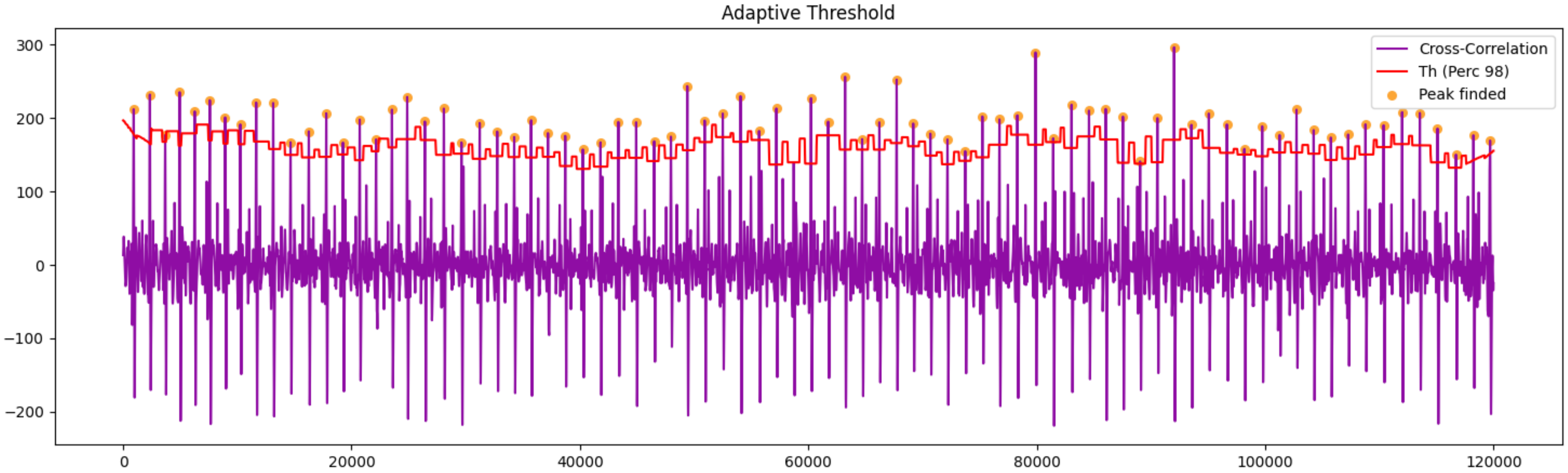




S4 → MQRS

4. M-QRS Detection



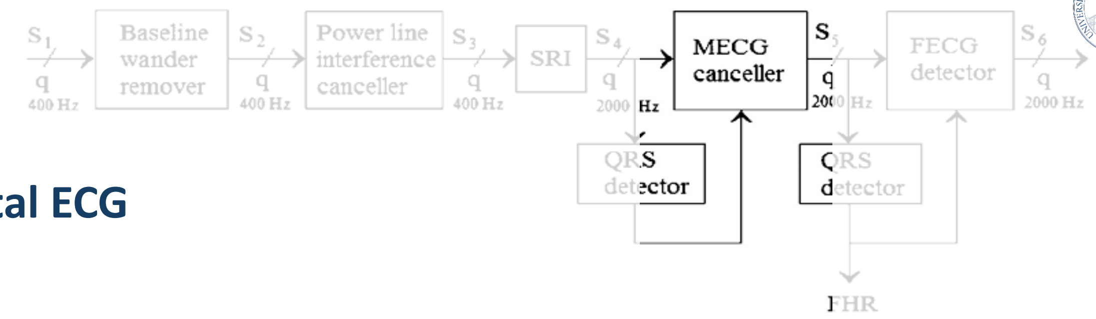



```
refractory_ms = 300, refine_ms = ±40,  duration_ms = 100
```

S4 → MQRS

5. MECG Canceller

Objective: **remove maternal ECG** (MECG) while **preserving fetal ECG**



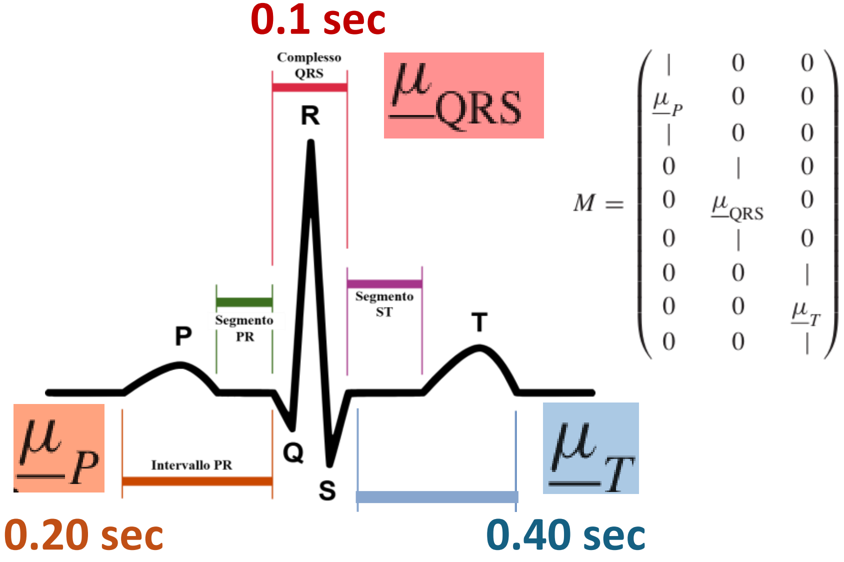
1. Extract window

$$m(t) = S4[R - 250\,ms : R + 450\,ms]$$

2. Create a template

$$\mu(t) = \frac{1}{N}\sum_{i=1}^{N} m_i(t)$$

3. Split and create matrix



4. Find adaptive scaling

$$\underline{a} = (M^T M)^{-1} M^T \underline{m}$$

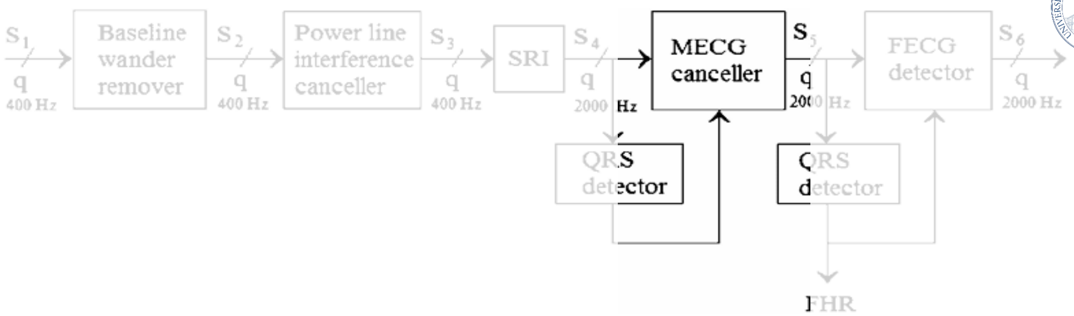
$$\widehat{\underline{m}} = M\underline{a}$$

5. Template subtraction

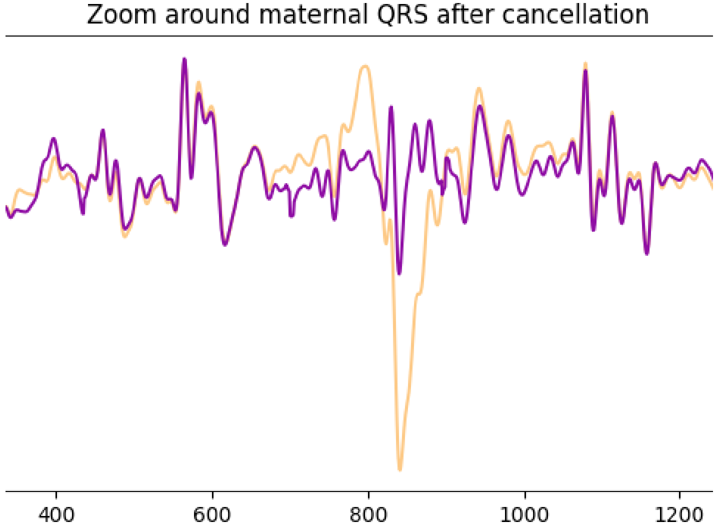
$$S5(t) = S4(t) - \hat{m}(t)$$

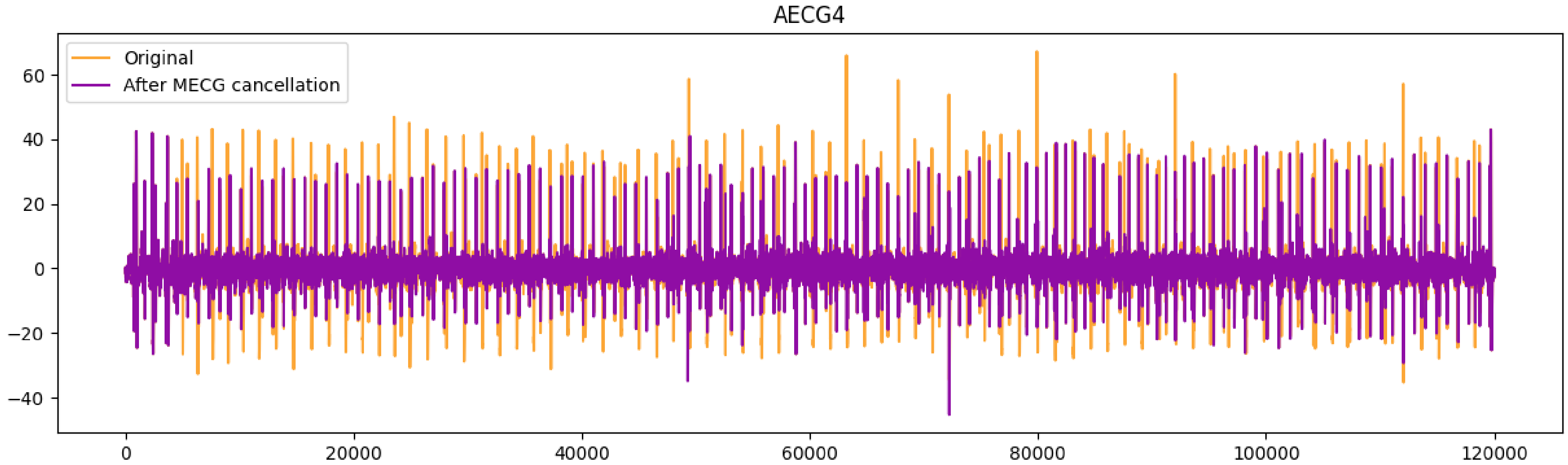
S4 → S5

5. MECG Canceller




```python
for i in range(3):
    S4 = mecg_canceller(S4, mQRS, fs_up, N=N)
```

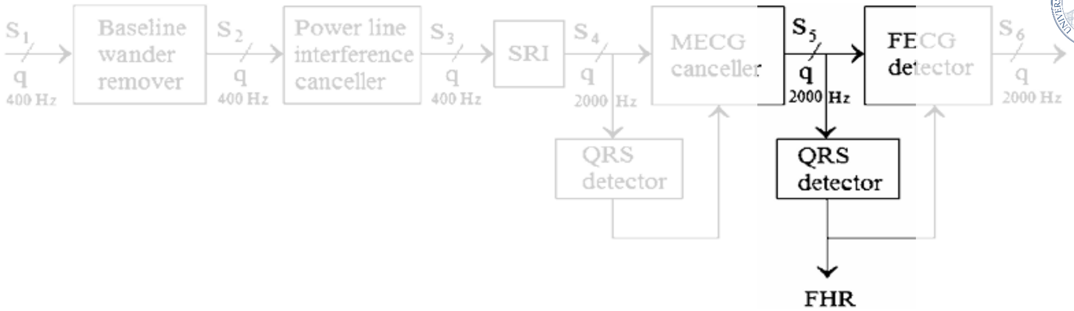




S4 → S5

6. F-QRS Detection

Objective: identify **fetal QRS complexes**

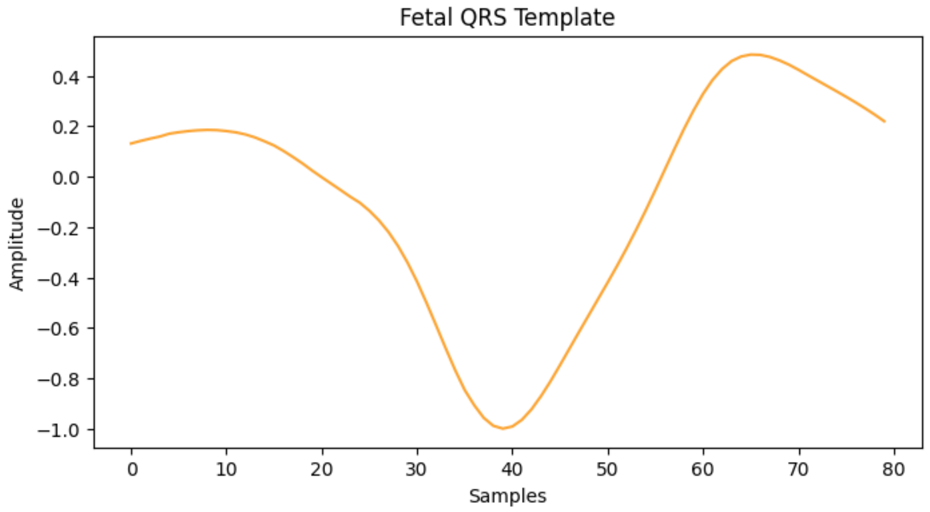


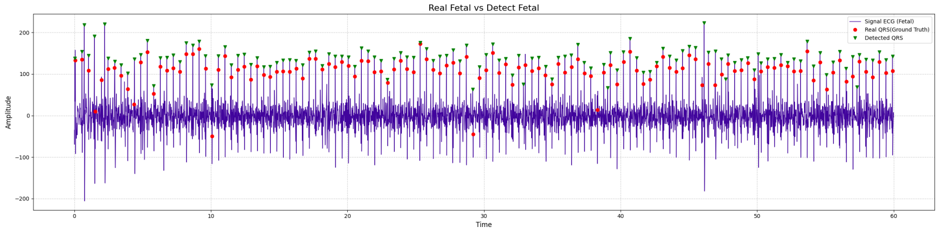
1. **PCA enhancement**
2. **Rough detection**
3. **Real Template**
4. **Final detection**

   short refractory period

   short peak refinement

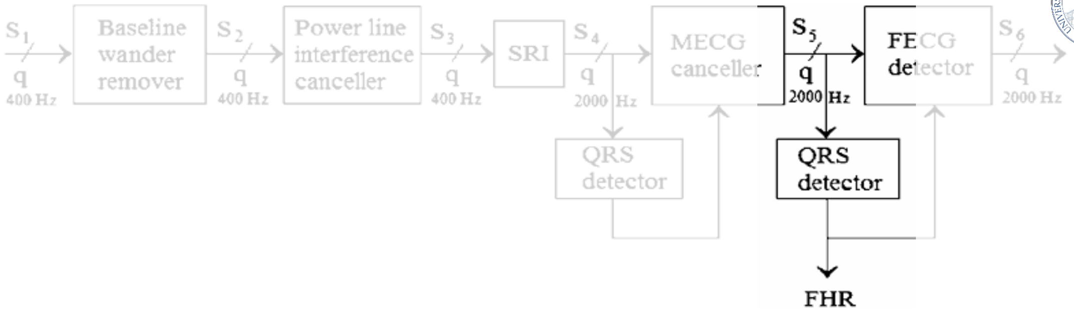
   short duration

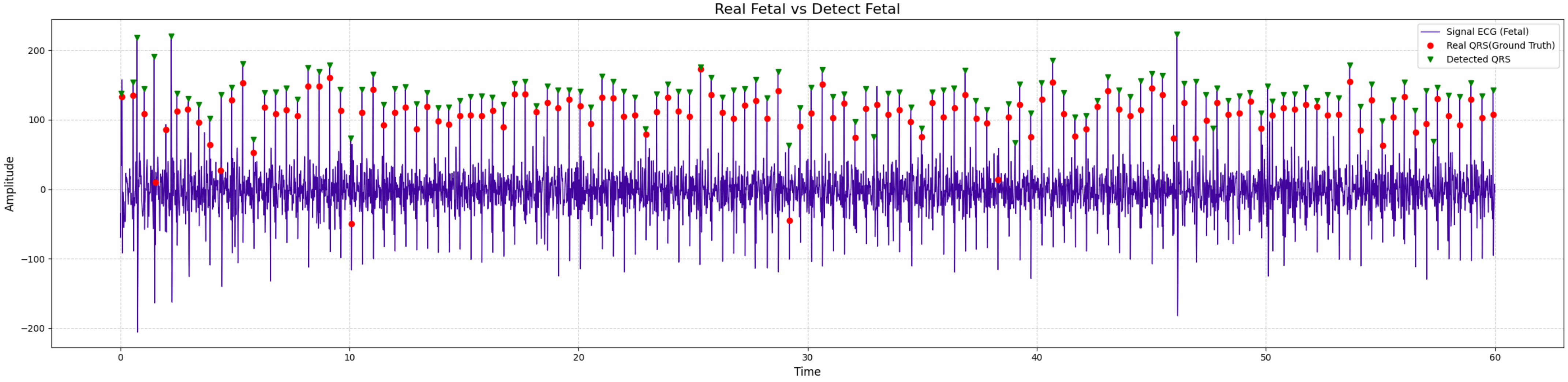




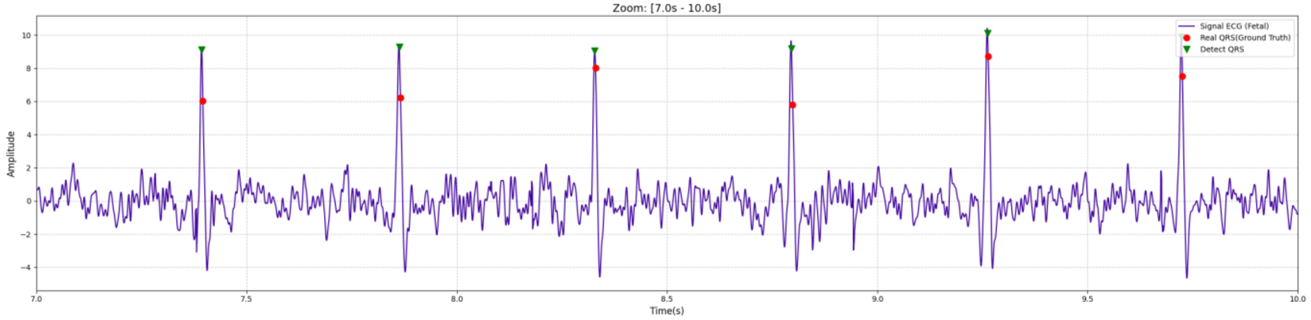
S5 → fQRS

6. F-QRS Detection



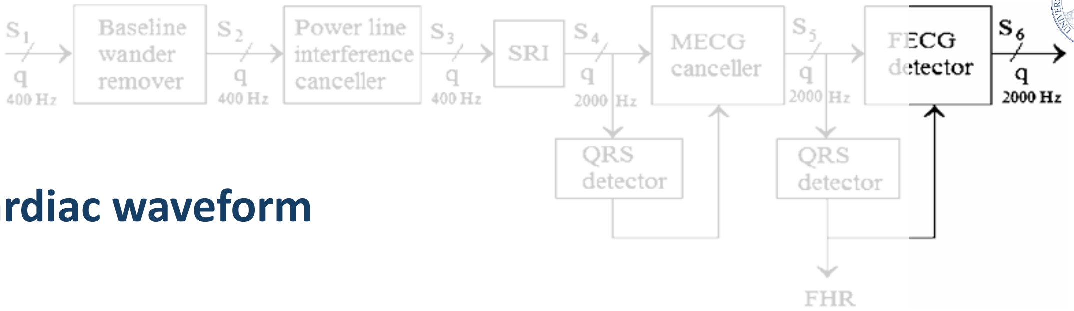



```
refractory_ms = 150,
refine_ms = ±20,
duration_ms = 40
```



S5 → fQRS

7.1 FECG Extraction

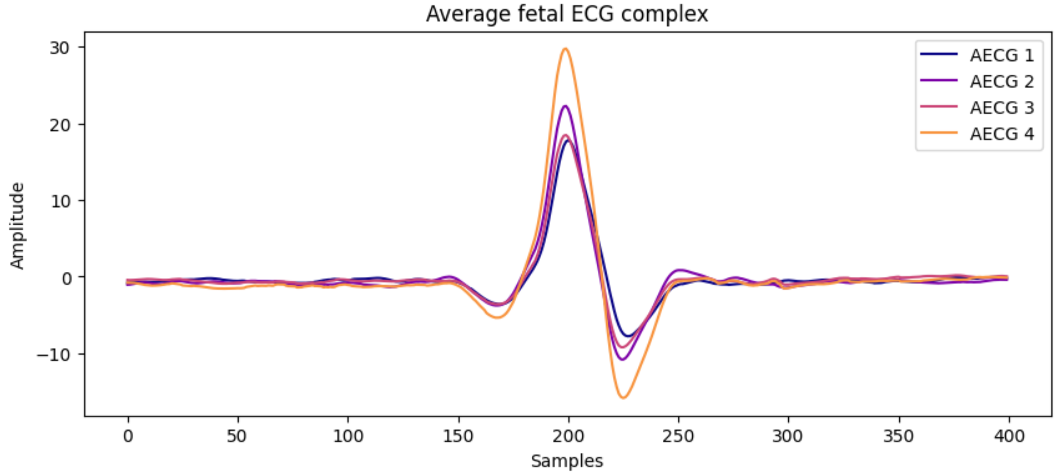


Objective: obtain a clean and reliable estimate of the fetal **cardiac waveform**

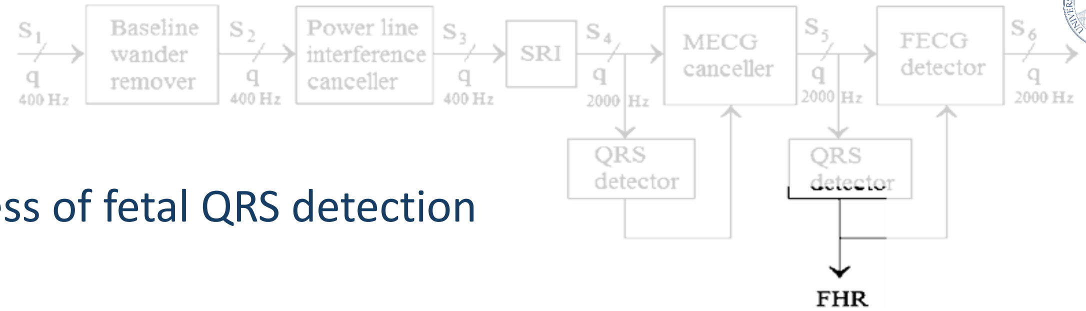
1. **Window extraction:**
   For each fetal QRS, a ±100 ms window centered on the R-peak.

2. **Intrinsic alignment:**
   Since each window is centered on the detected QRS, all segments are aligned.

3. **Ensemble averaging:**
   The first *150** aligned segments are averaged, reducing uncorrelated noise by a factor of √150 ≈ 12.



S5 → S6

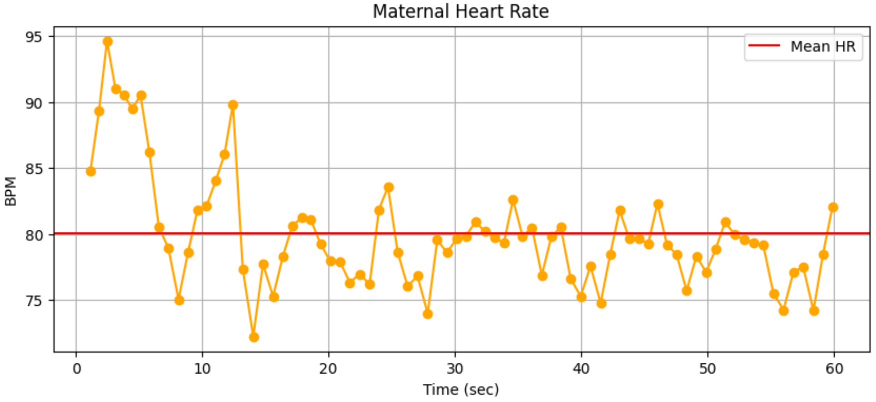


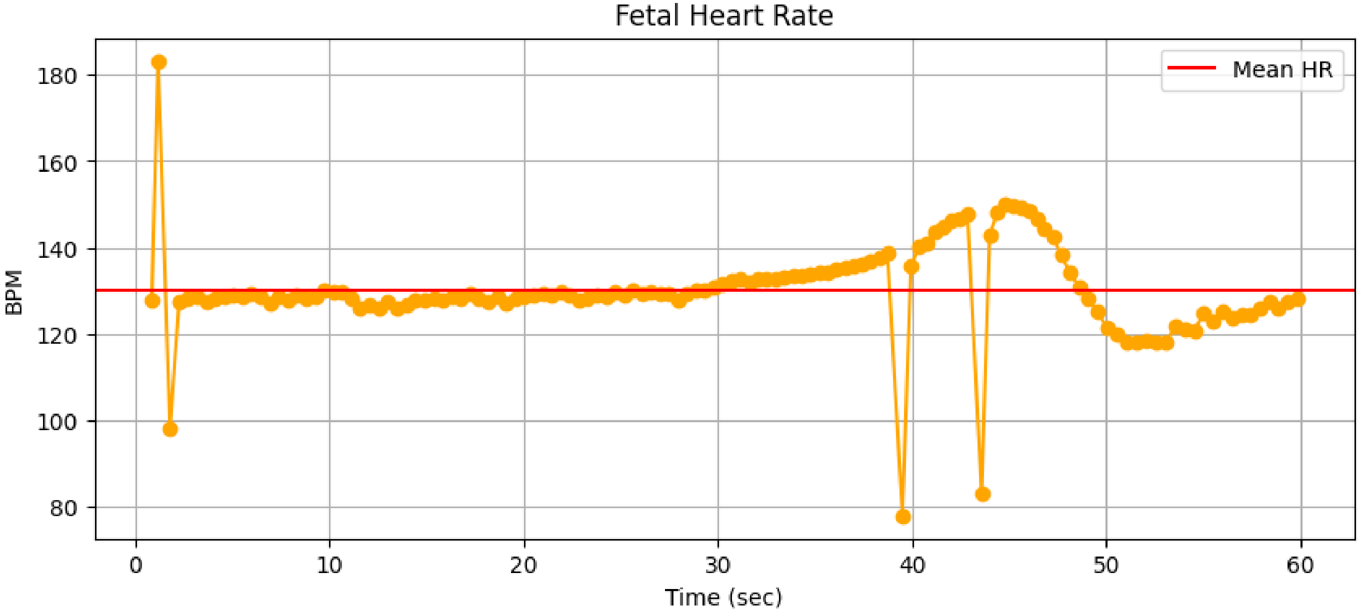
7.2 FHR

Objective: **evaluate the temporal consistency** and correctness of fetal QRS detection

$$RR_i = \frac{R_{i+1} - R_i}{f_s}$$

$$FHR_i = \frac{60}{RR_i}$$





Mean bpm 130.21 detected
Mean bpm 128.76 real

S5 → S6

Table of content

Dataset

PhysioNet Challenge 2013 (Set A): https://physionet.org/content/challenge-2013/1.0.0/

Characteristics:

25 real-world recordings

4 simultaneous abdominal channels

Duration: 60 sec

Sampling frequency: 1000 Hz

+ fQRS annotations

AECG1, AECG2, AECG3, AECG4

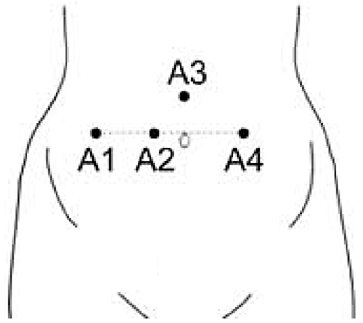


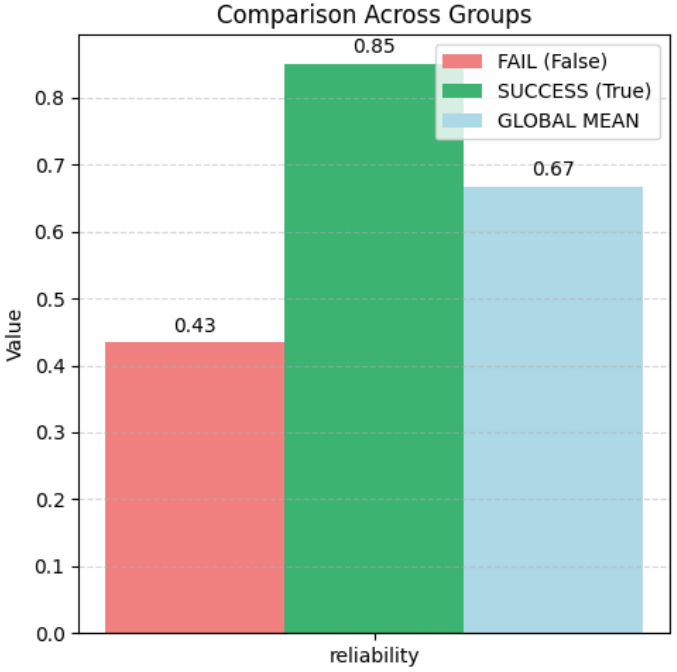
Table of content

Signal quality metrics

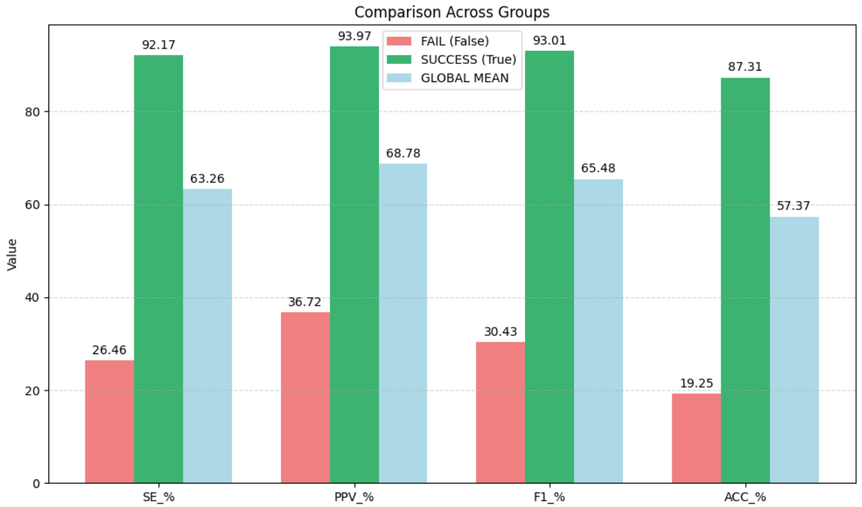
$$Reliability = 1 - \frac{num\_outliers}{total\_point\_FHR}$$

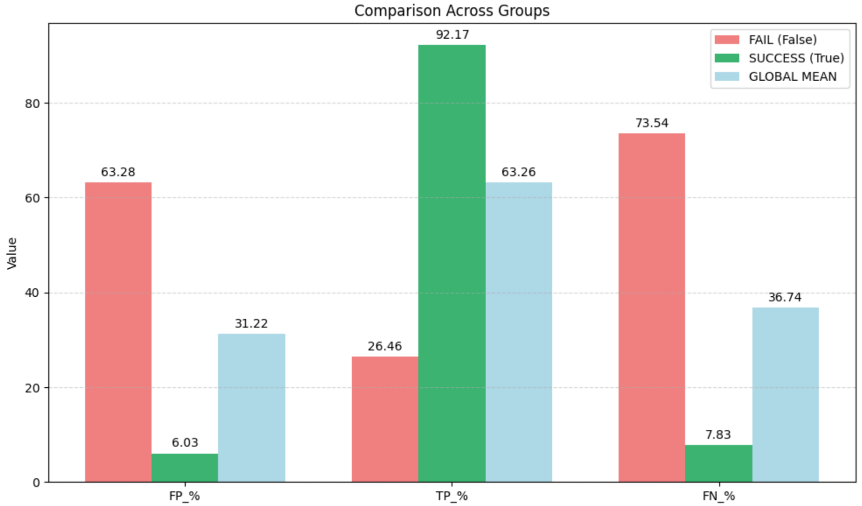
$$num\_outliers = |FHR\ i\ - median\ | > 10\ bpm$$

```
SUCCESS = (60 <= mean_bpm <= 220) and (reliability > 0.60)
```



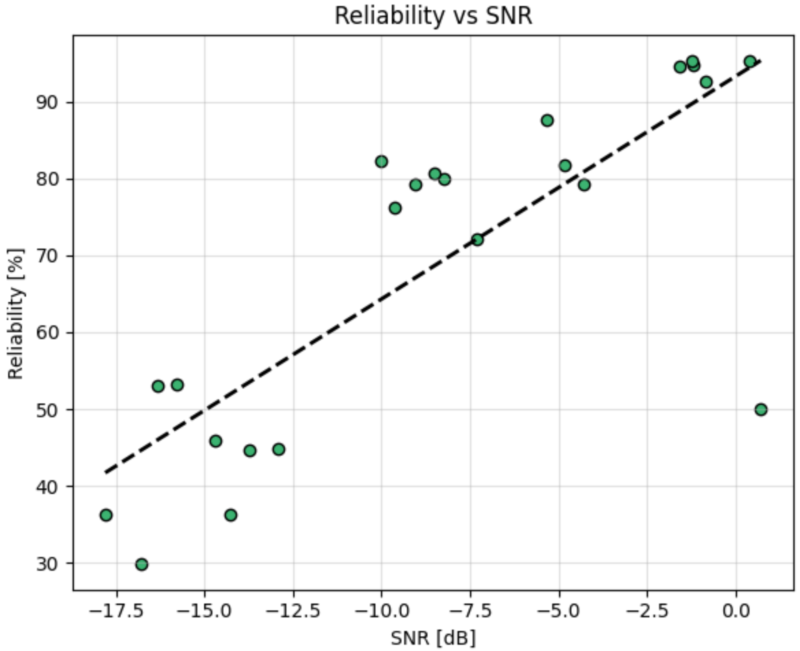
Signal quality metrics

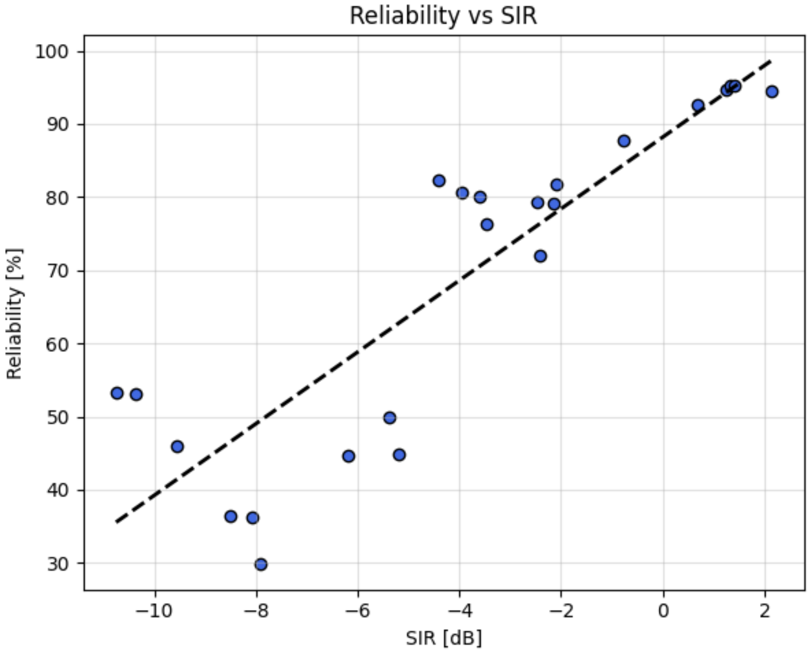




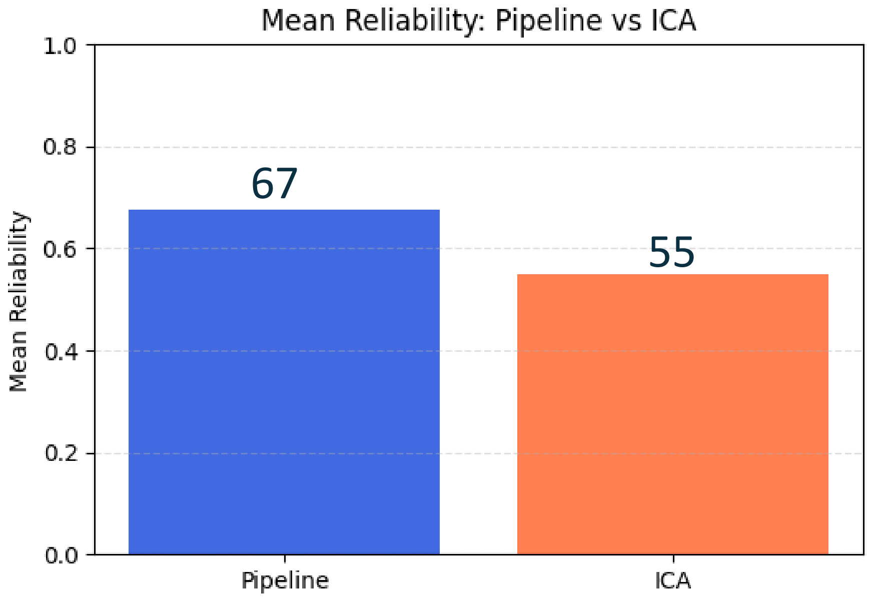
$$\mathrm{SNR}_j = \frac{P_{F_j}}{P_{N_j}} = \frac{P_{S_{6,j}}}{P_{S_{5,j}-S_{6,j}}},$$

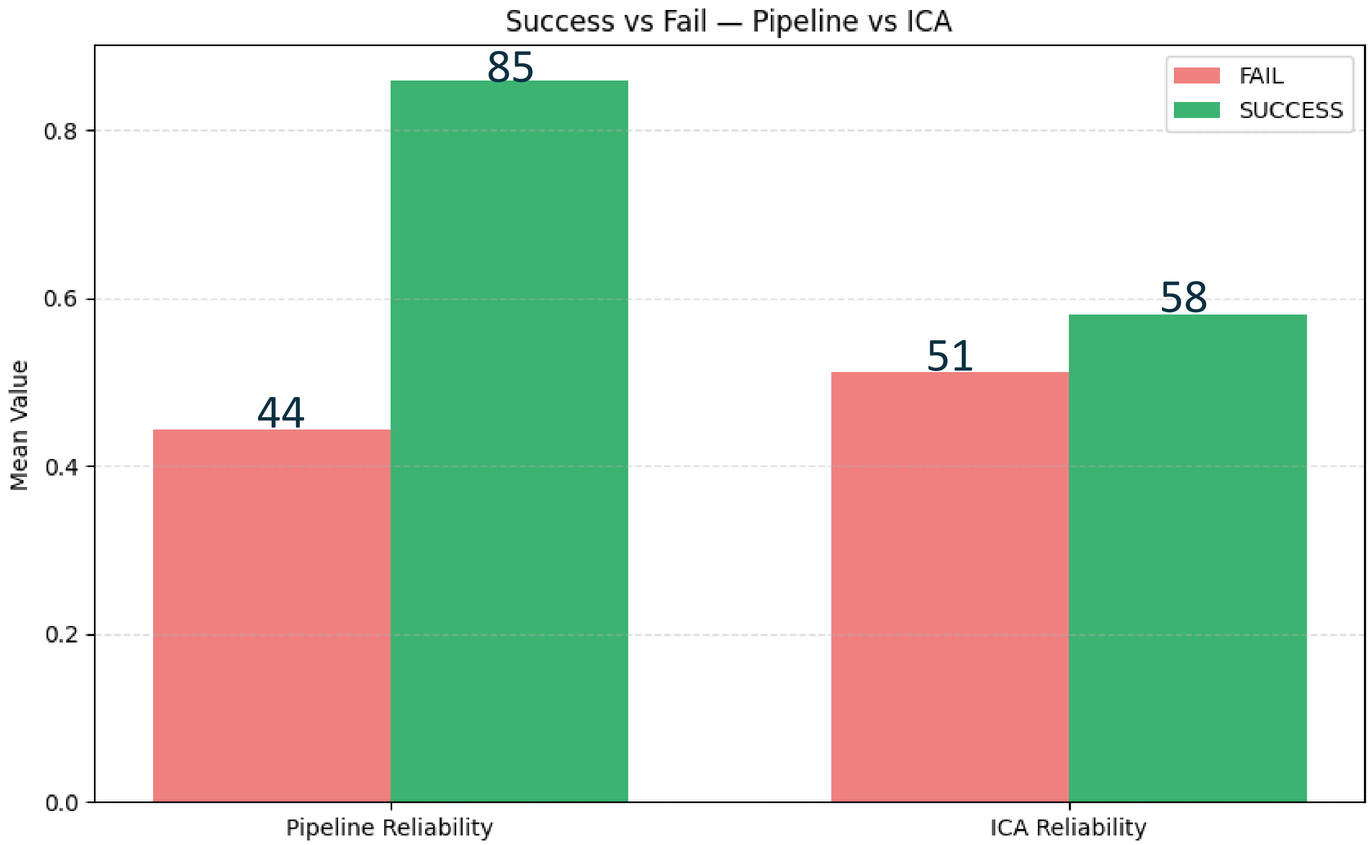
$$\mathrm{SIR}_j = \frac{P_{F_j}}{P_{M_j}} = \frac{P_{S_{6,j}}}{P_{S_{4,j}-S_{5,j}}}.$$



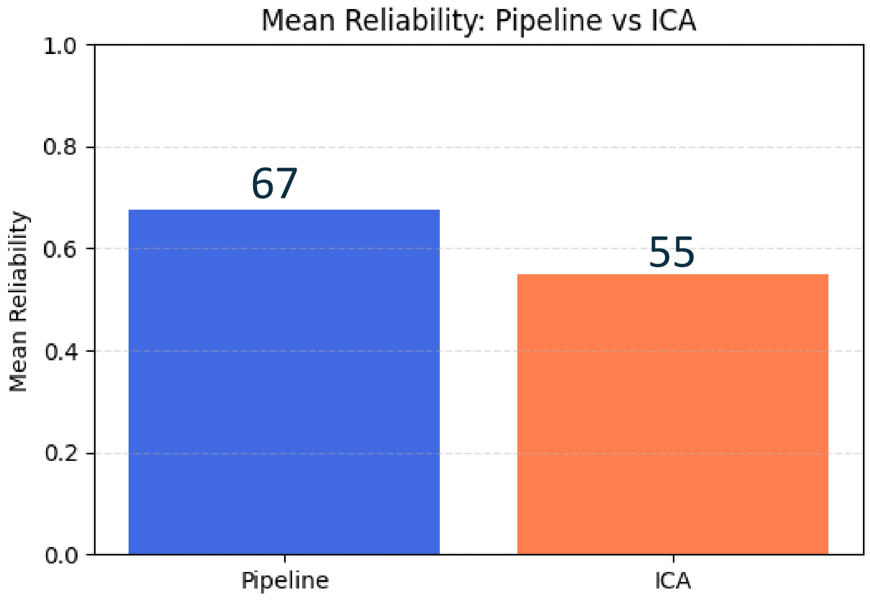


Comparison with FastICA





Comparison with FastICA



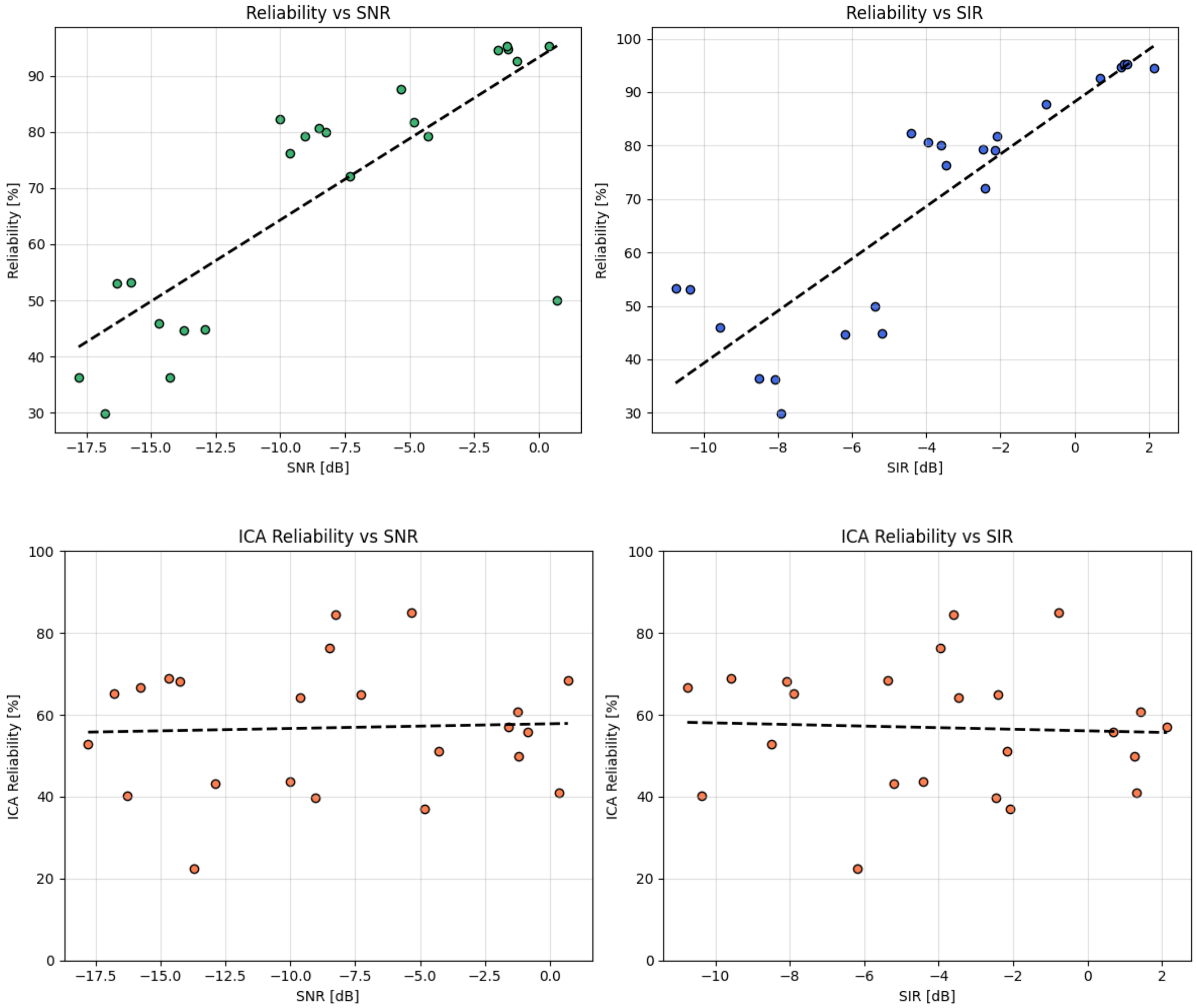
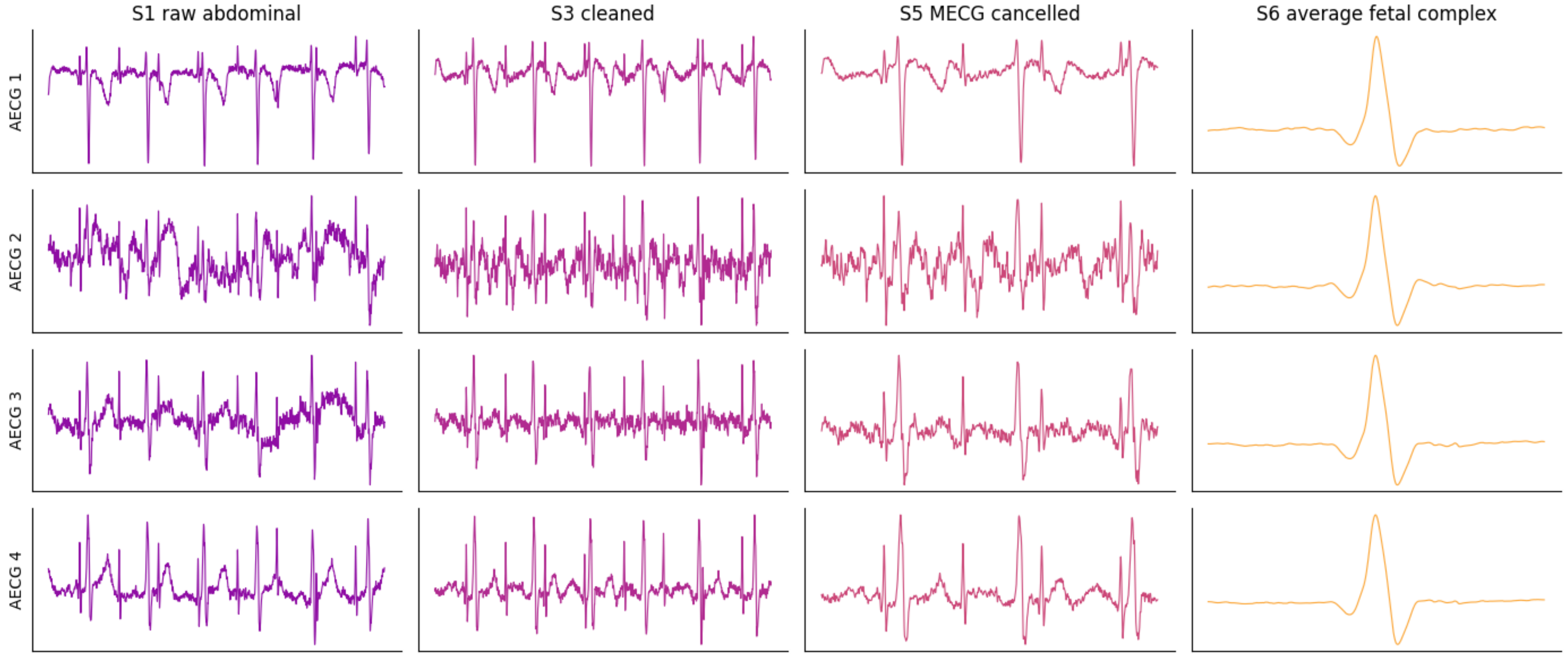


Table of content

Conclusion

Non-blind methods outperform blind ICA.

The **paper-pipeline** is more **controllable** and consistent with **SNR/SIR**, while **FastICA** shows **higher variability**.



Thanks

Porcelli Angelica – 78083A

Biomedical Signal Processing