



A robust fetal ECG detection method for abdominal recordings

Porcelli Angelica

Biomedical Signal Processing



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Fetal ECG Extraction Challenges

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

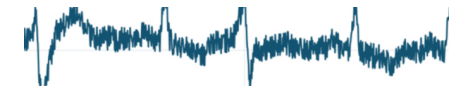
1. Maternal ECG (MECG)



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**.

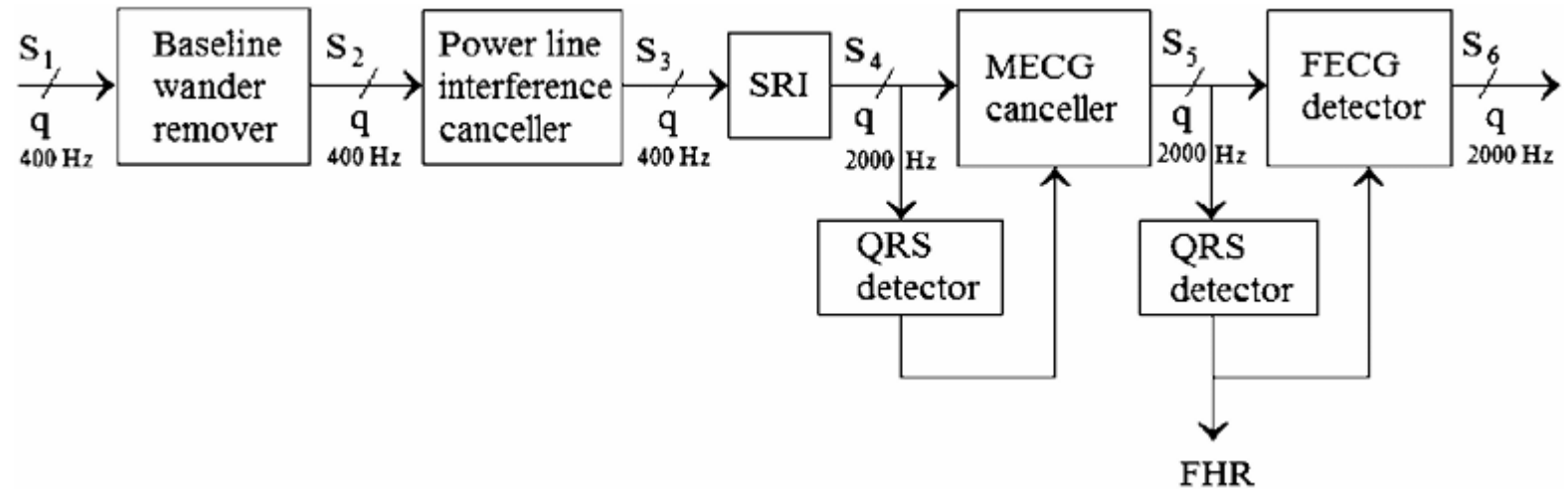


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The Algorithm

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

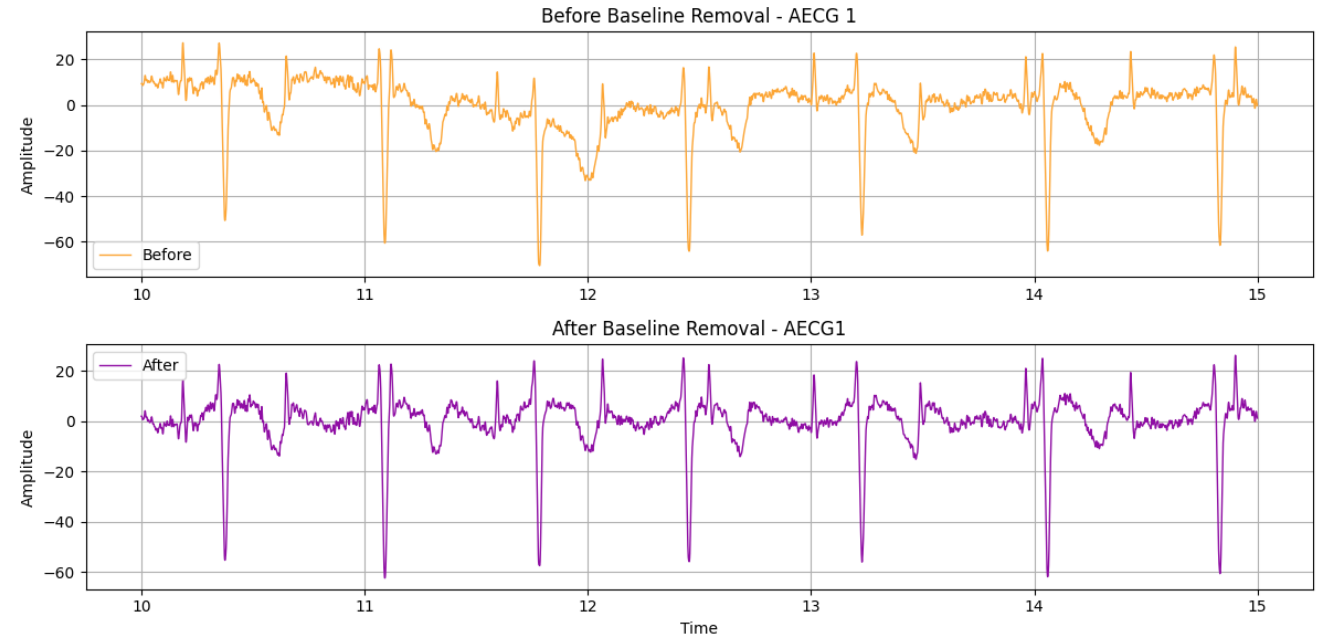
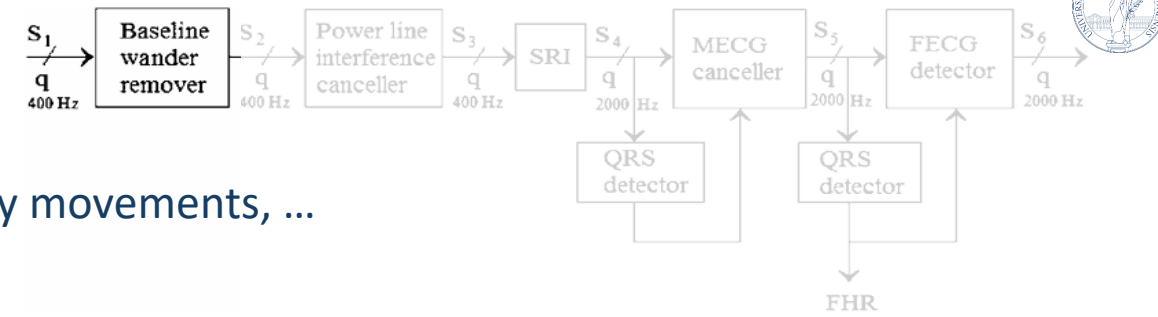
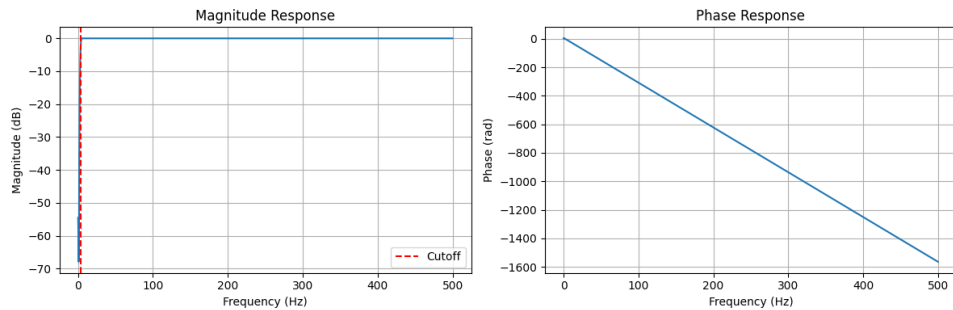


1. Remove Baseline

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

High-pass FIR filter :

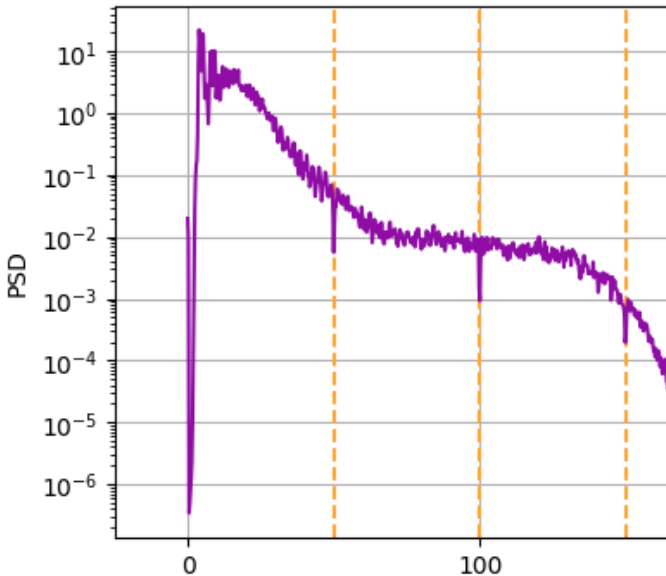
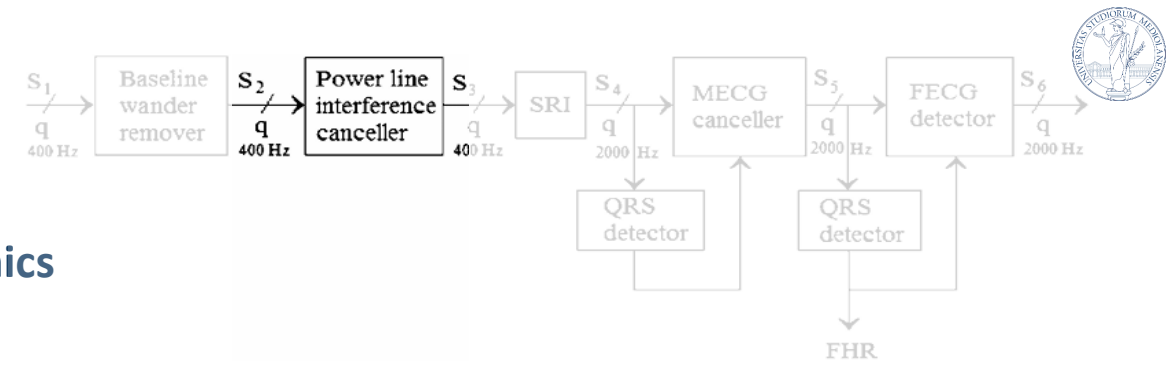
- 1000 + 1 coefficients
- 3 Hz cutoff frequency
- Window Hamming



$S_1 \rightarrow S_2$

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*

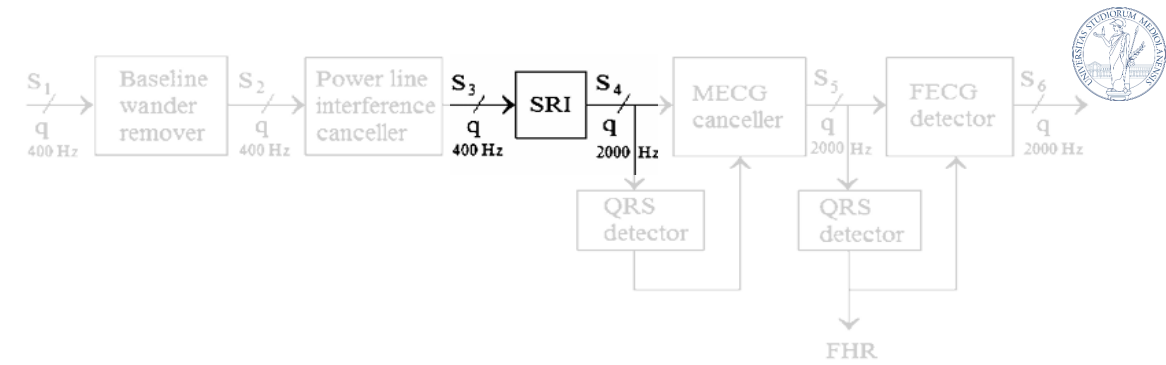
$$\hat{d}(t) = A(t)\sin(\phi(t)) + B(t)\cos(\phi(t))$$

Clean Signal → Update of Coefficients → Phase Adaptation
using an LMS rule driven
by the residual error

$S_2 \rightarrow S_3$

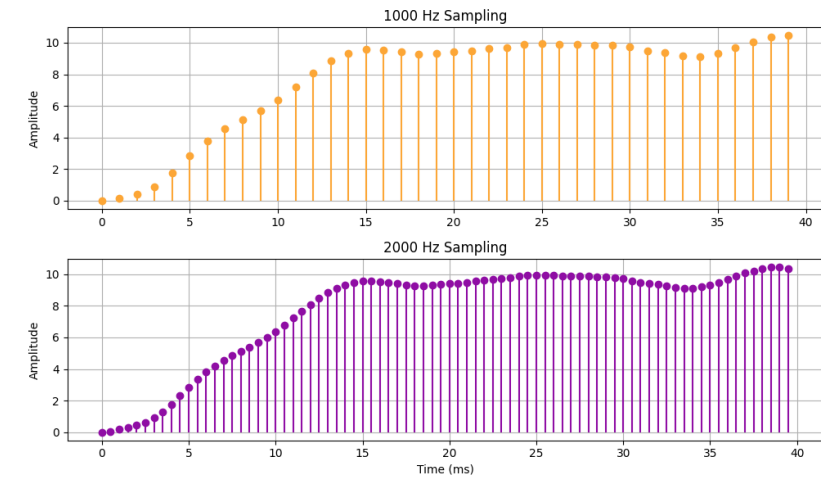
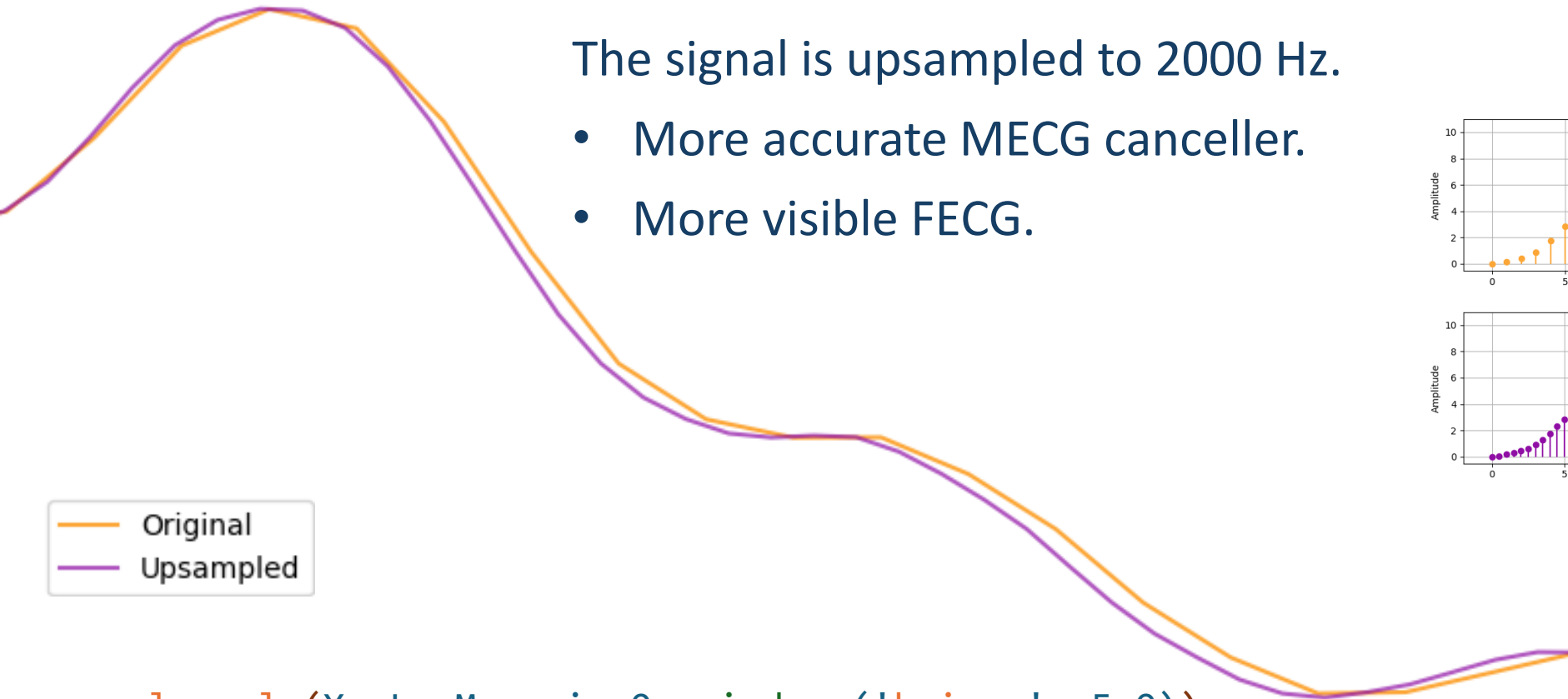
3. Increase samplings

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))
```

$S_3 \rightarrow S_4$

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

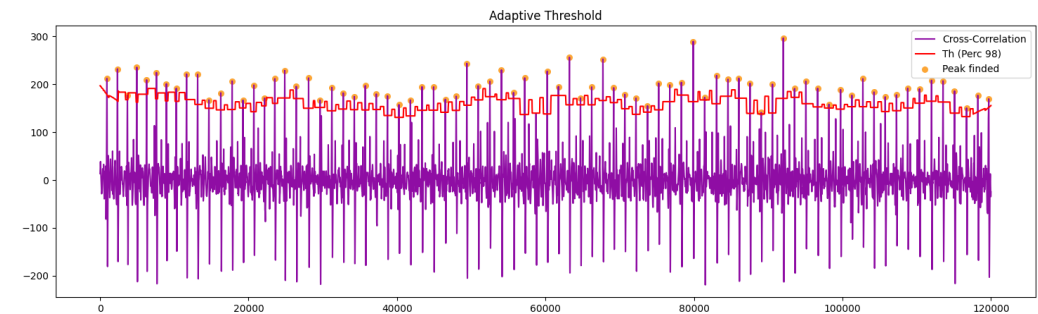
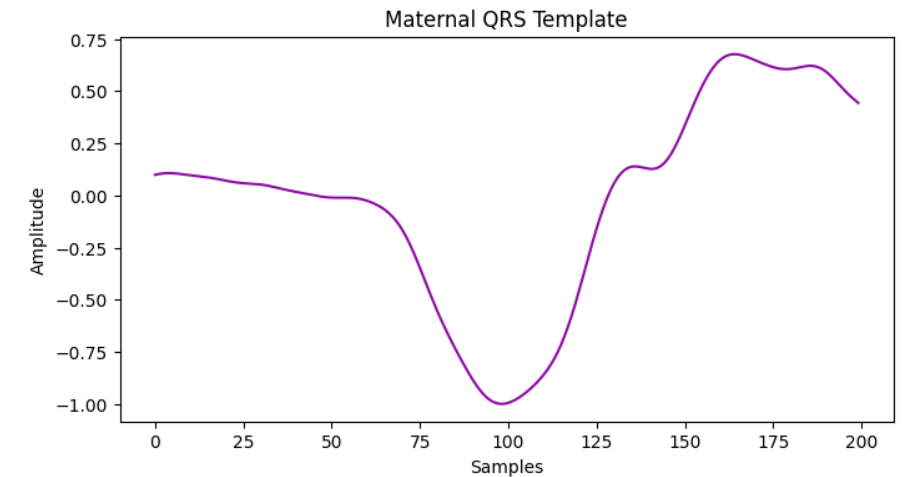
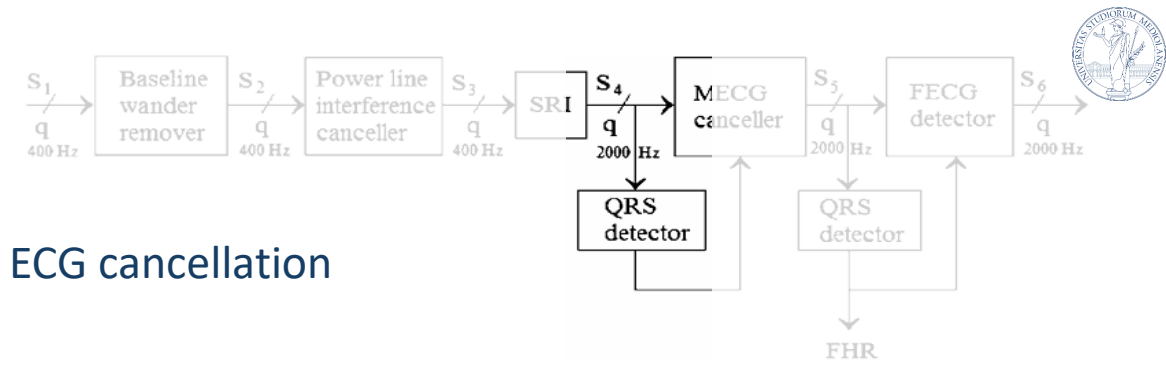
Cross-correlation with a synthetic QRS template

3. Real Template

Averaging of ± 50 ms segments around subset

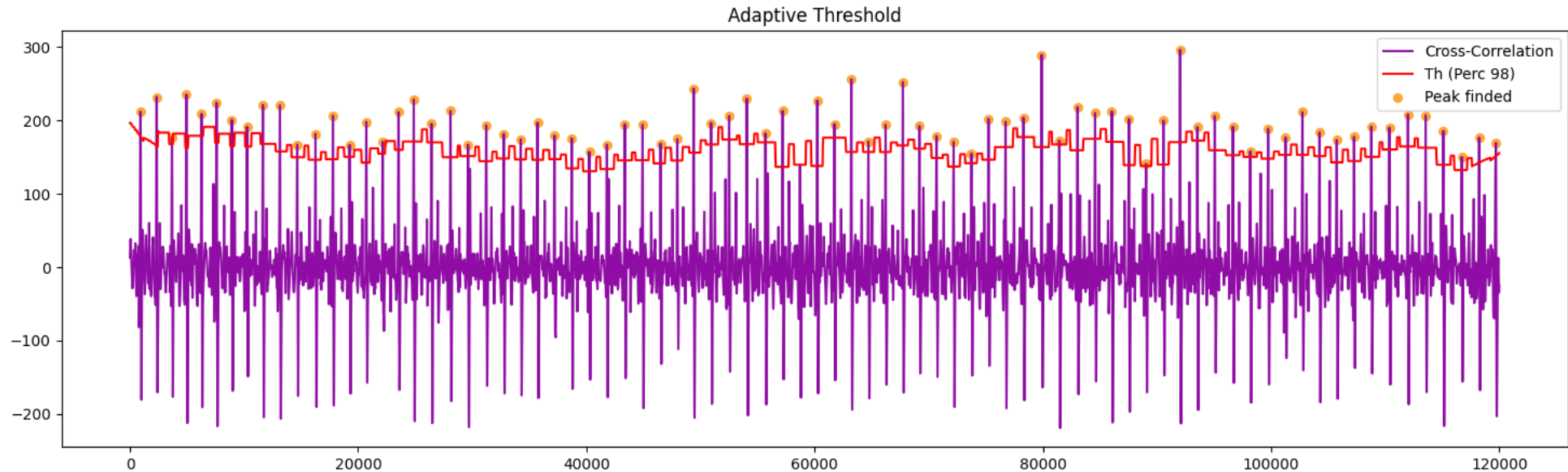
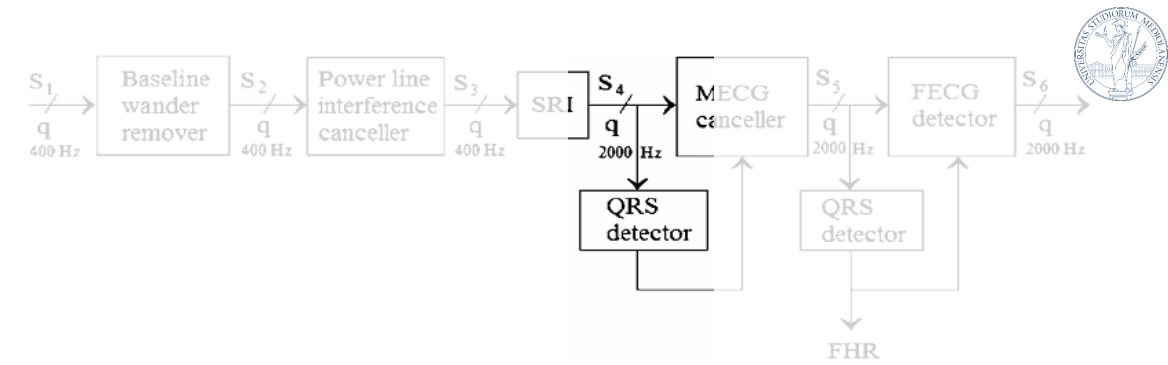
4. Final detection

Cross-correlation with QRS template



$S_4 \rightarrow \text{M-QRS}$

4. M-QRS Detection

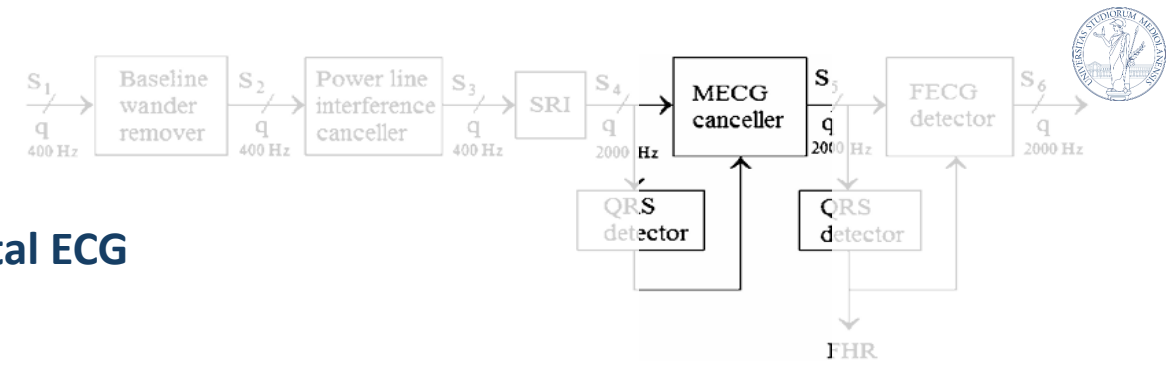


refractory_ms = 300, refine_ms = ± 40 , duration_ms = 100

$S_4 \rightarrow \text{M-QRS}$

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

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

4. Find adaptive scaling

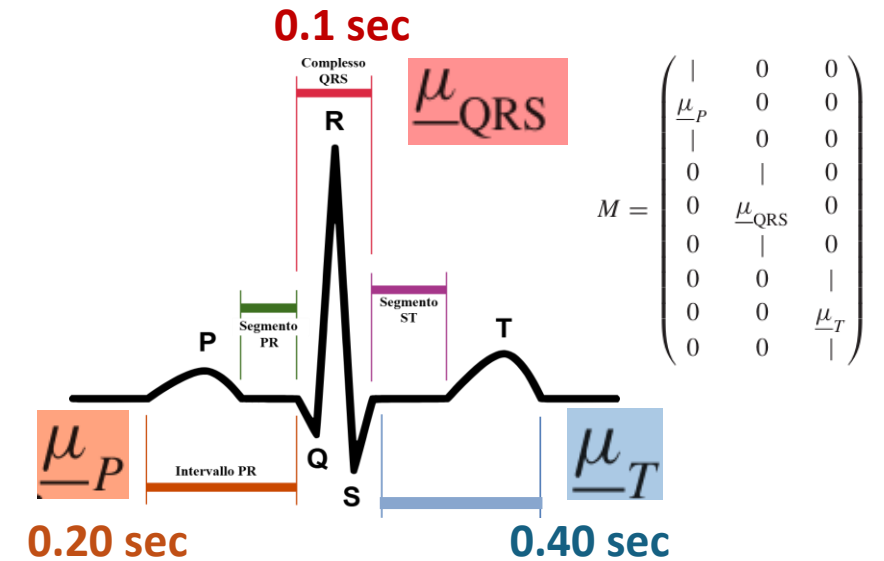
$$\underline{a} = (M^T M)^{-1} M^T \underline{m}$$

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

5. Template subtraction

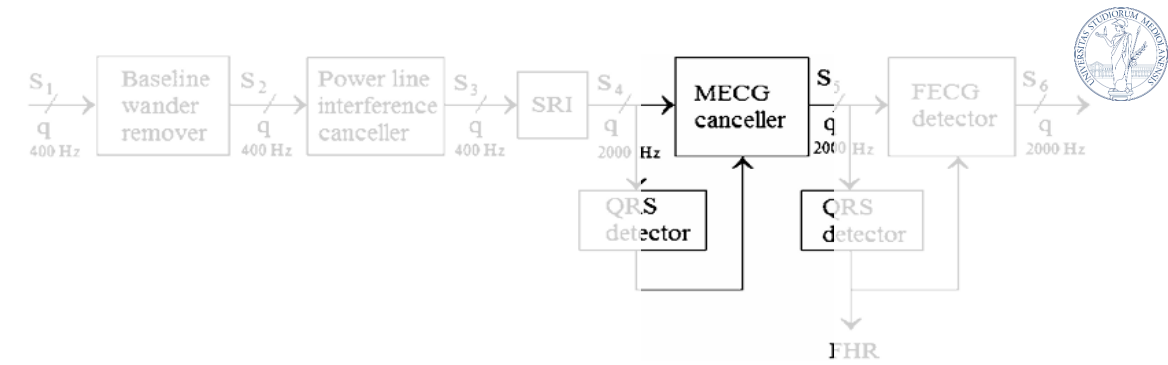
$$S5(t) = S4(t) - \hat{m}(t)$$

3. Split and create matrix

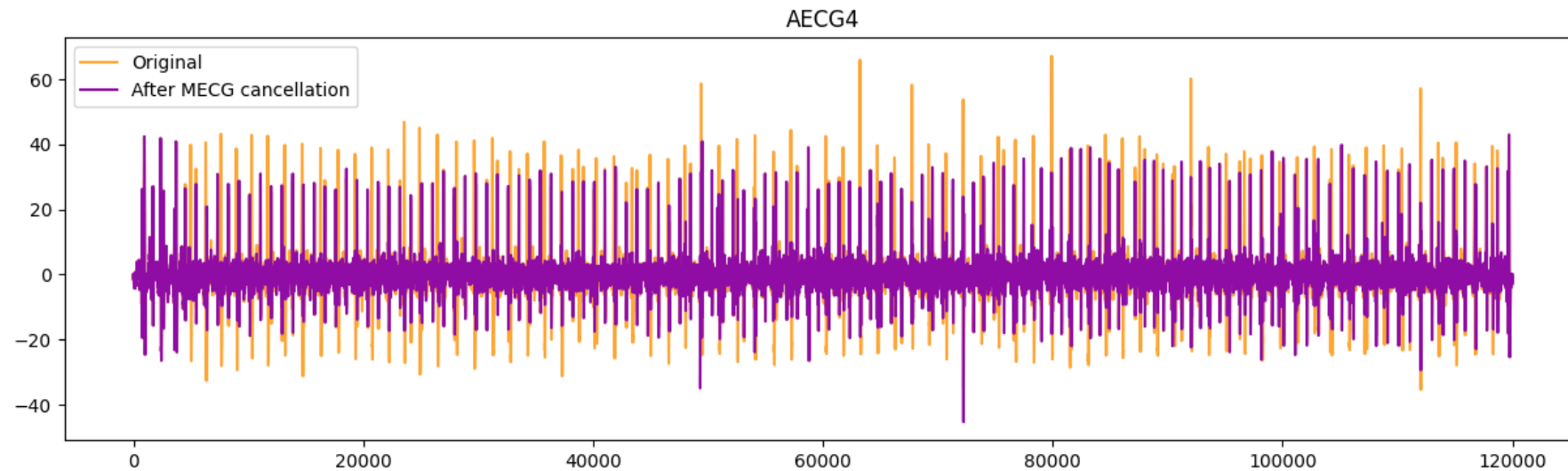
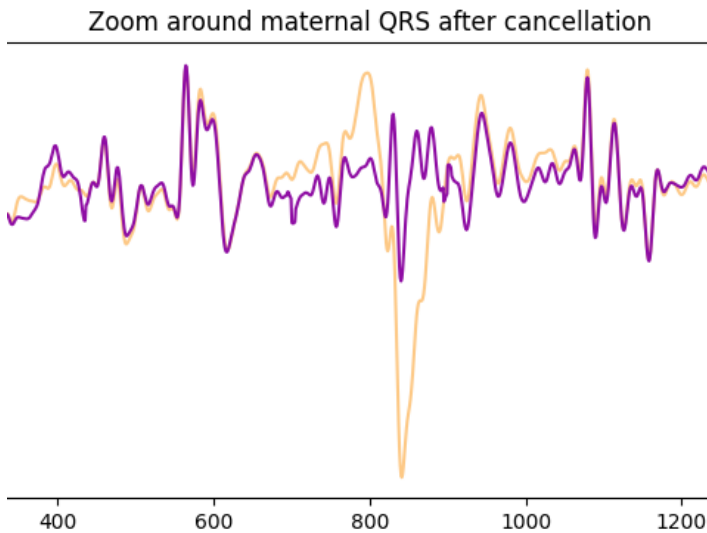


S4 → S5

5. MECG Canceller



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



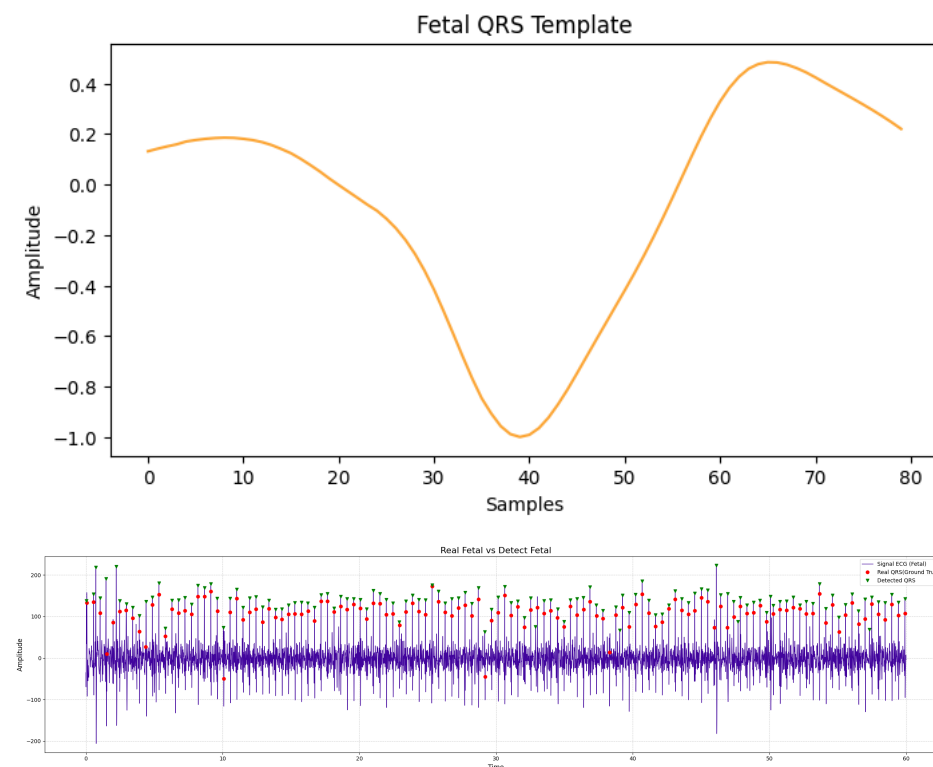
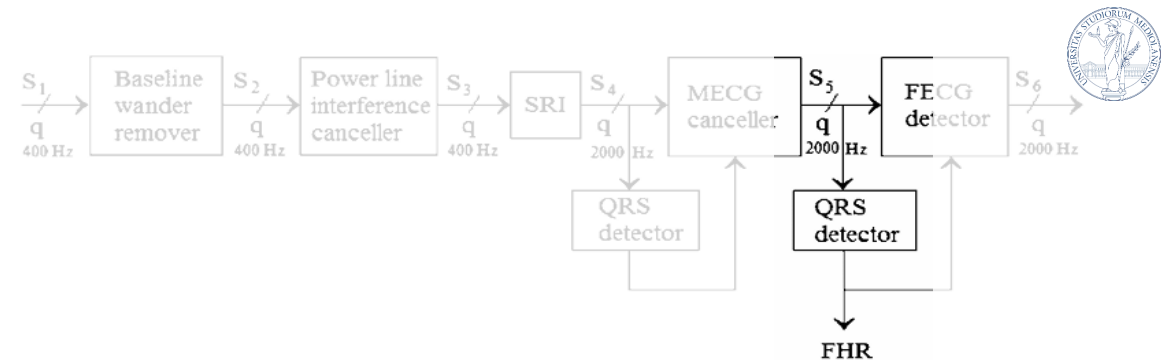
$S4 \rightarrow S5$

6. F-QRS Detection

Objective: identify fetal QRS complexes

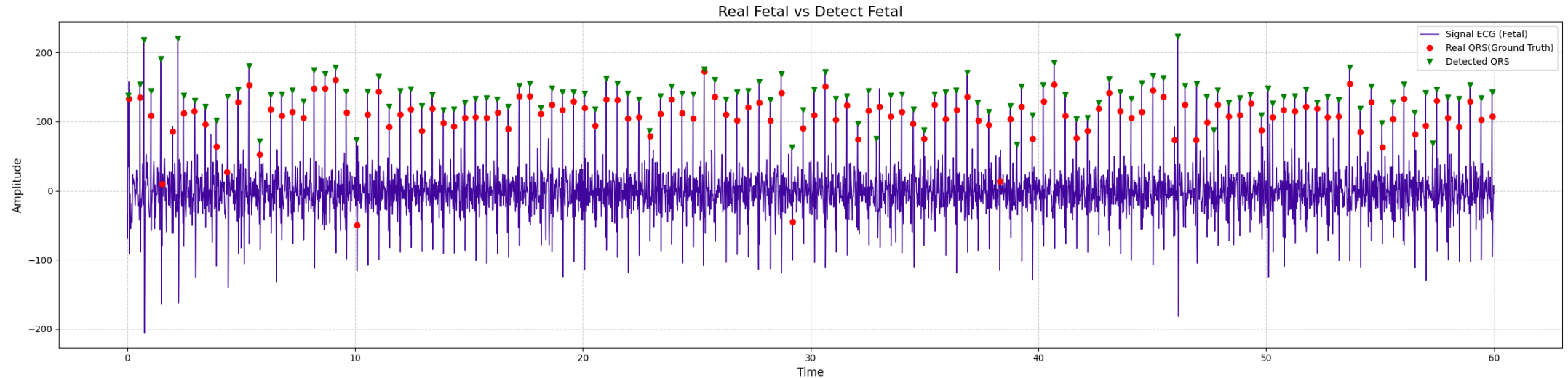
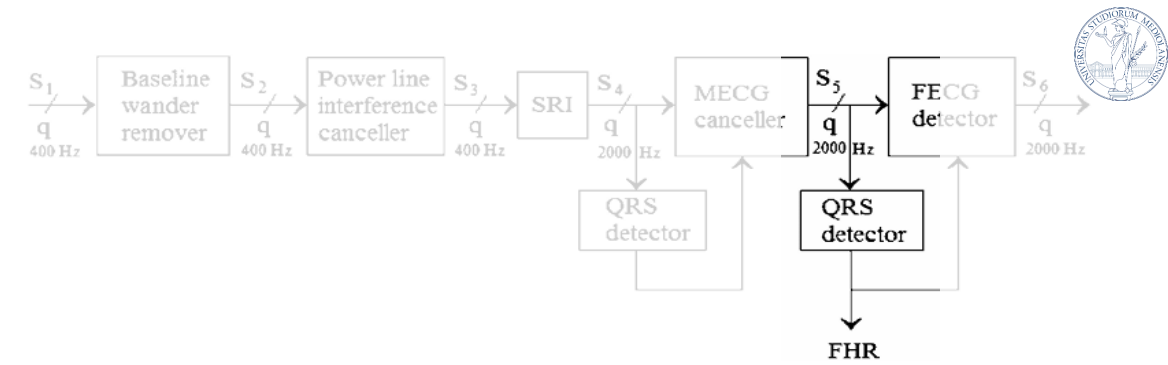
1. PCA enhancement
2. Rough detection
3. Real Template
4. Final detection

short refractory period
short peak refinement
short duration

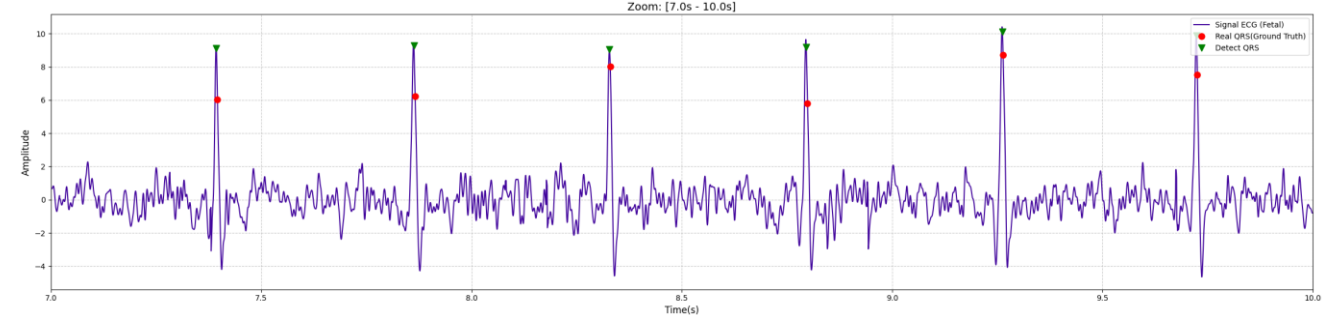


$S_5 \rightarrow \text{fQRS}$

6. F-QRS Detection



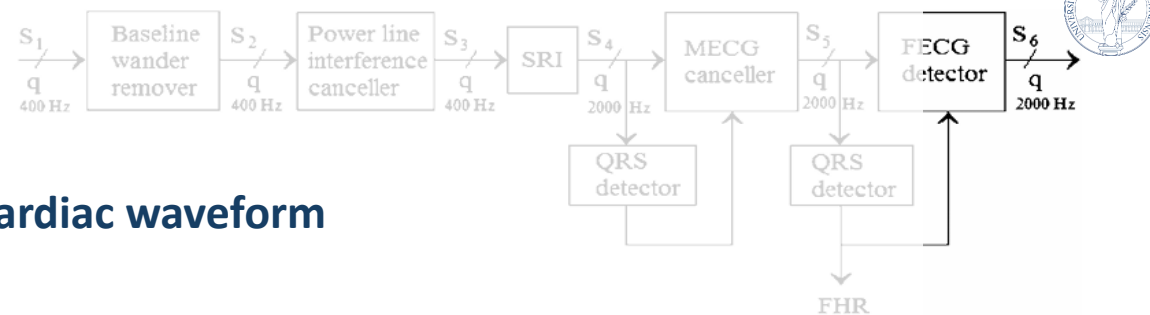
refractory_ms = 150,
refine_ms = ± 20 ,
duration_ms = 40



$S_5 \rightarrow \text{fQRS}$

7.1 FECG Extraction

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



1. Window extraction:

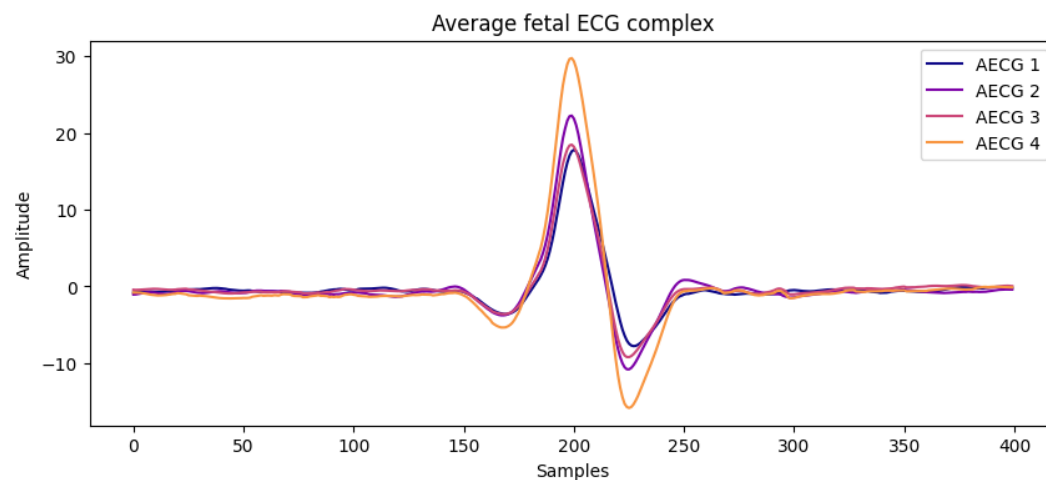
For each fetal QRS, a ± 100 ms window centered on the R-peak.

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 $\sqrt{150} \approx 12$.



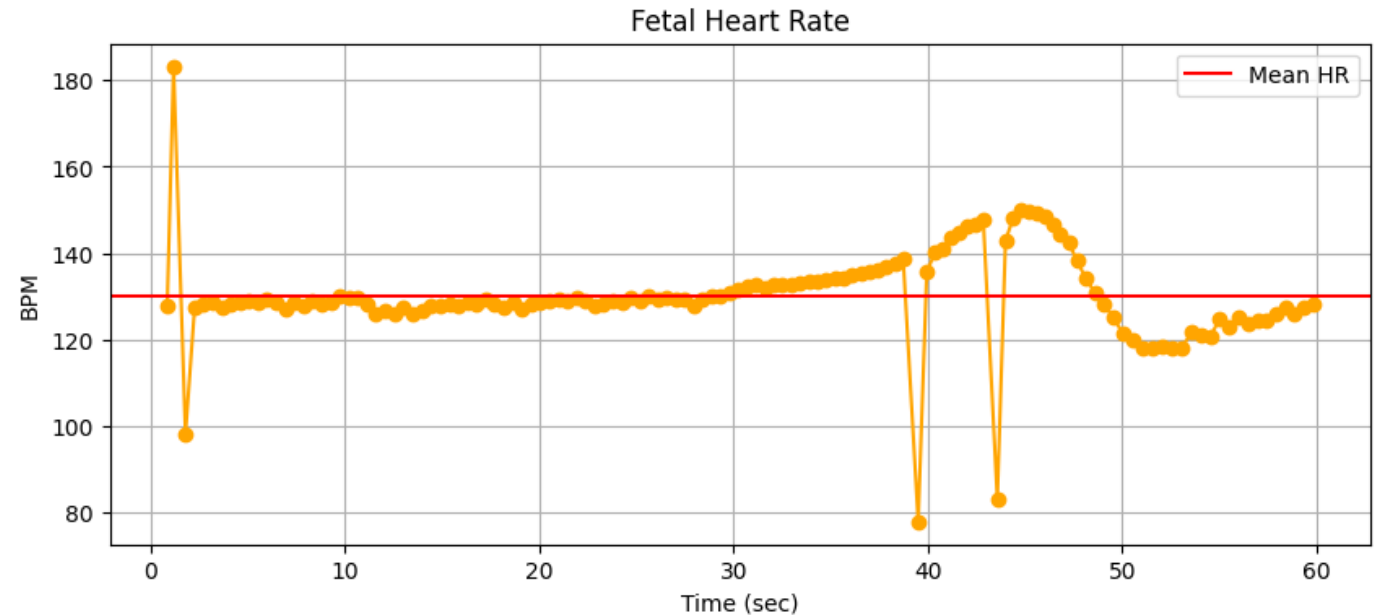
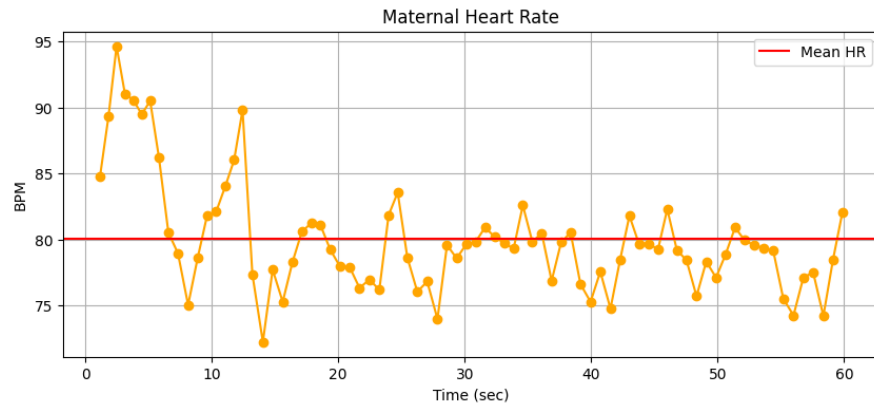
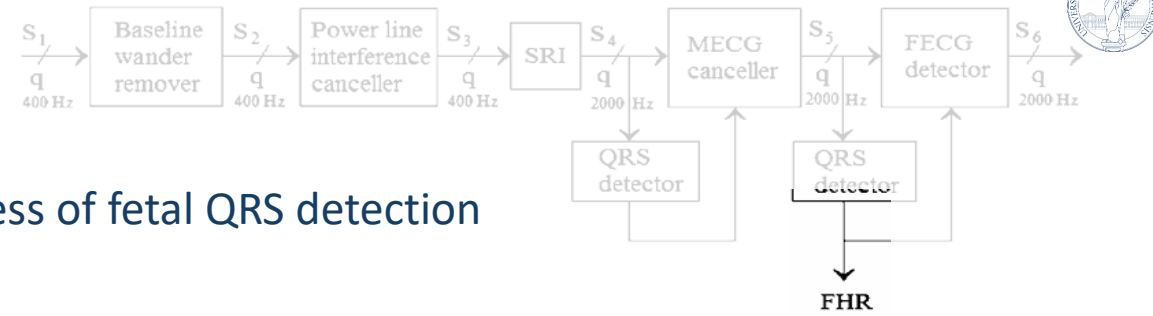
S5 → S6

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



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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

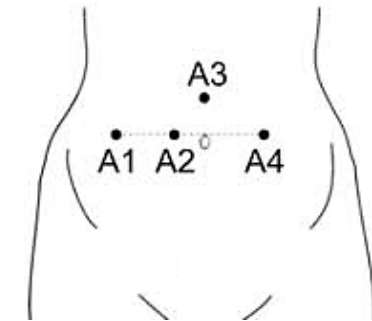




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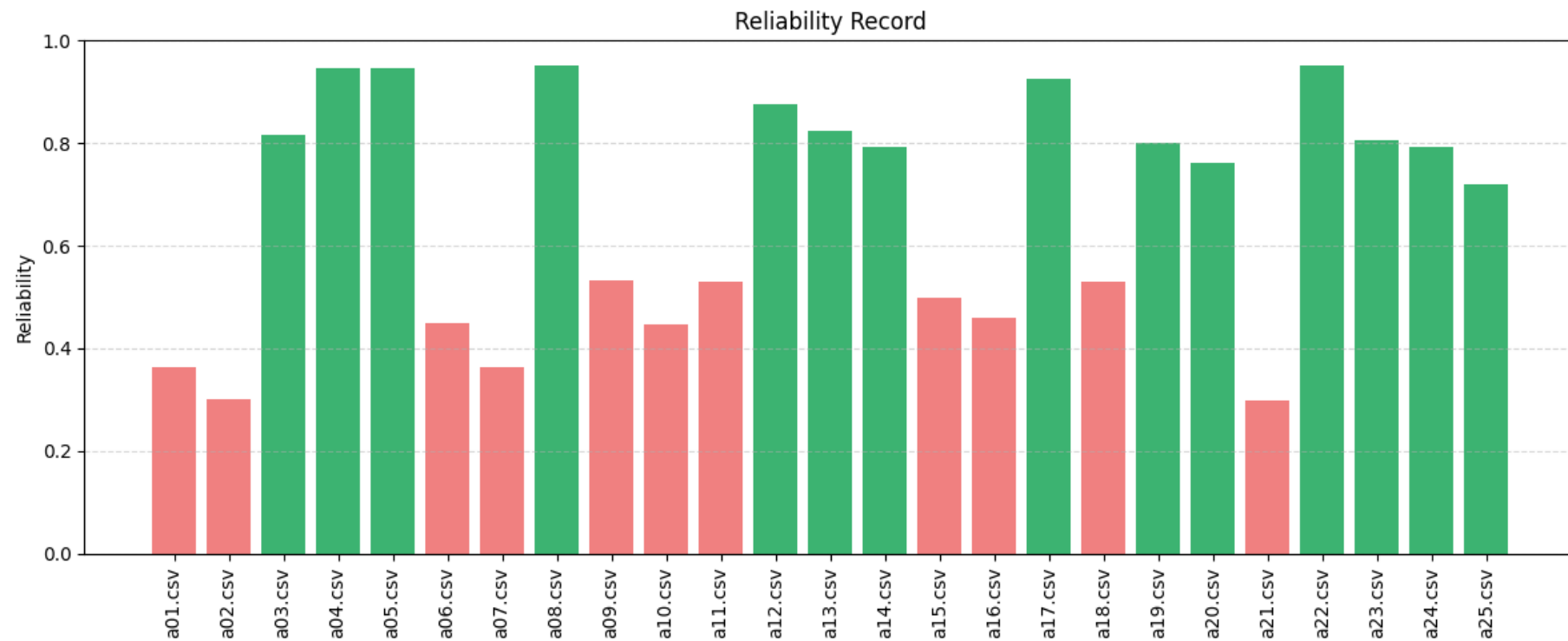
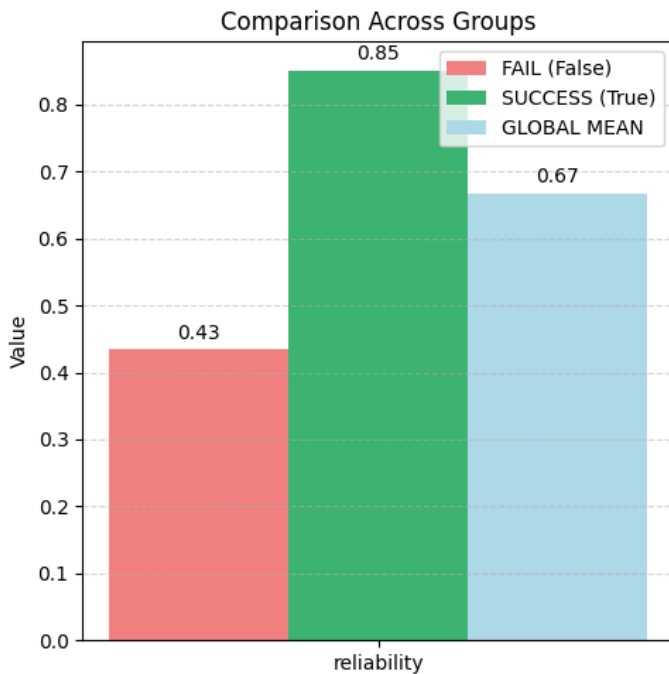
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Signal quality metrics

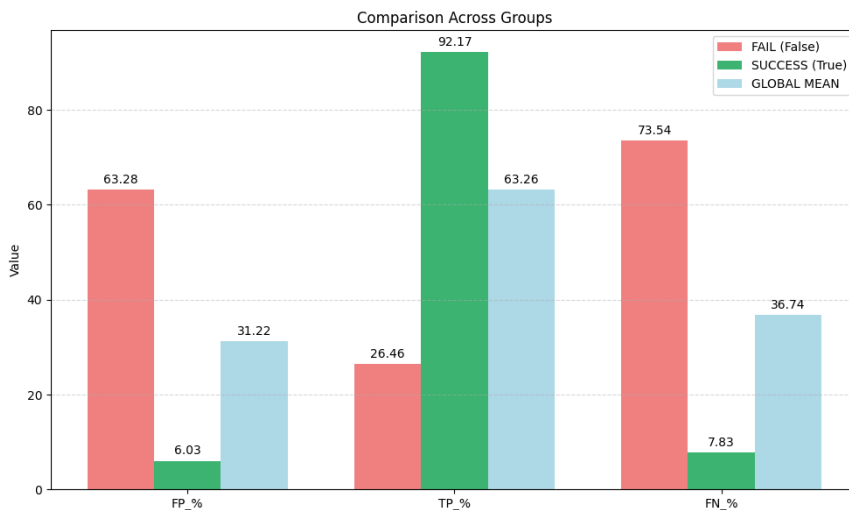
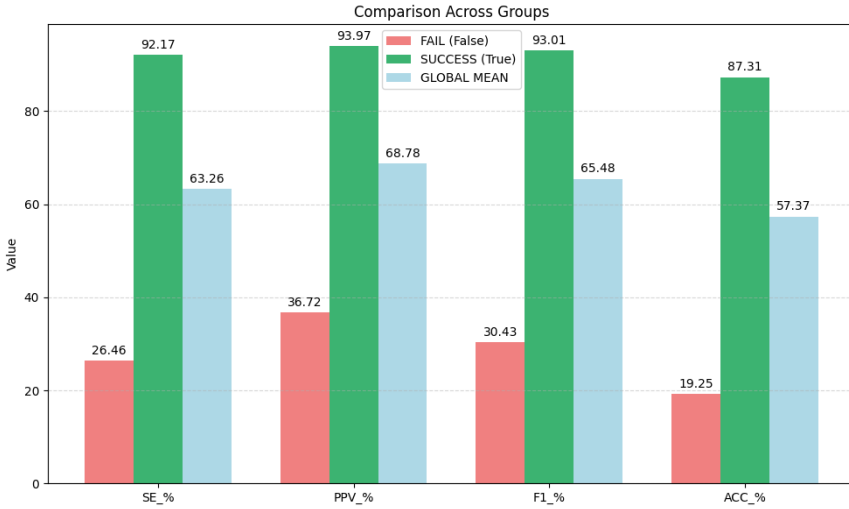
$$Reliability = 1 - \frac{num_outliers}{total_point_FHR}$$

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

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

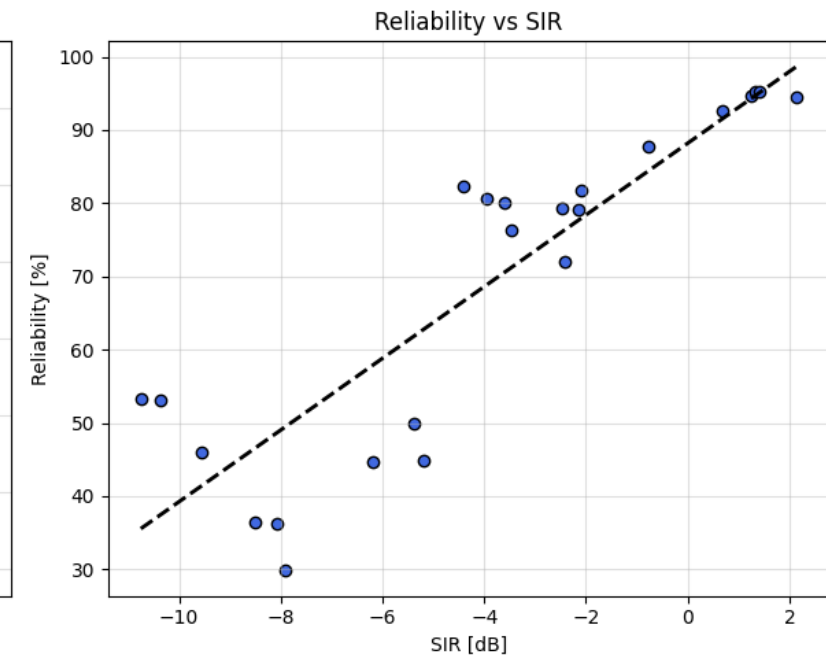
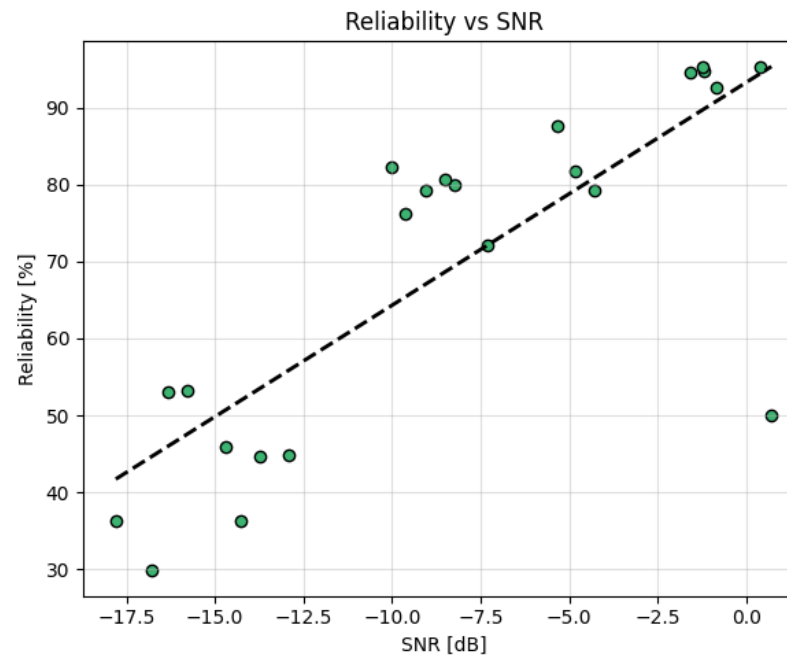


Signal quality metrics

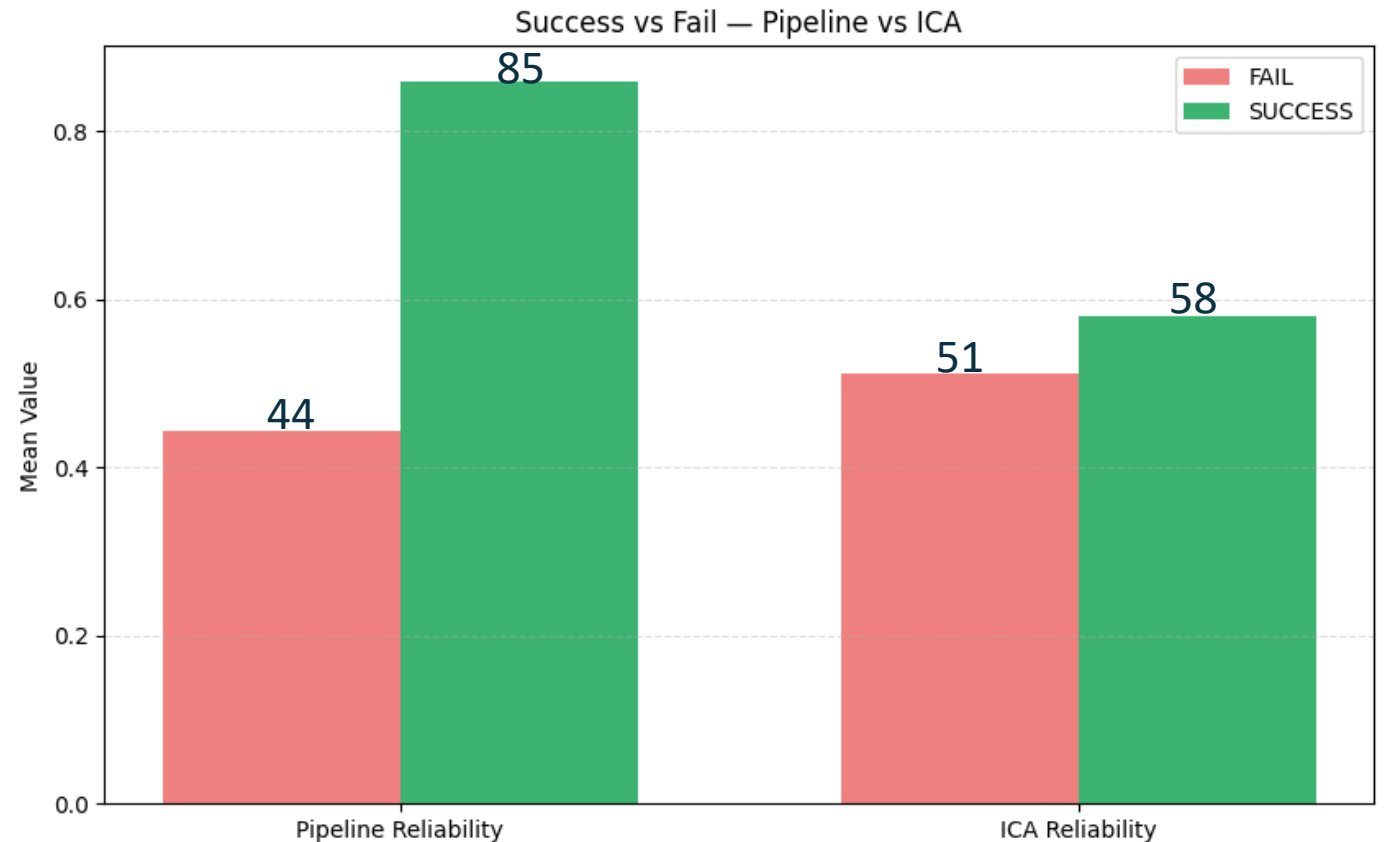
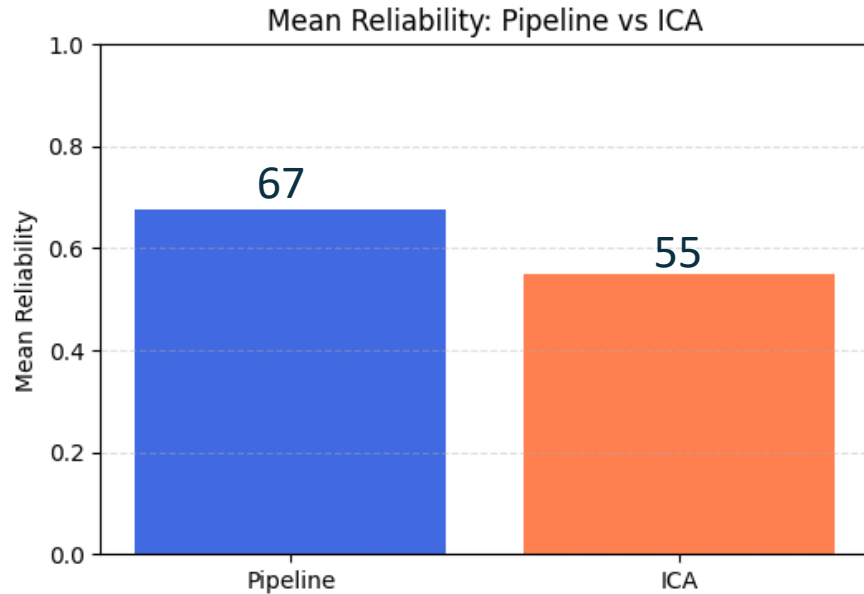


$$SNR_j = \frac{P_{F_j}}{P_{N_j}} = \frac{P_{S_{6,j}}}{P_{S_{5,j} - S_{6,j}}},$$

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



Comparison with FastICA



Comparison with FastICA

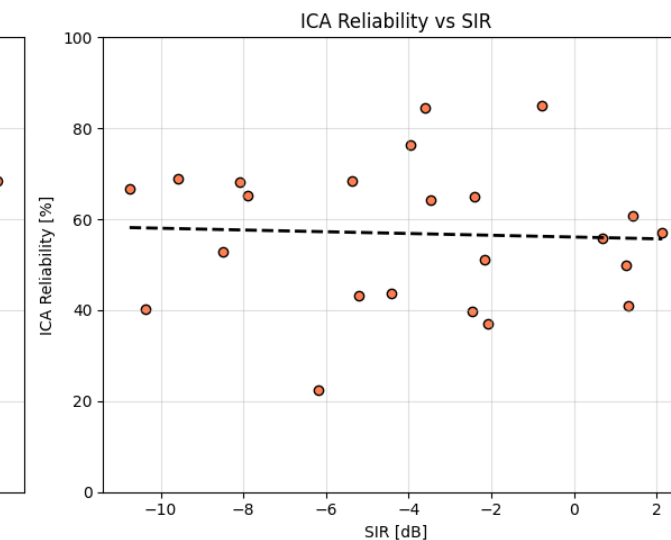
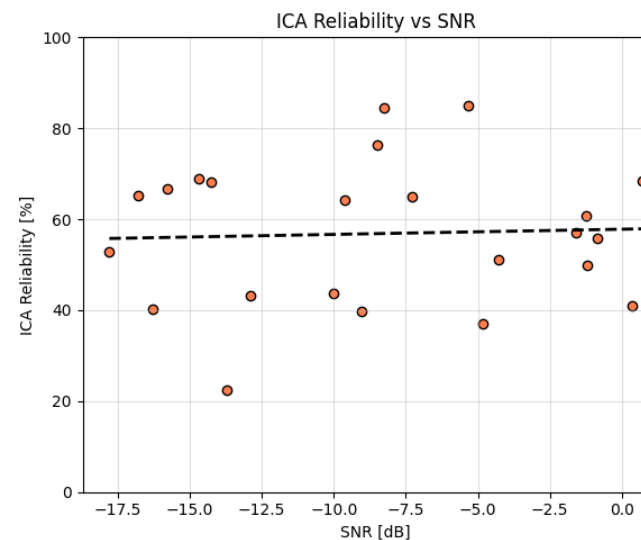
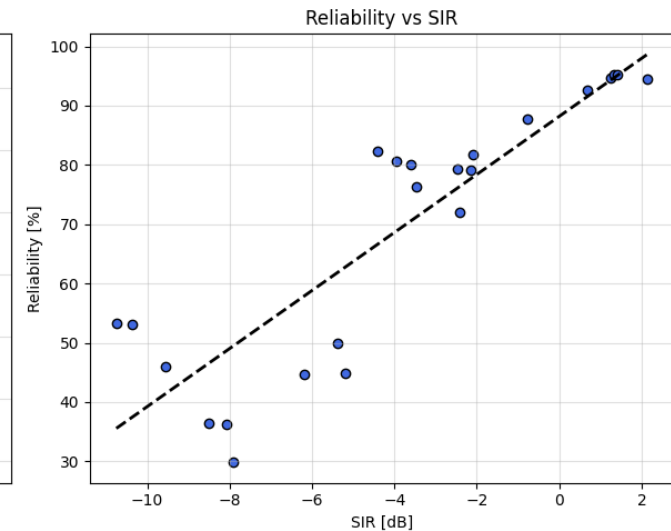
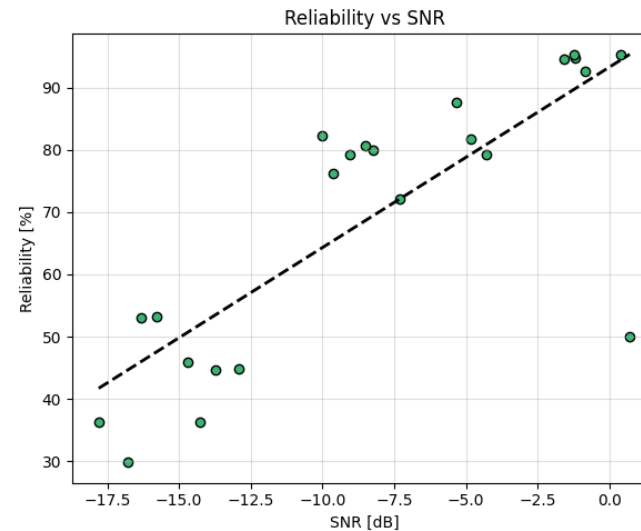
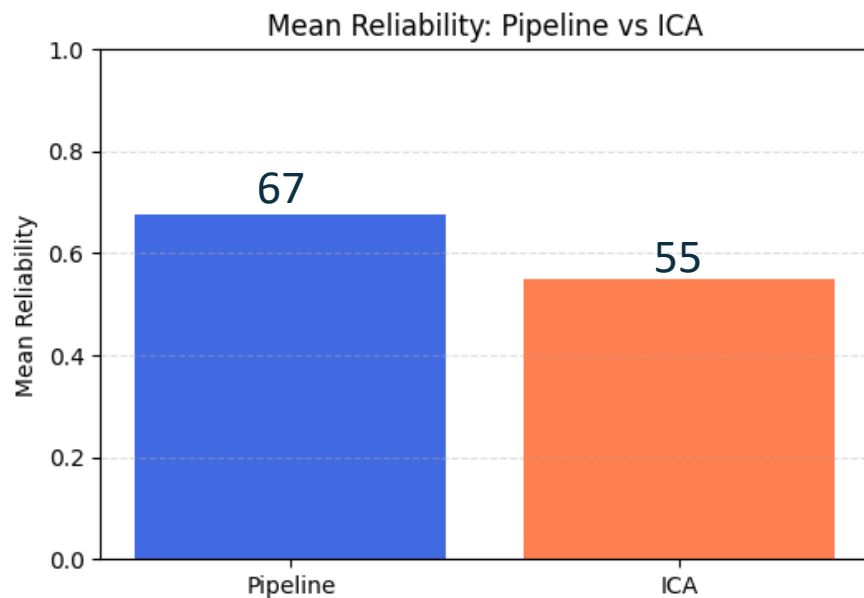




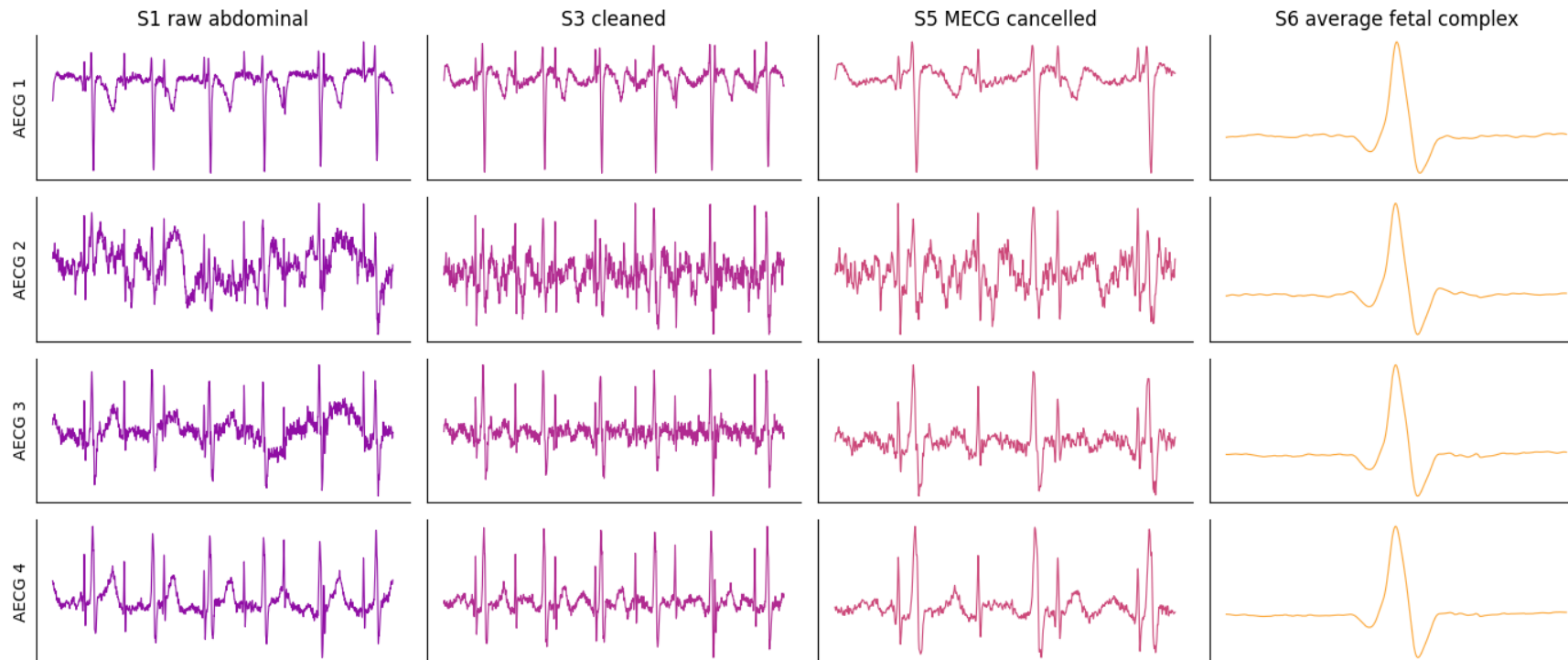
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Conclusion

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