



A robust fetal ECG detection method for abdominal recordings

Porcelli Angelica

Biomedical Signal Processing



Table of content

- ▶ Introduction
- ▶ The algorithm
- ▶ Dataset
- ▶ Result
- ▶ Conclusion



Fetal ECG Extraction Challenges

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

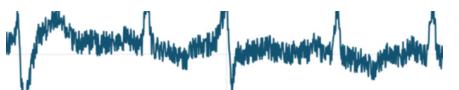
1. **Maternal ECG (MECG)**



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.

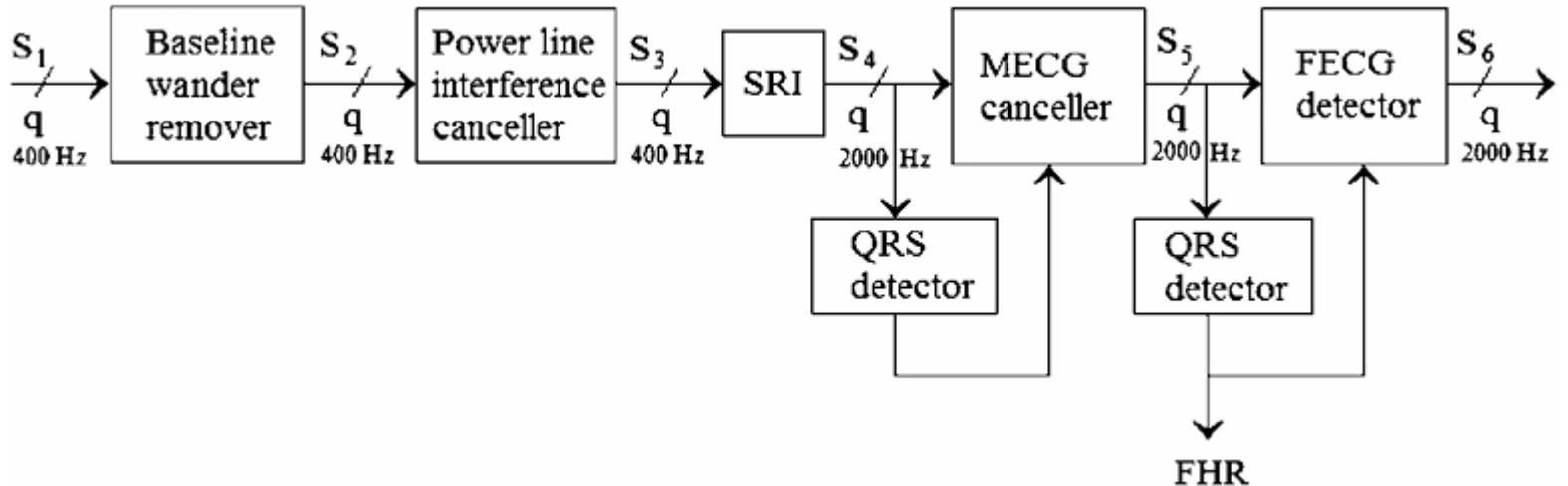


Table of content

- ▶ Introduction
- ▶ The algorithm
- ▶ Dataset
- ▶ Result
- ▶ Conclusion

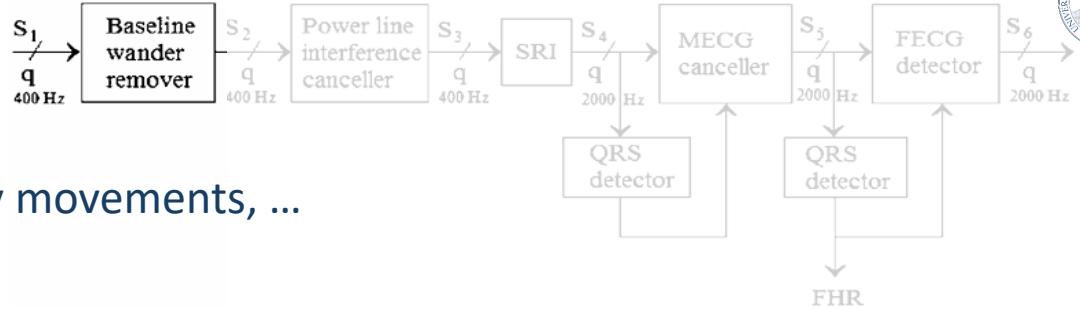
The Algorithm

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



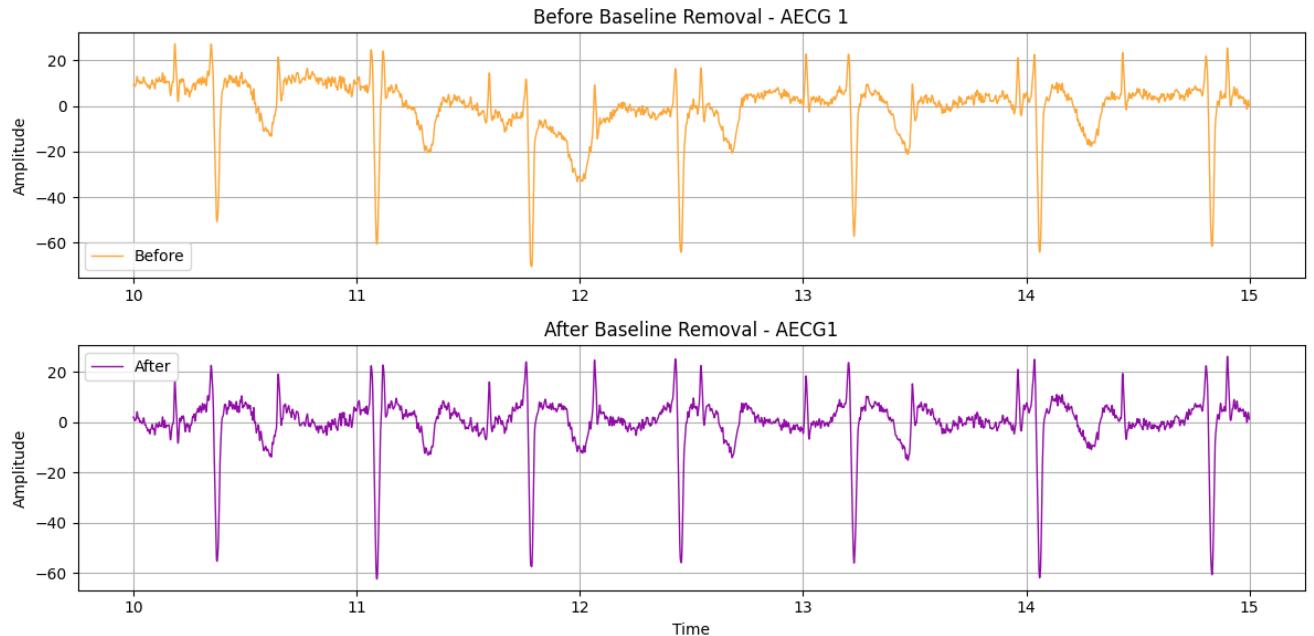
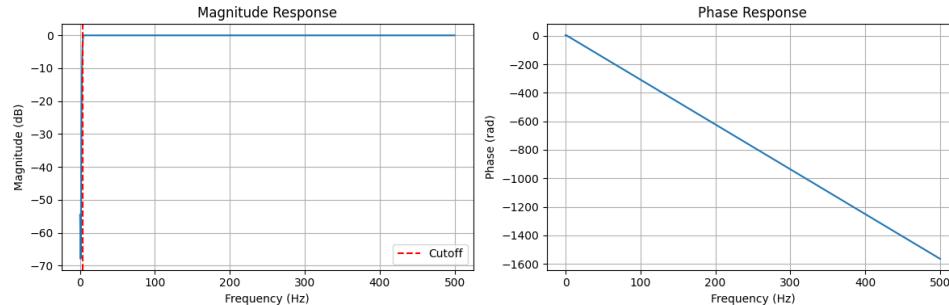
1. Remove Baseline

Objective: remove slow oscillations caused by breathing, body movements, ...



High-pass FIR filter :

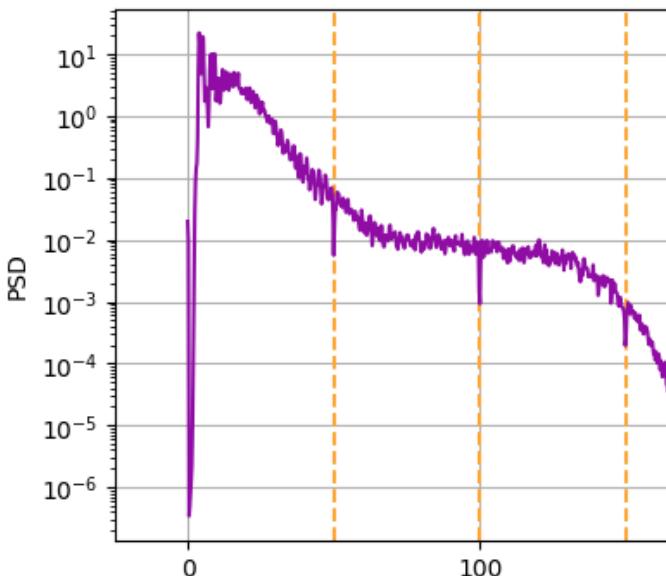
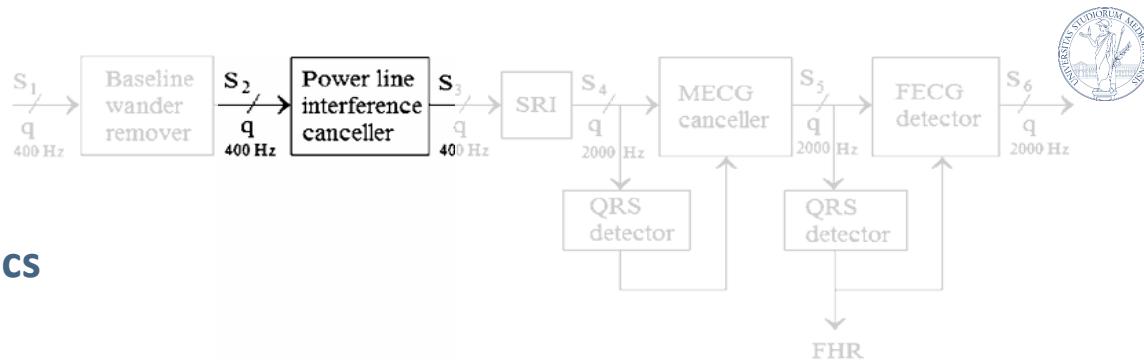
- 1000 + 1 coefficients
- 3 Hz cutoff frequency
- Window Hamming



$S1 \rightarrow S2$

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**

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

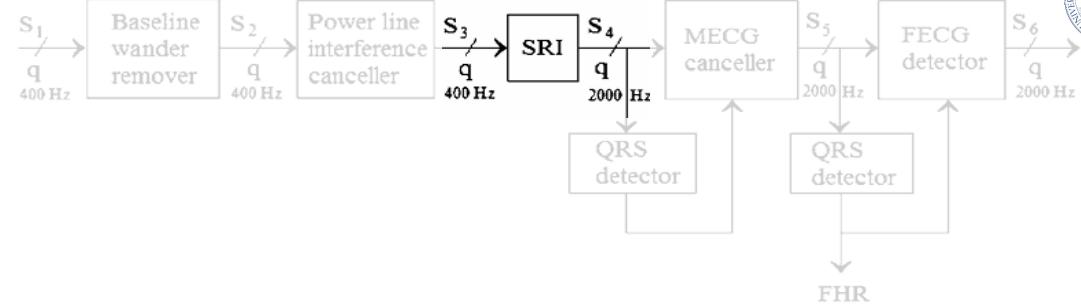
Clean Signal → Update of Coefficients → Phase Adaptation

using an LMS rule driven
by the residual error

$S_2 \rightarrow S_3$

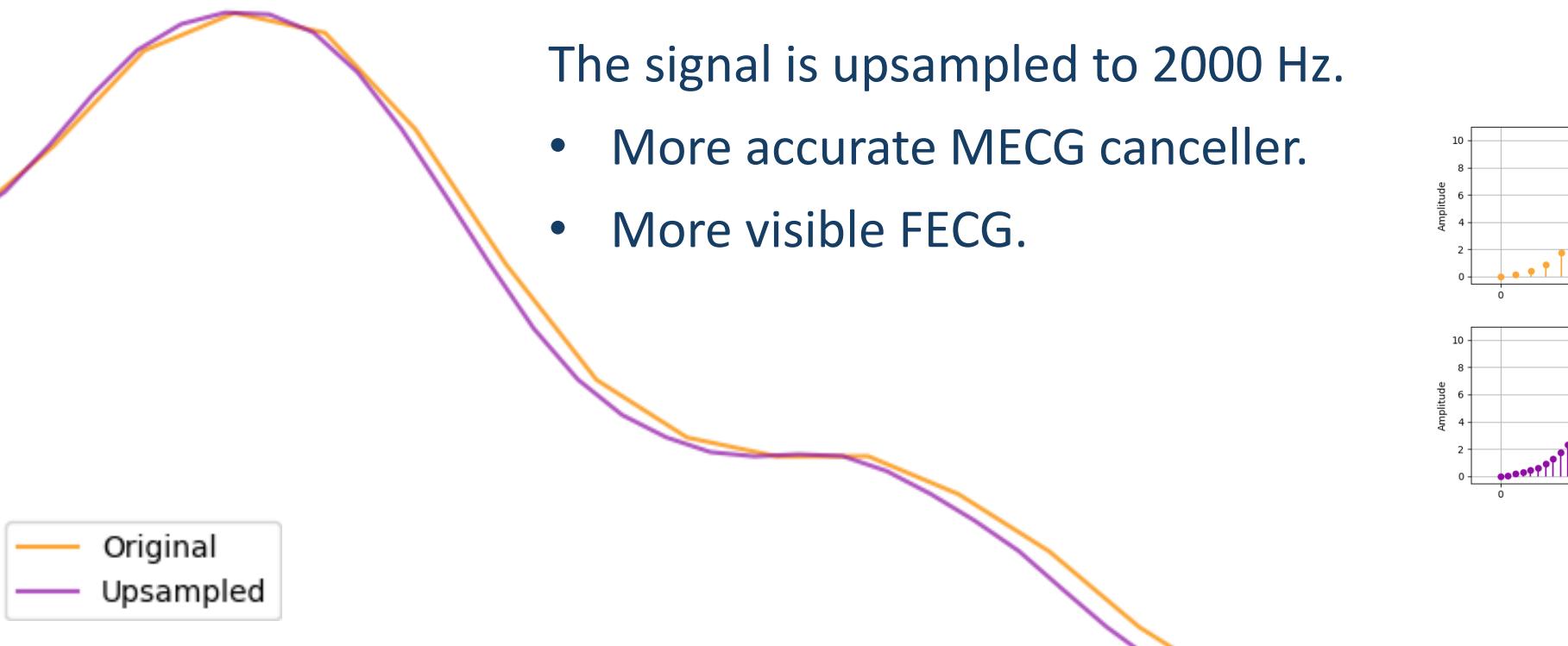
3. Increase samplings

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

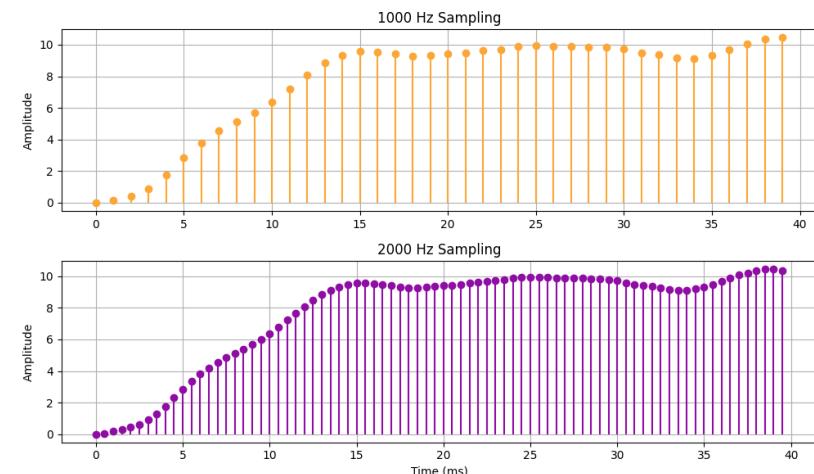


The signal is upsampled to 2000 Hz.

- 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

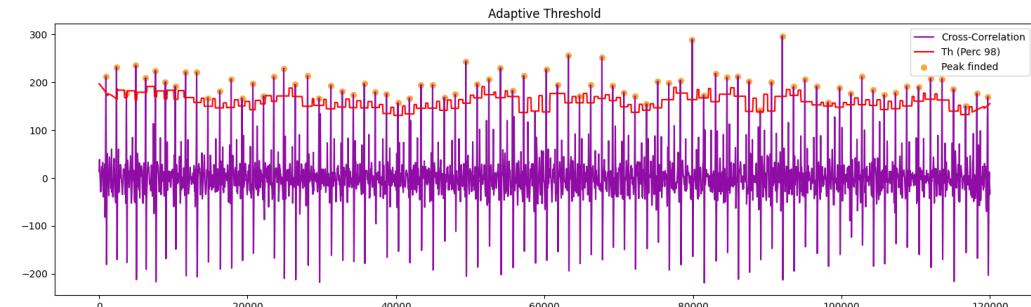
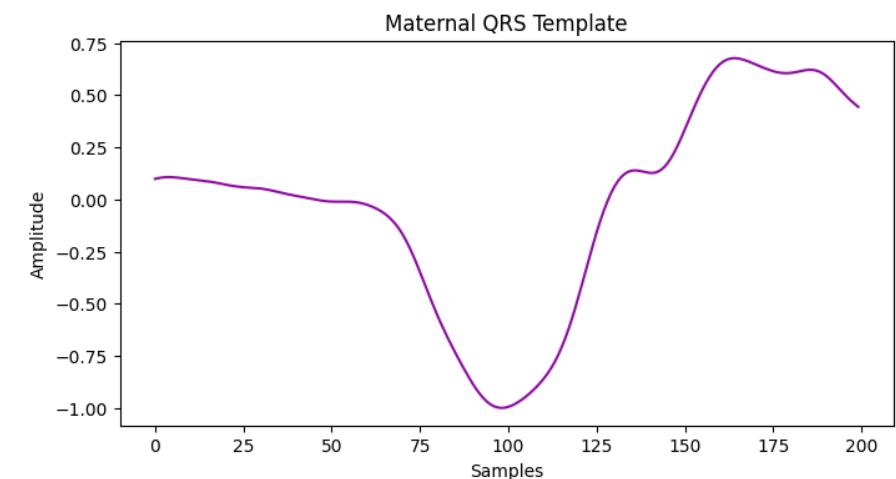
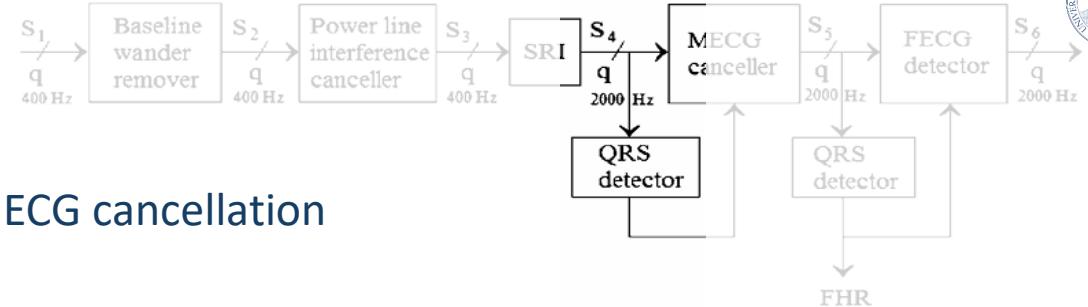
Cross-correlation with a synthetic QRS template

3. Real Template

Averaging of ± 50 ms segments around subset

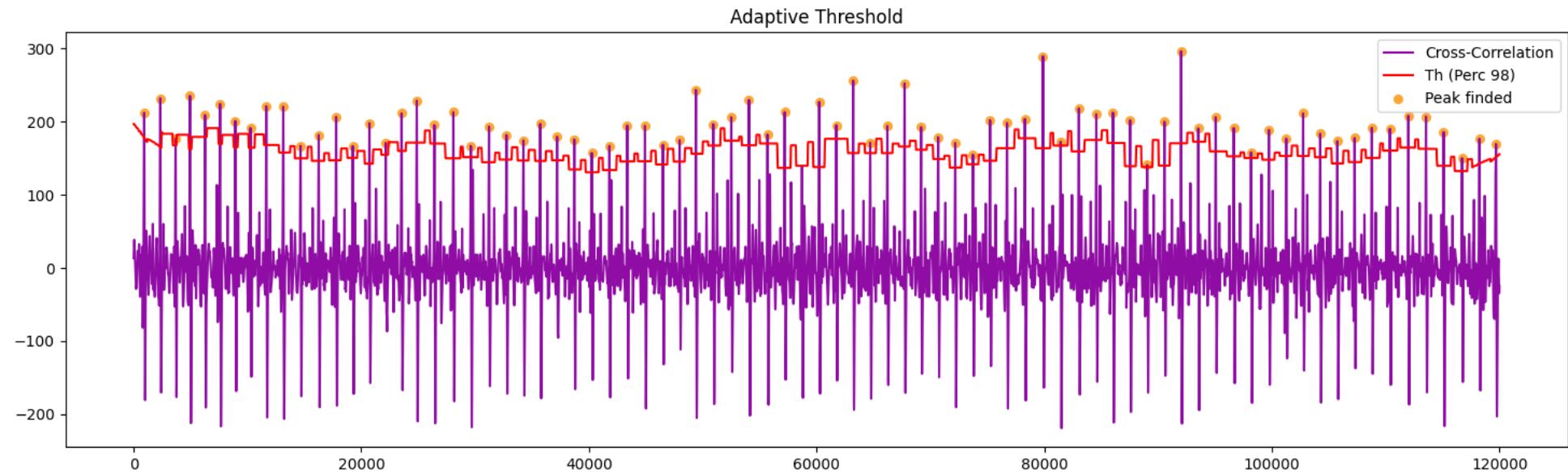
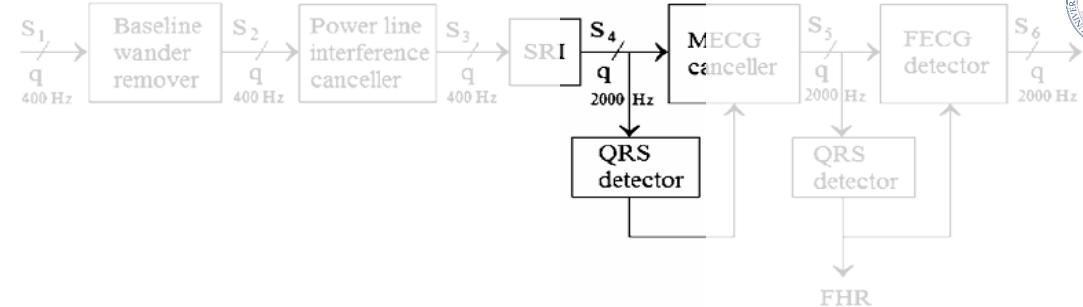
4. Final detection

Cross-correlation with QRS template



S4 → MQRS

4. M-QRS Detection

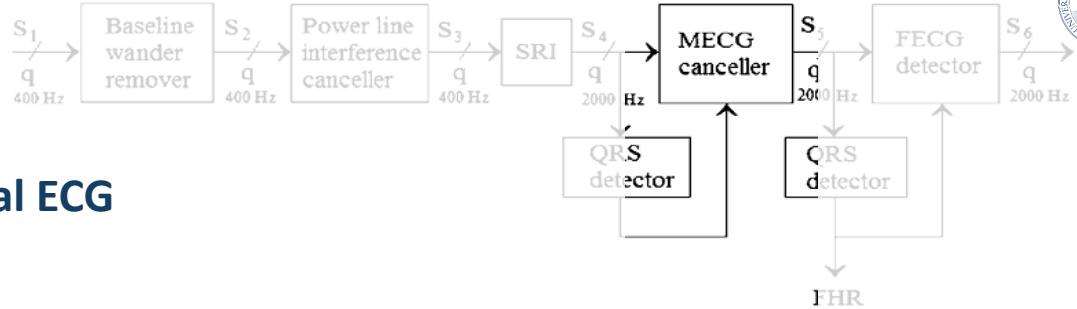


```
refractory_ms = 300, refine_ms = ±40, duration_ms = 100
```

S4 → MQRS

5. MECG Canceller

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



1. Extract window

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

2. Create a template

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

4. Find adaptive scaling

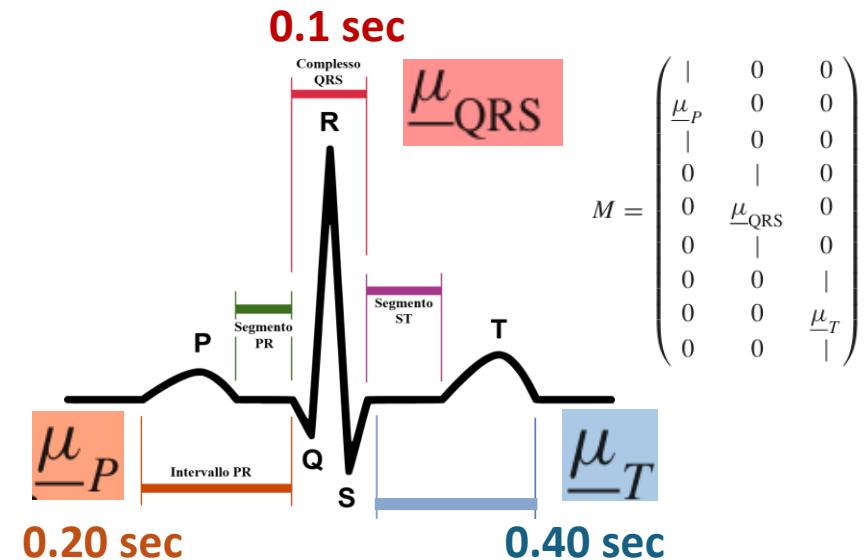
$$\underline{a} = (M^T M)^{-1} M^T \underline{m}$$

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

5. Template subtraction

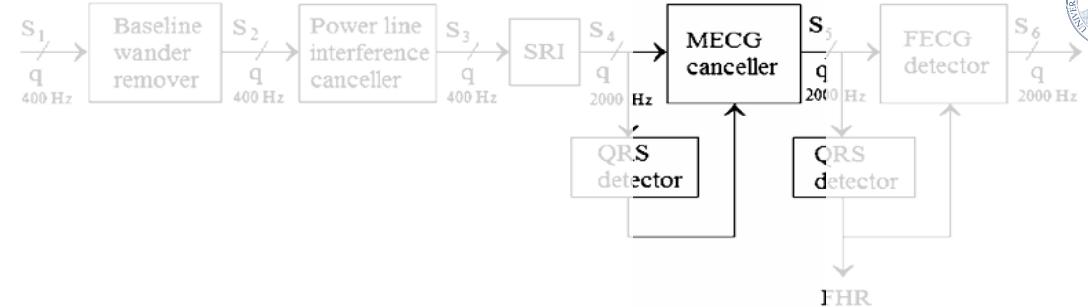
$$S5(t) = S4(t) - \hat{m}(t)$$

3. Split and create matrix



S4 → S5

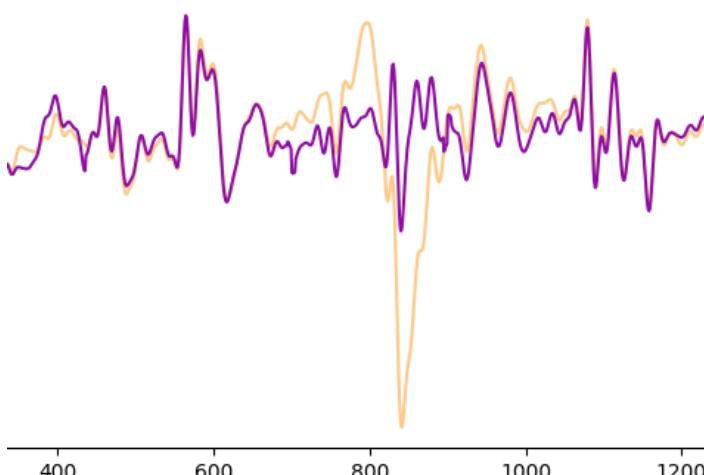
5. MECG Canceller



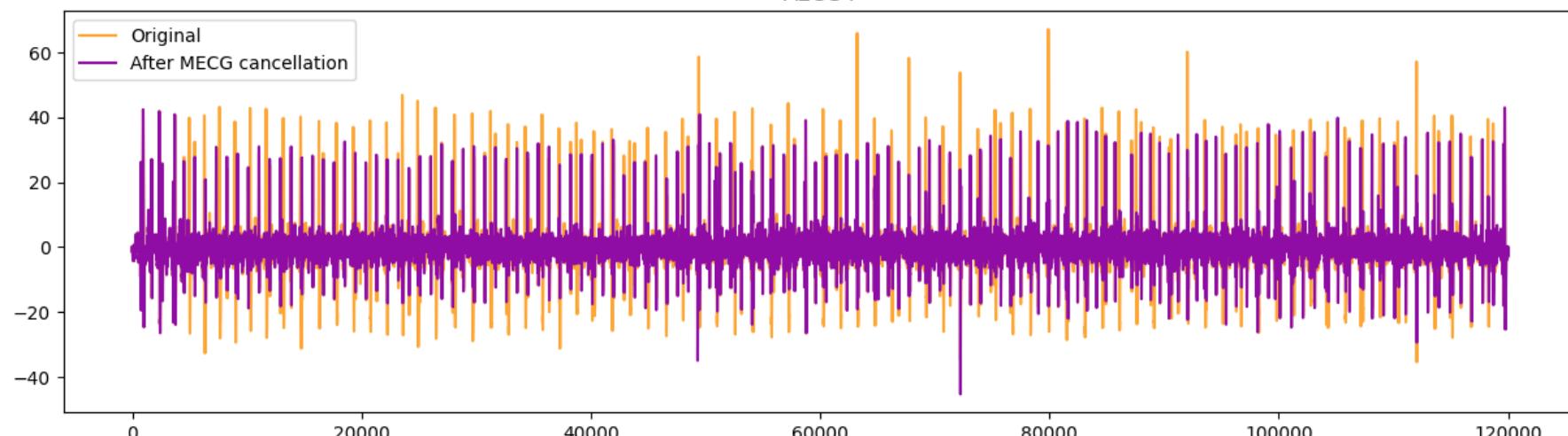
```

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

Zoom around maternal QRS after cancellation



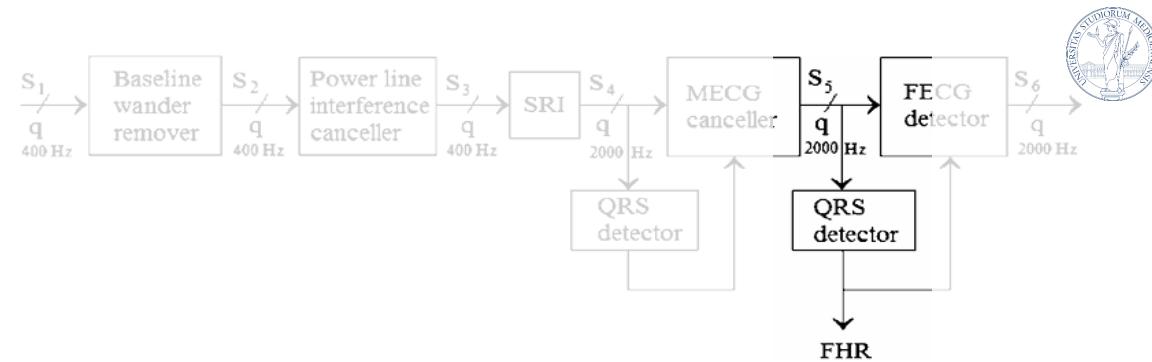
AECG4



$S4 \rightarrow S5$

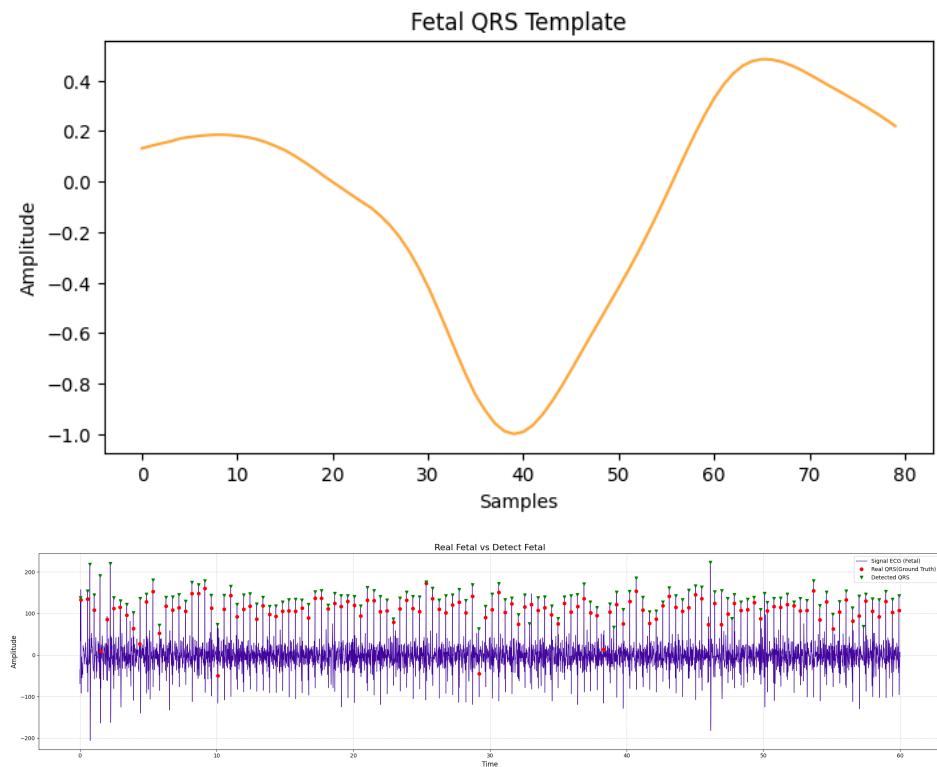
6. F-QRS Detection

Objective: identify **fetal QRS complexes**



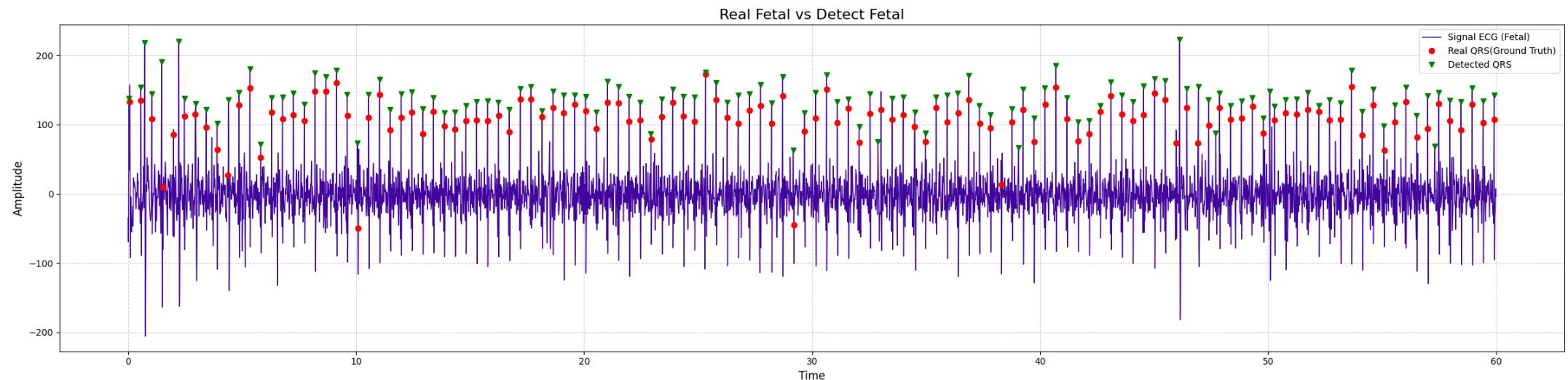
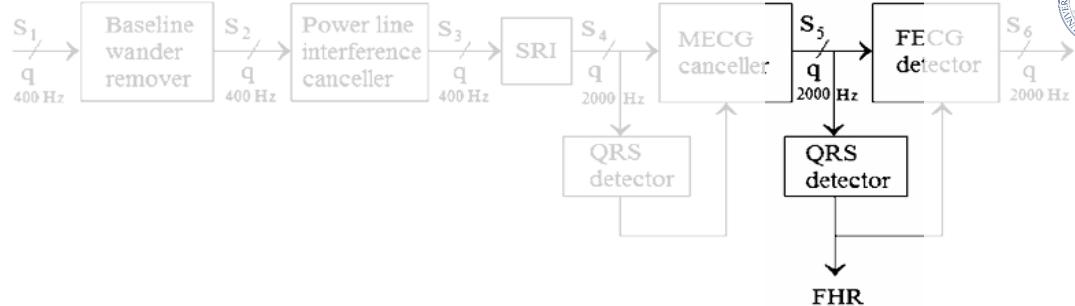
1. **PCA enhancement**
2. **Rough detection**
3. **Real Template**
4. **Final detection**

short refractory period
short peak refinement
short duration



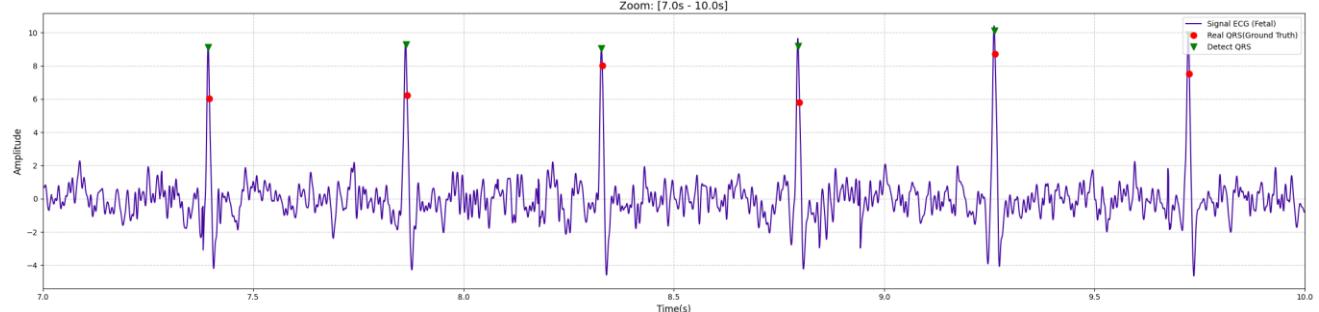
$S_5 \rightarrow fQRS$

6. F-QRS Detection



```

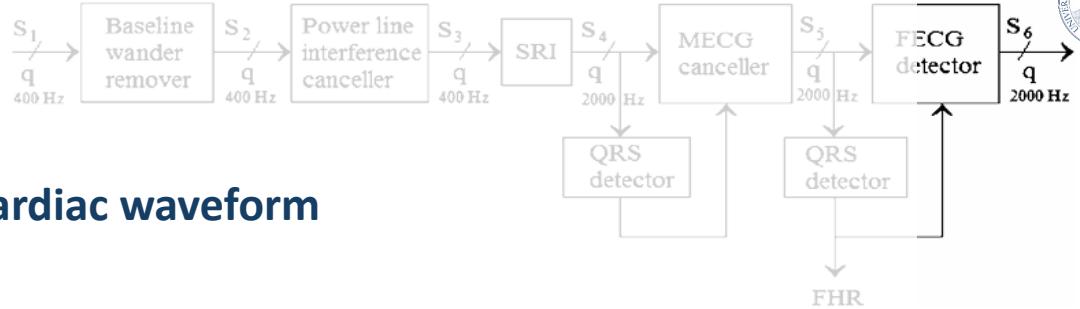
refractory_ms = 150,
refine_ms = ±20,
duration_ms = 40
  
```



S5 → fQRS

7.1 FECG Extraction

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



1. Window extraction:

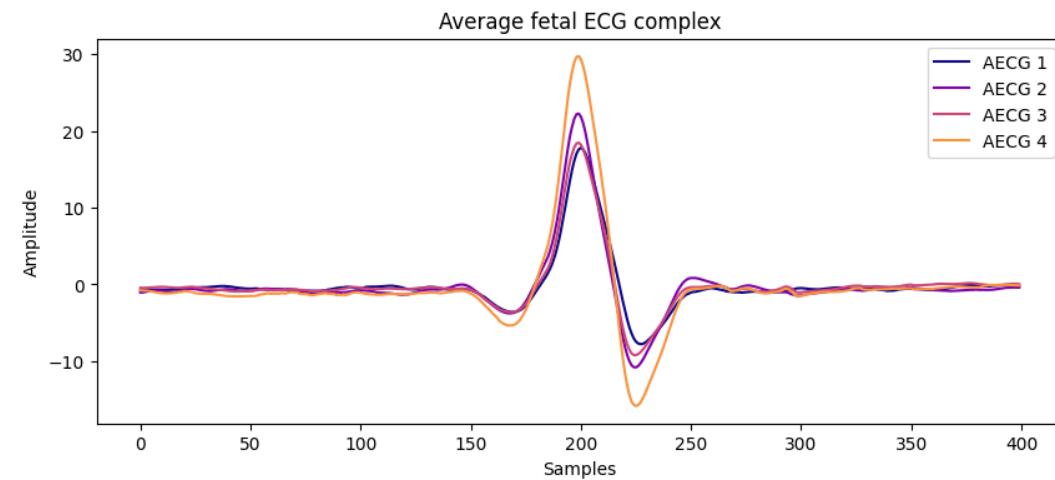
For each fetal QRS, a ± 100 ms window centered on the R-peak.

2. Intrinsic alignment:

Since each window is centered on the detected QRS, all segments are aligned.

3. Ensemble averaging:

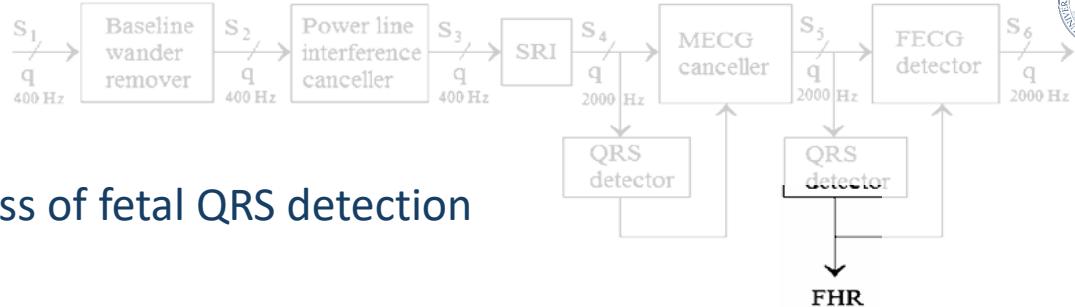
The first 150^* aligned segments are averaged, reducing uncorrelated noise by a factor of $\sqrt{150} \approx 12$.



S5 \rightarrow S6

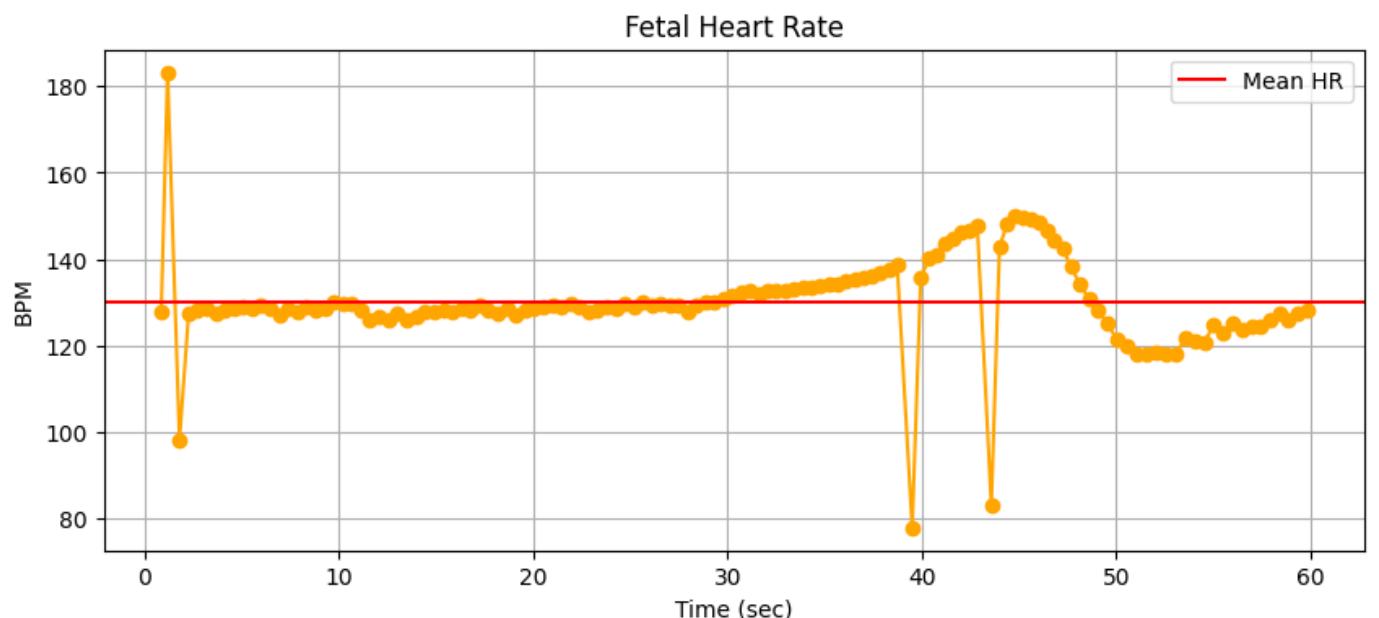
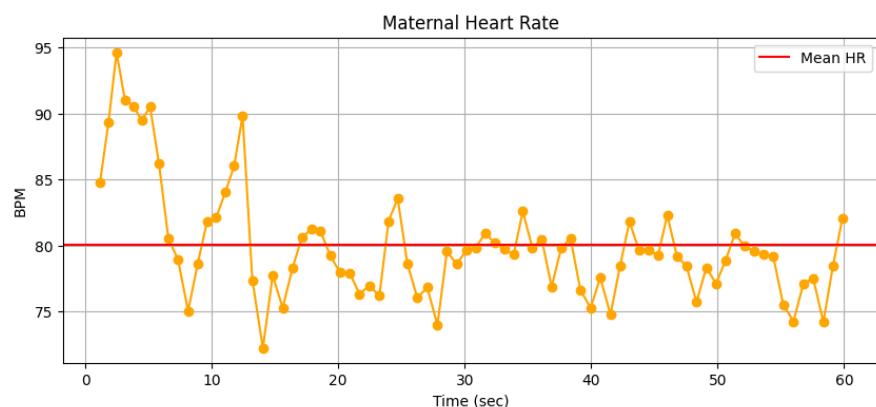
7.2 FHR

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

- ▶ Introduction
- ▶ The algorithm
- ▶ Dataset
- ▶ Result
- ▶ Conclusion



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

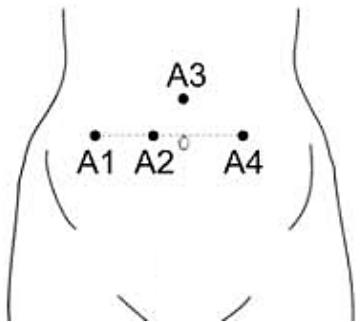




Table of content

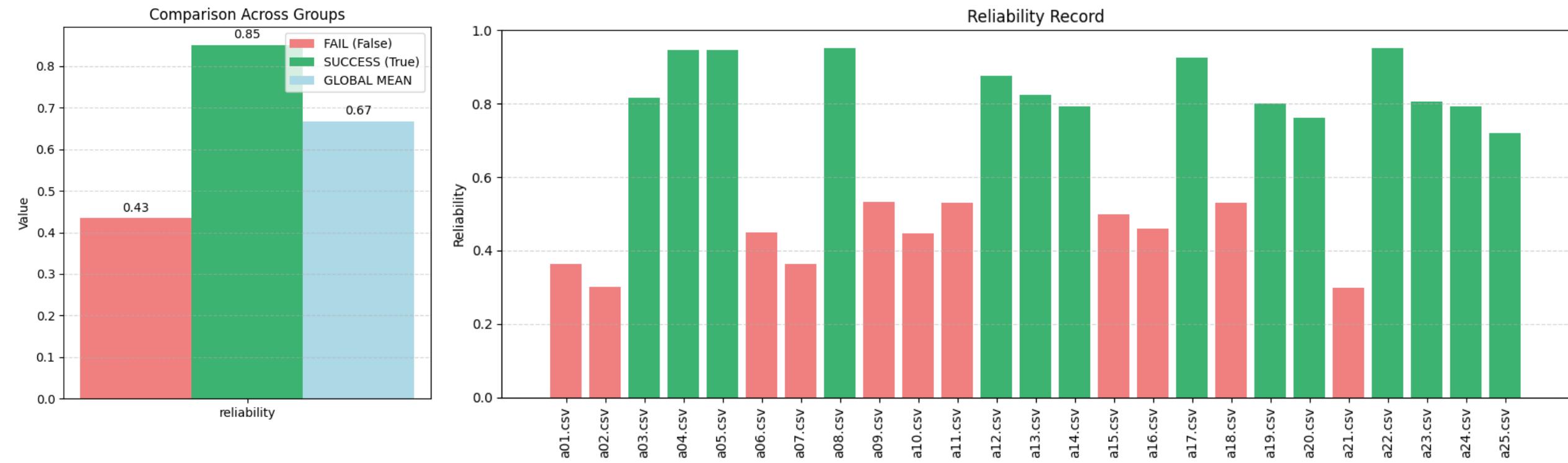
- ▶ Introduction
- ▶ The algorithm
- ▶ Dataset
- ▶ Result
- ▶ Conclusion

Signal quality metrics

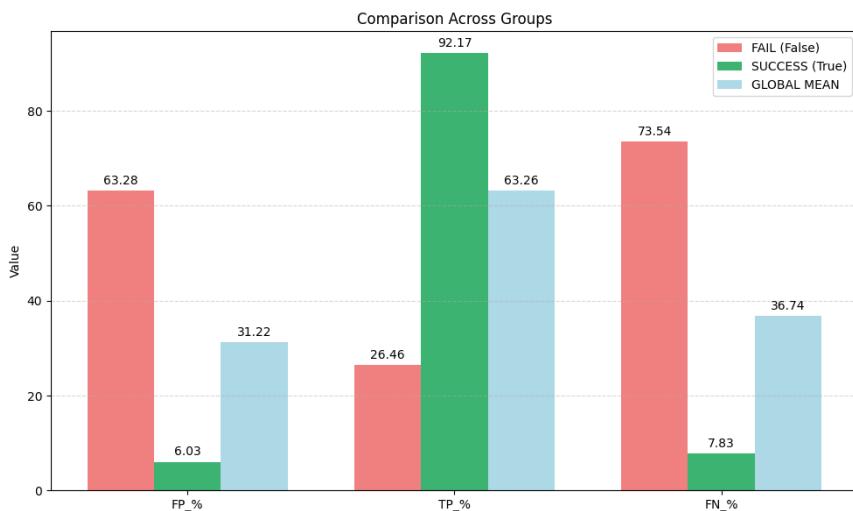
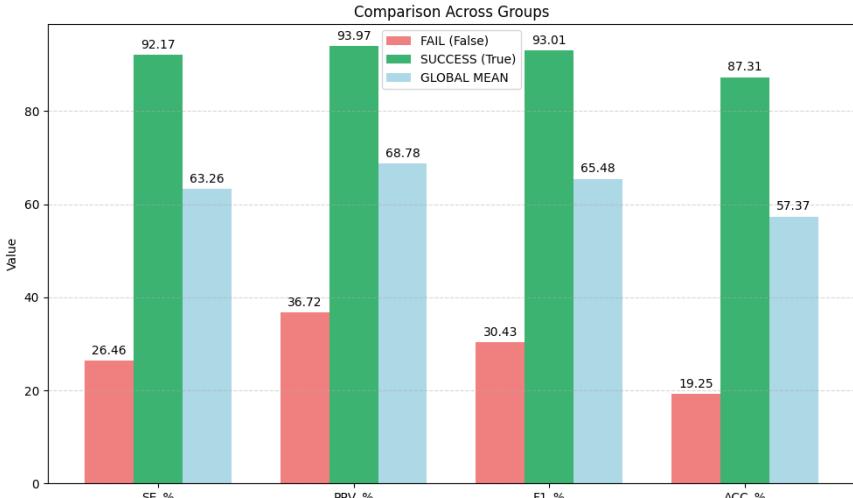
$$Reliability = 1 - \frac{\text{num_outliers}}{\text{total_point_FHR}}$$

$$\text{num_outliers} = |FHR_i - \text{median}| > 10 \text{ bpm}$$

SUCCESS = ($60 \leq \text{mean_bpm} \leq 220$) and (reliability > 0.60)

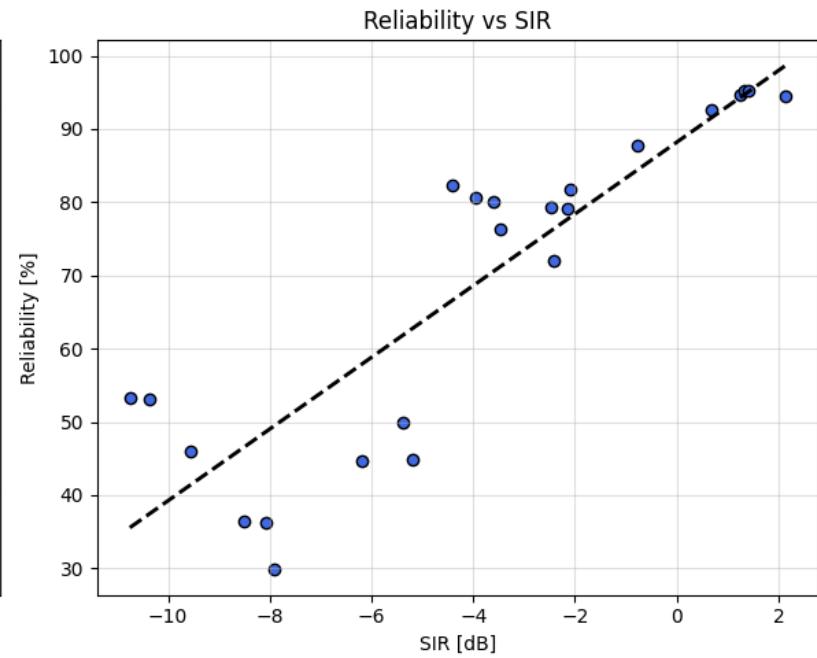
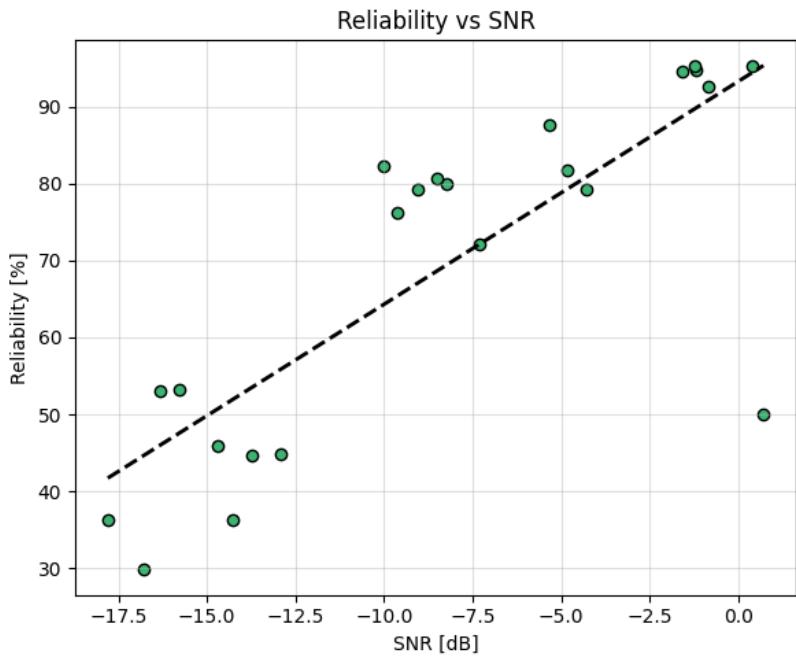


Signal quality metrics

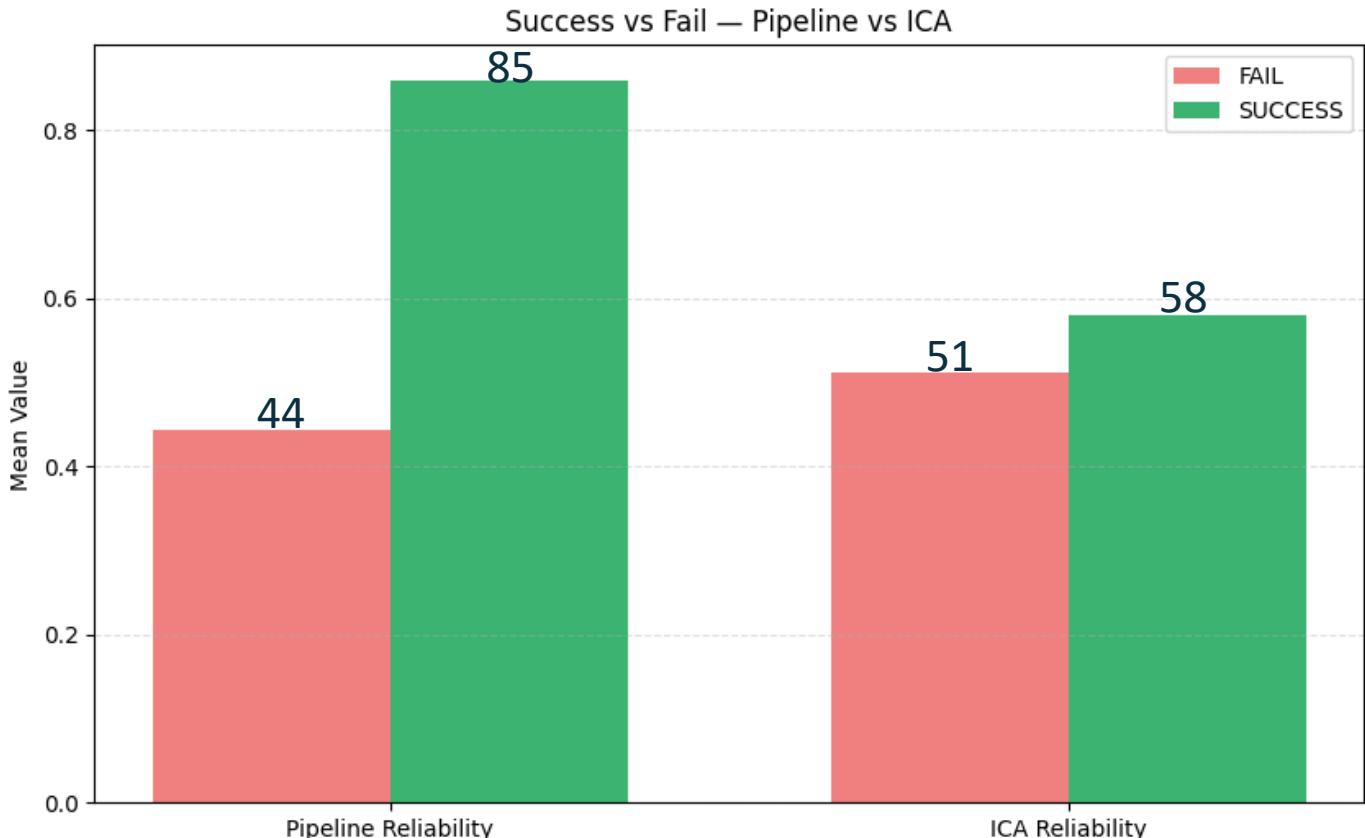
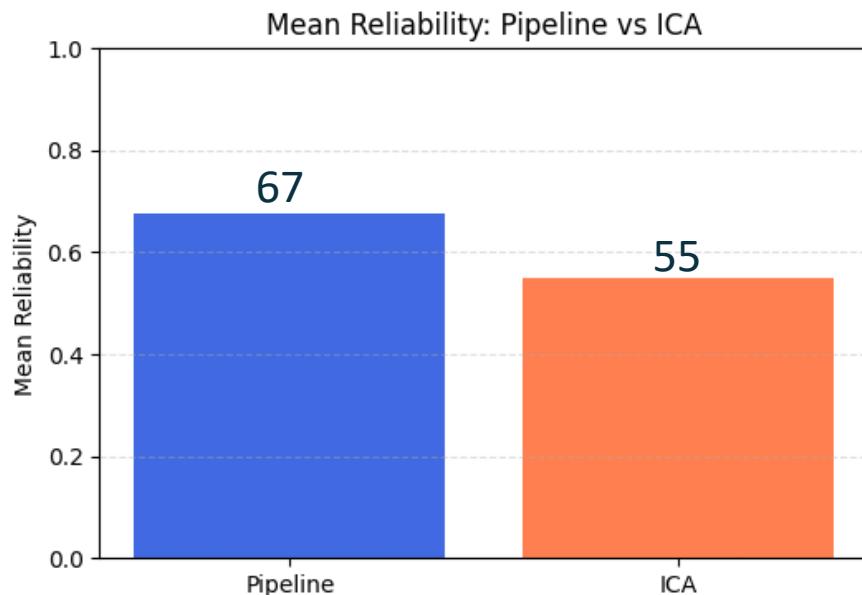


$$\text{SNR}_j = \frac{P_{F_j}}{P_{N_j}} = \frac{P_{S_{6,j}}}{P_{S_{5,j}-S_{6,j}}},$$

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



Comparison with FastICA



Comparison with FastICA

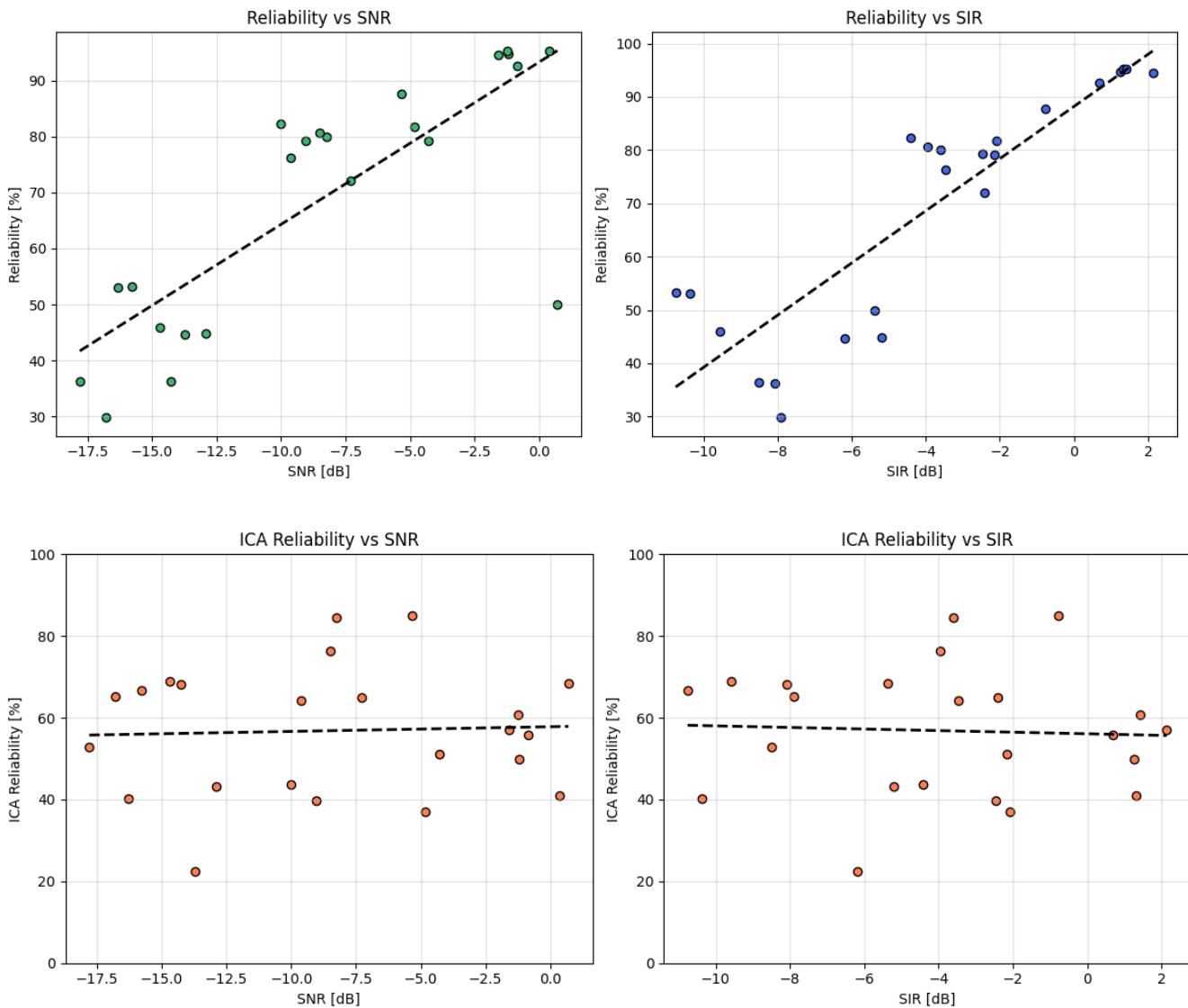
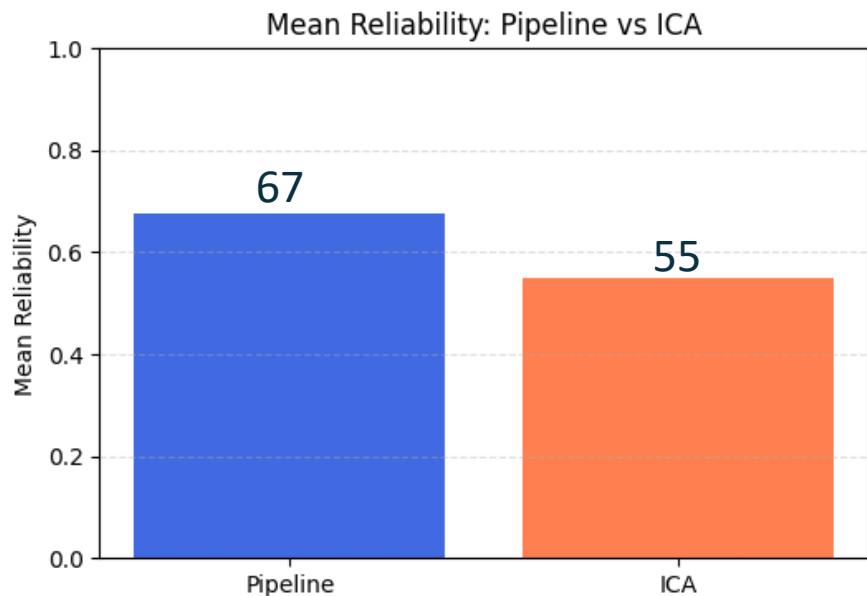




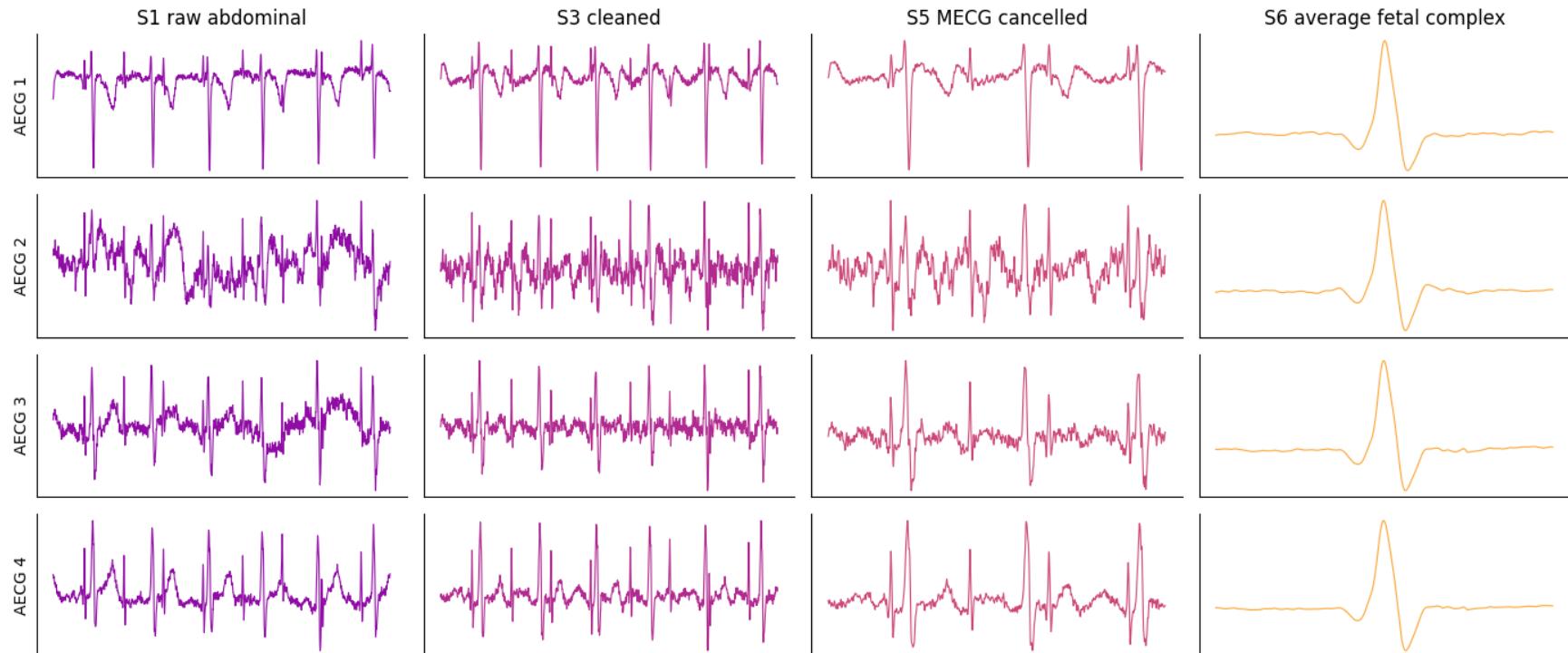
Table of content

- ▶ Introduction
- ▶ The algorithm
- ▶ Dataset
- ▶ Result
- ▶ Conclusion

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
Biomedical Signal Processing