A robust fetal ECG detection method for abdominal recordings

Porcelli Angelica – 78083A

Biomedical Signal Processing

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Fetal ECG Extraction Challenges

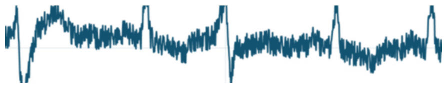
When recording **abdominal ECG** from a *pregnant woman*, the signal is a **mixture** of different physiological and non-physiological components:

1. **Maternal ECG (MECG)**


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.**

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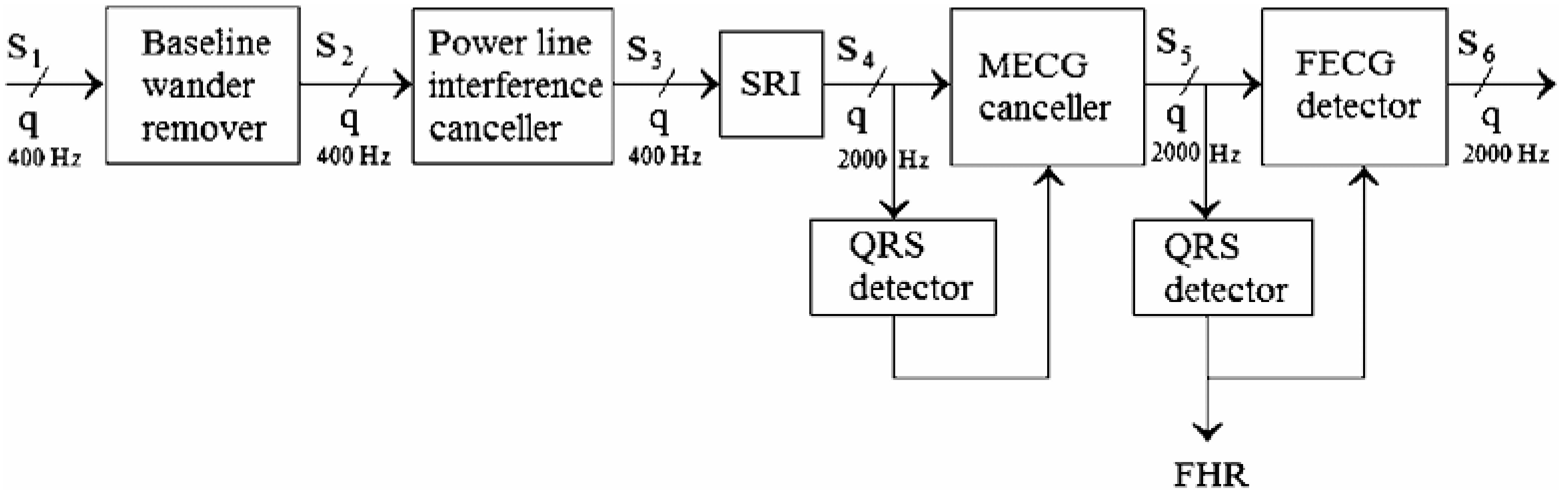
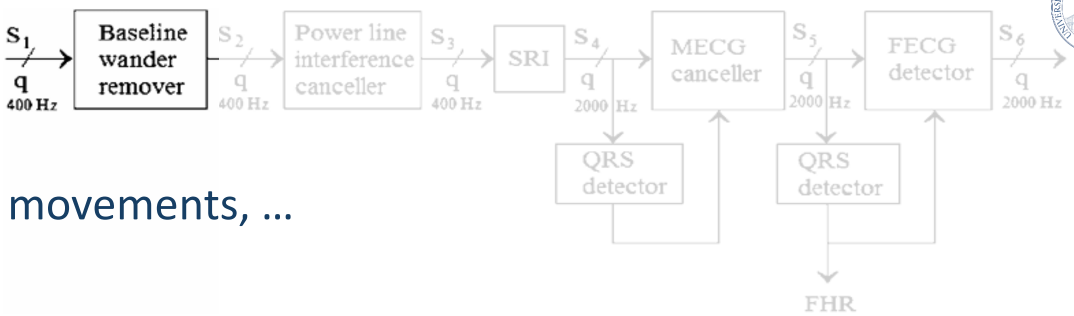
The Algorithm

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



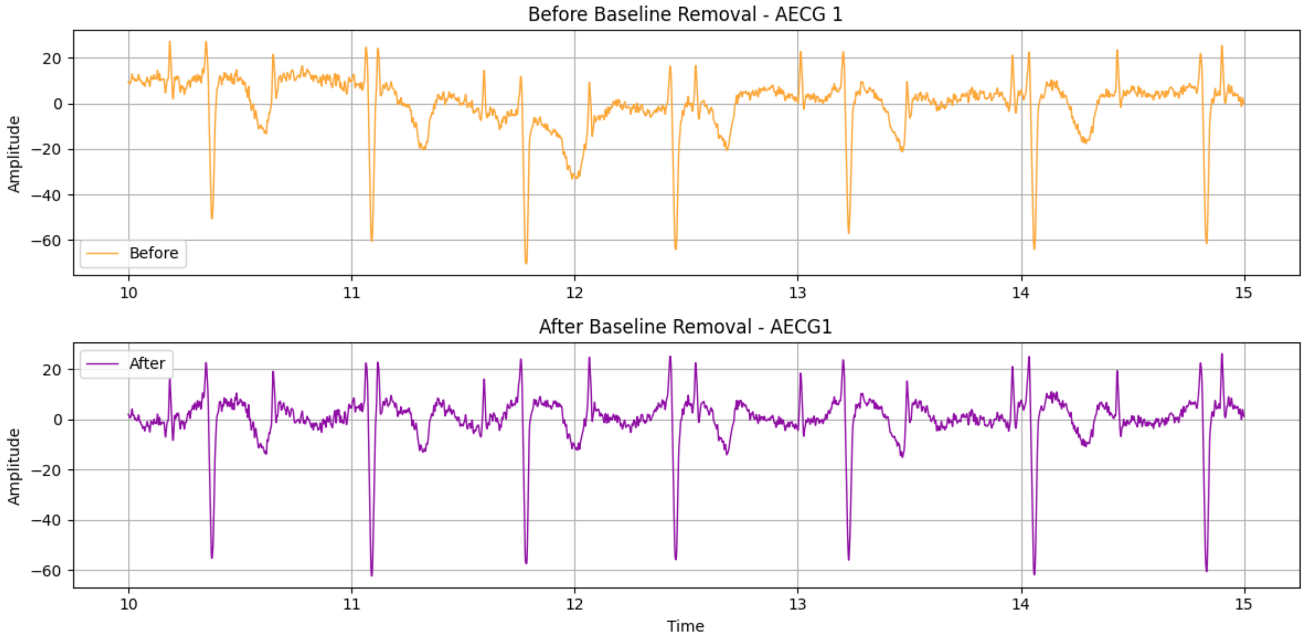
1. Remove Baseline

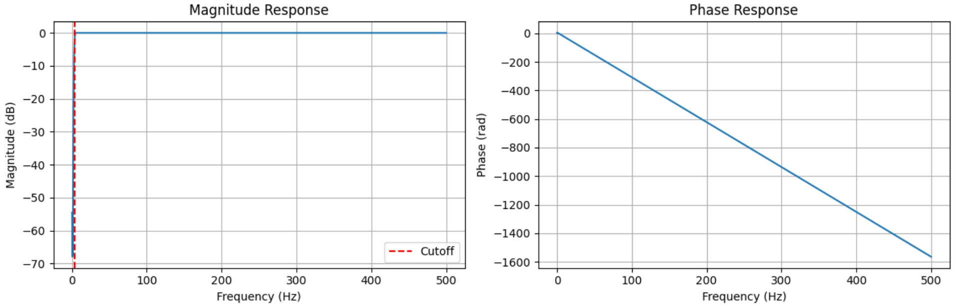
Objective: **remove slow oscillations** caused by breathing, body movements, …



High-pass FIR filter :

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

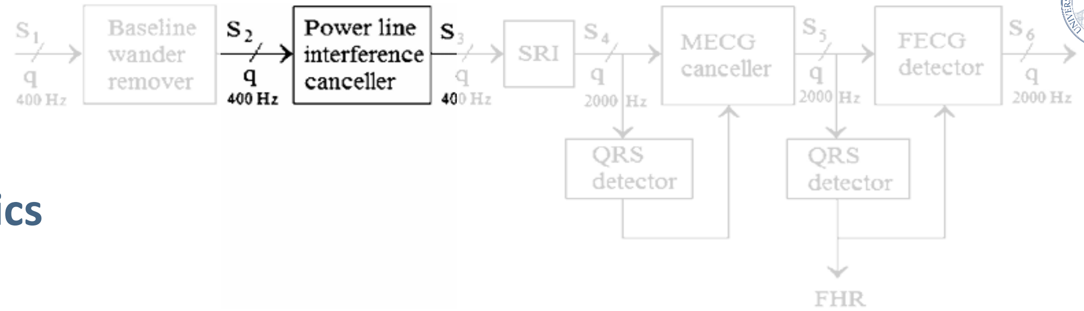


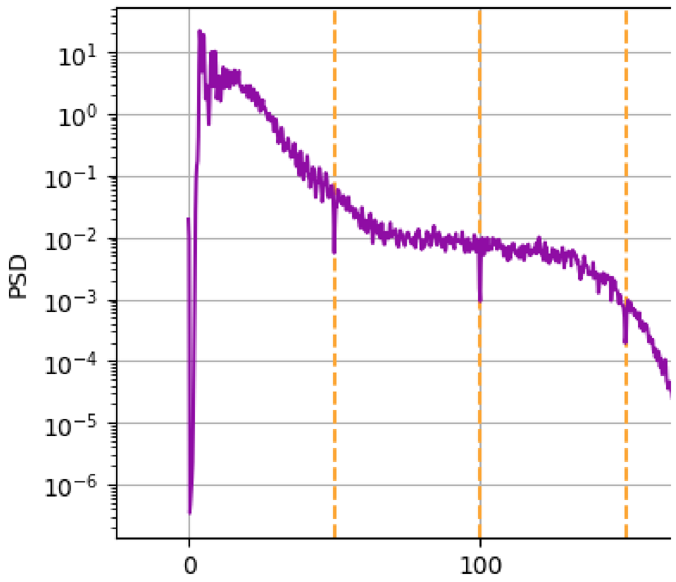


S1 → S2

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*

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

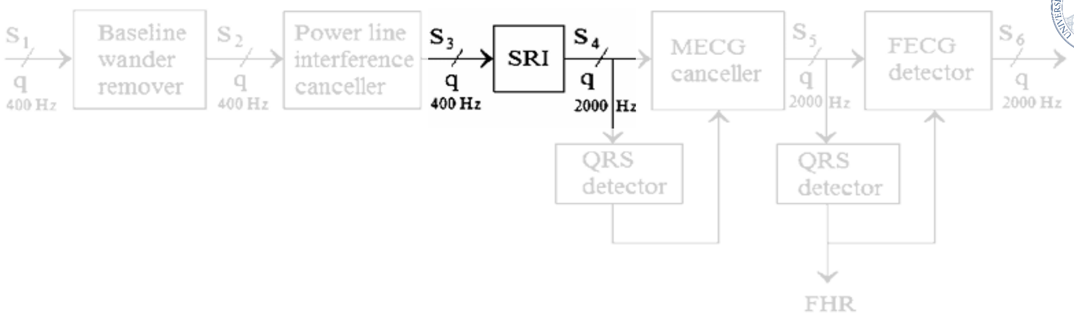
Clean Signal → Update of Coefficients → Phase Adaptation

using an LMS rule driven
by the residual error

S2 → S3

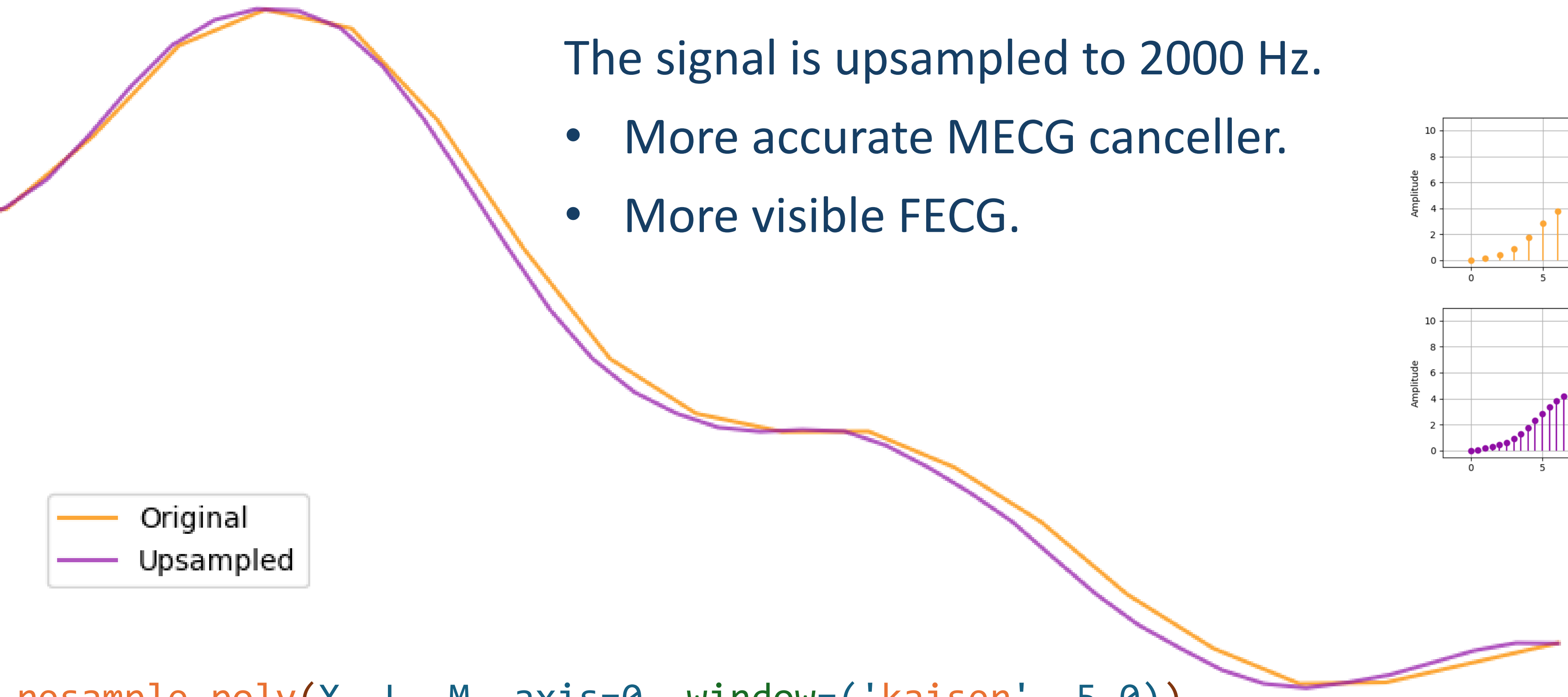
3. Increase samplings

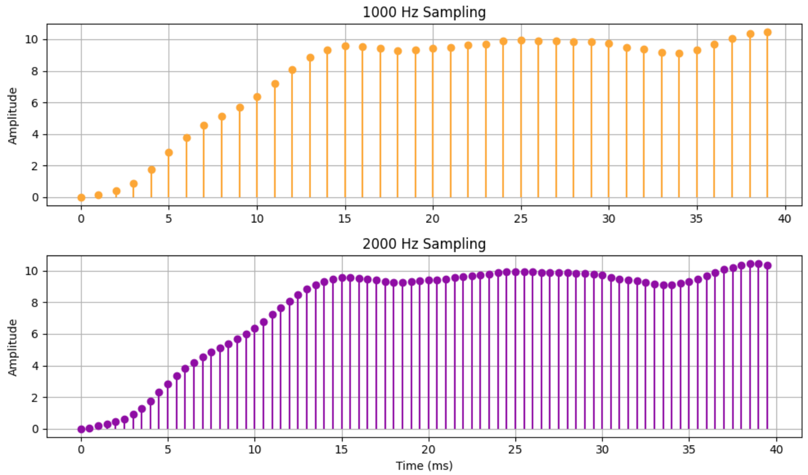
Objective: **improve temporal resolution** and QRS alignment



The signal is upsampled to 2000 Hz.

- More accurate MECG canceller.
- More visible FECG.

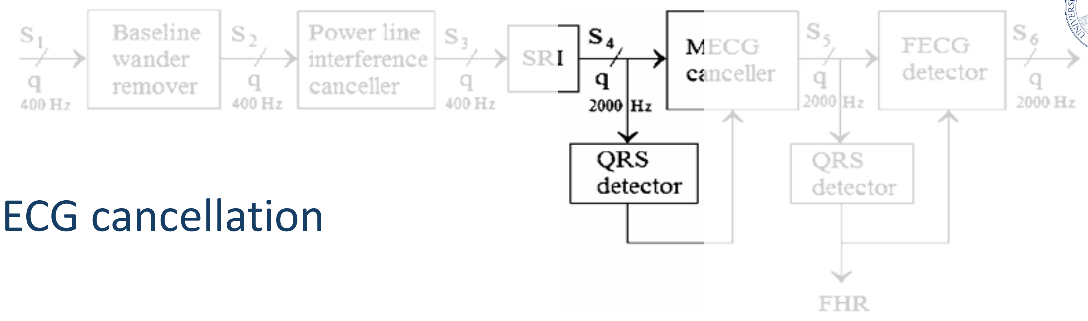





```
resample_poly(X, L, M, axis=0, window=('kaiser', 5.0))
```

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

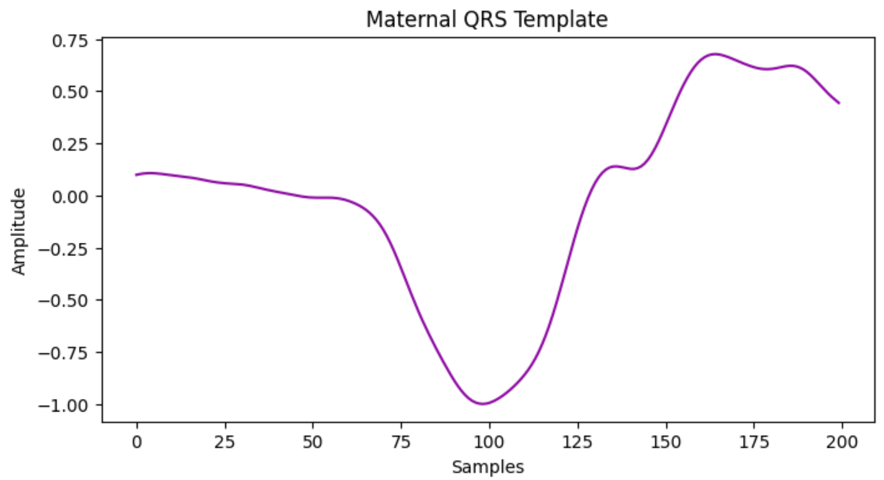
Cross-correlation with a synthetic QRS template

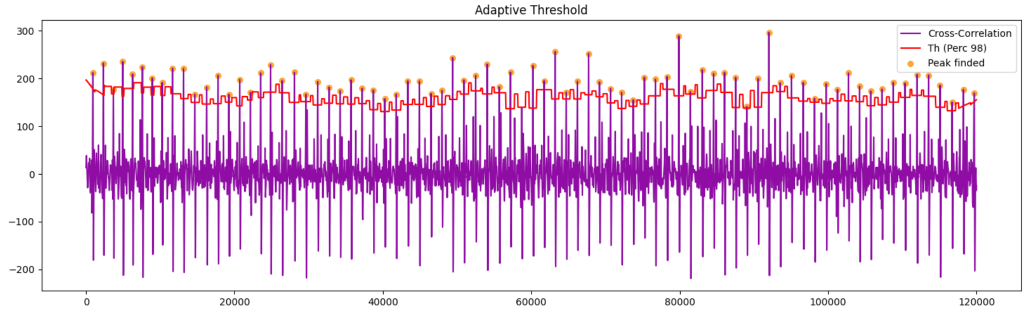
3. Real Template

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

4. Final detection

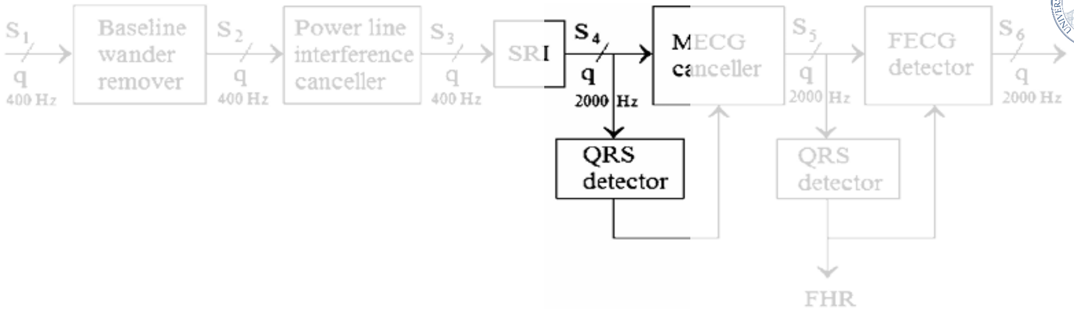
Cross-correlation with QRS template

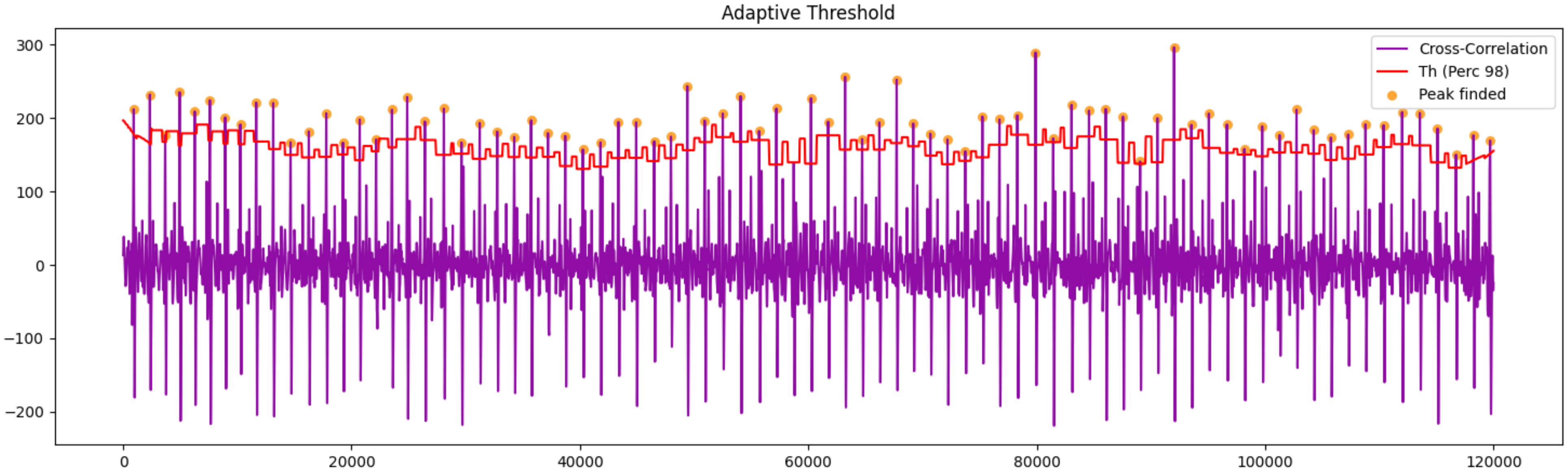




S4 → MQRS

4. M-QRS Detection



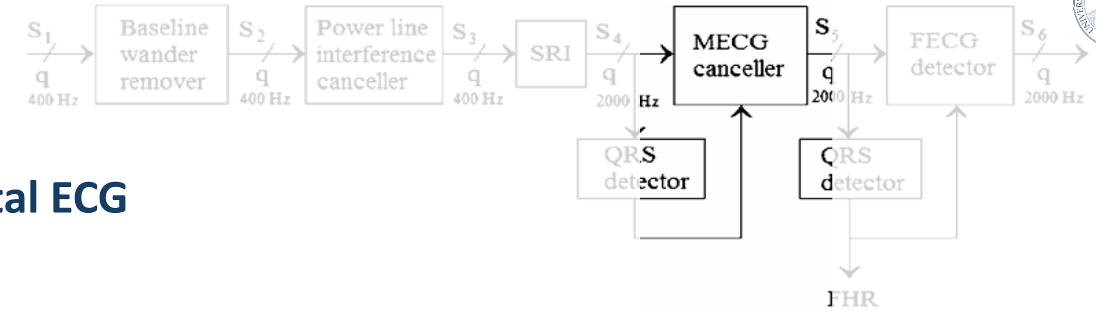



```
refractory_ms = 300, refine_ms = ±40,  duration_ms = 100
```

S4 → MQRS

5. MECG Canceller

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



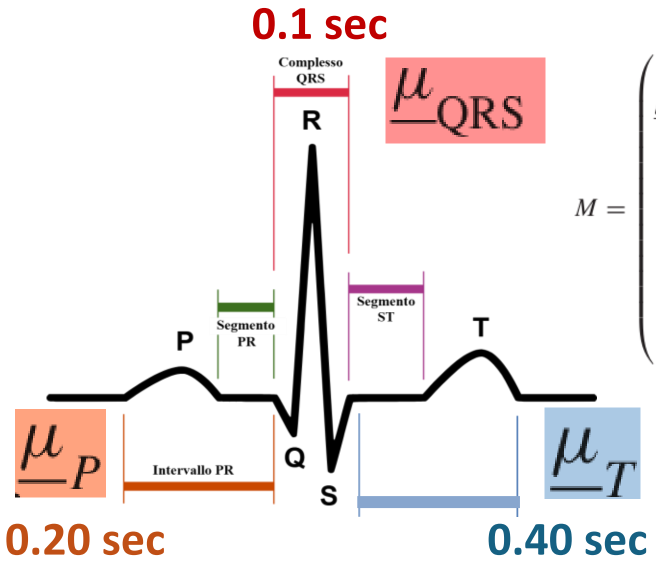
1. Extract window

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

2. Create a template

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

3. Split and create matrix



$$M = \begin{pmatrix} | & 0 & 0 \\ \underline{\mu}_P & 0 & 0 \\ | & 0 & 0 \\ 0 & | & 0 \\ 0 & \underline{\mu}_{QRS} & 0 \\ 0 & | & 0 \\ 0 & 0 & | \\ 0 & 0 & \underline{\mu}_T \\ 0 & 0 & | \end{pmatrix}$$

4. Find adaptive scaling

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

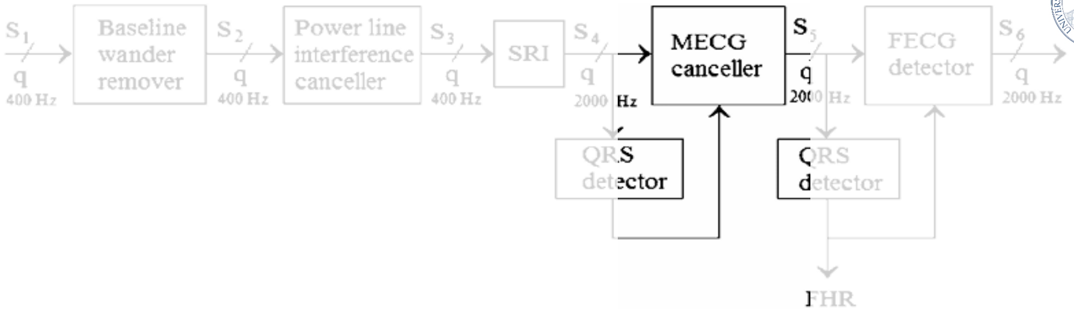
$$\underline{\hat{m}} = M\underline{a}$$

5. Template subtraction

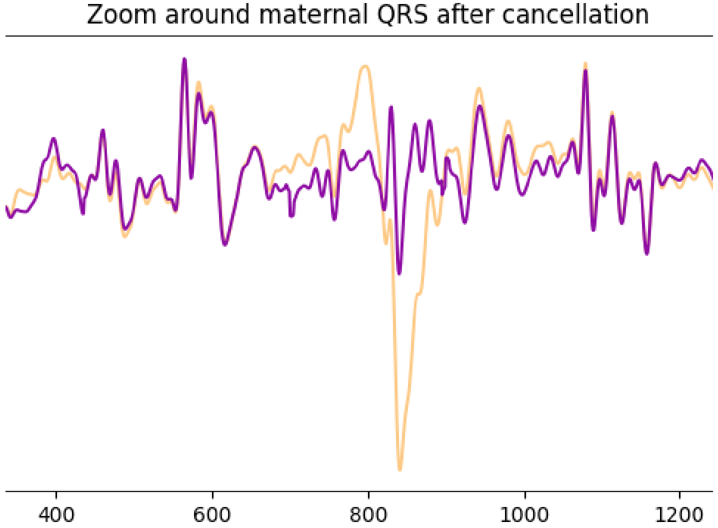
$$S5(t) = S4(t) - \hat{m}(t)$$

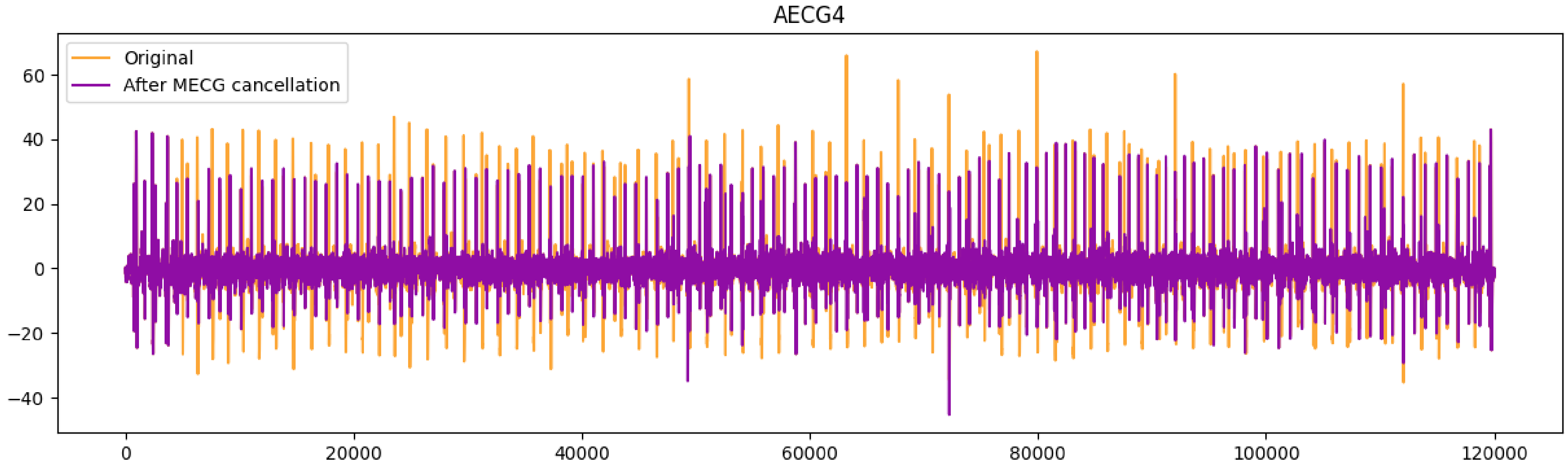
S4 → S5

5. MECG Canceller




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

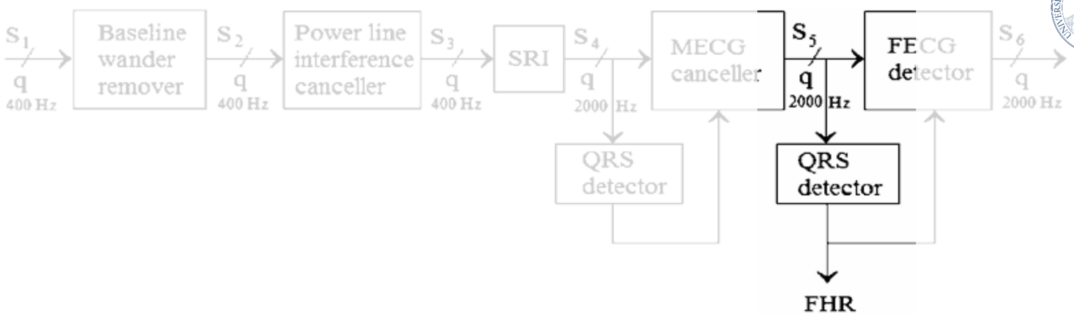




S4 → S5

6. F-QRS Detection

Objective: identify **fetal QRS complexes**

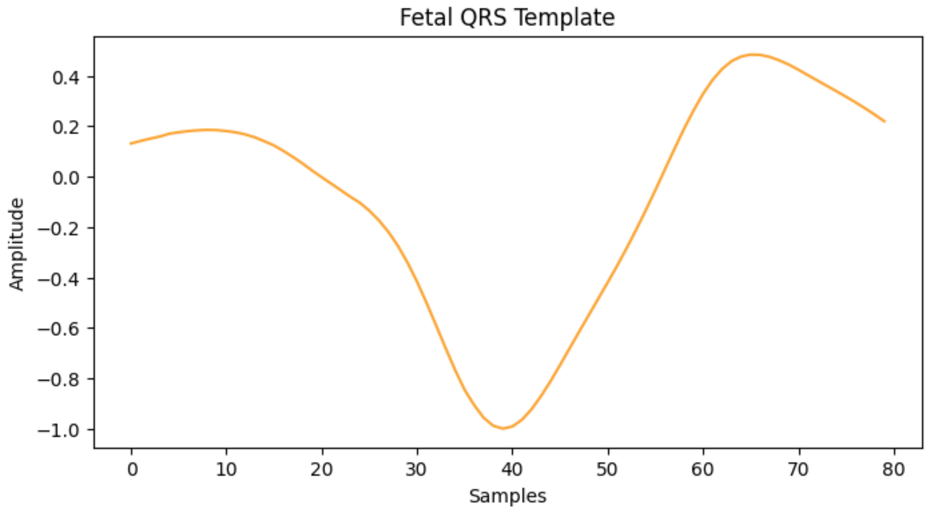


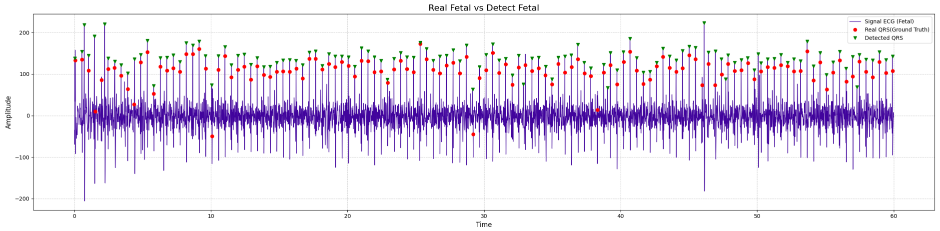
1. **PCA enhancement**
2. **Rough detection**
3. **Real Template**
4. **Final detection**

    short refractory period

    short peak refinement

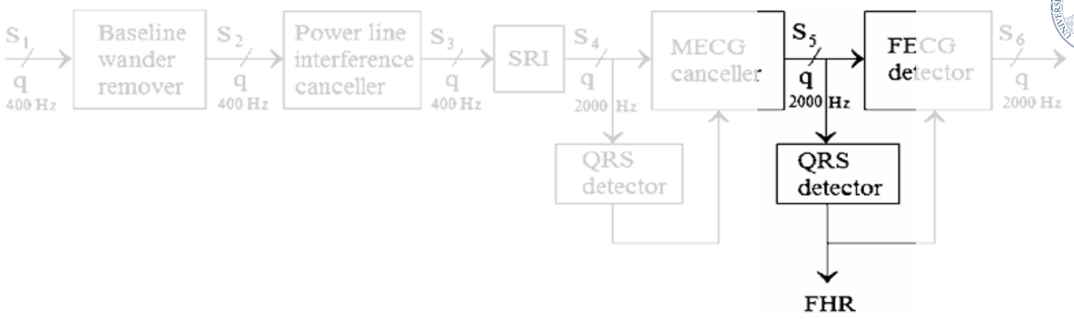
    short duration

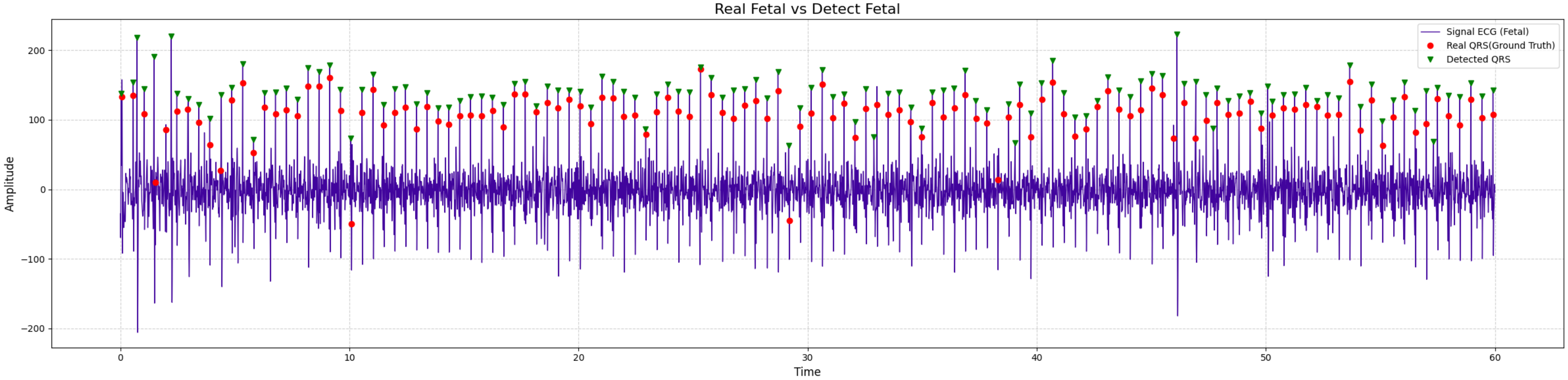




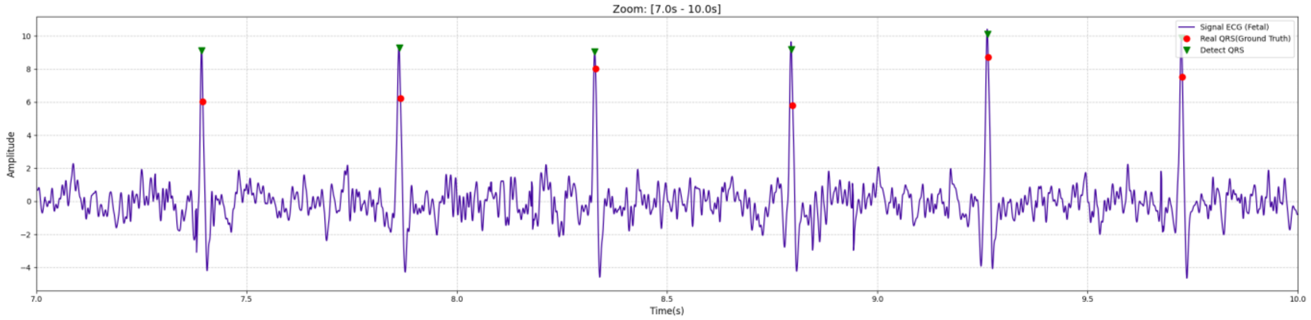
S5 → fQRS

6. F-QRS Detection



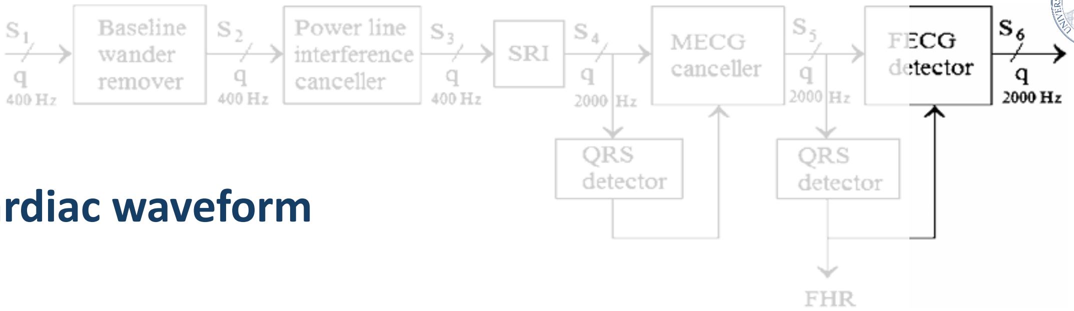



```
refractory_ms = 150,
refine_ms = ±20,
duration_ms = 40
```



S5 → fQRS

7.1 FECG Extraction

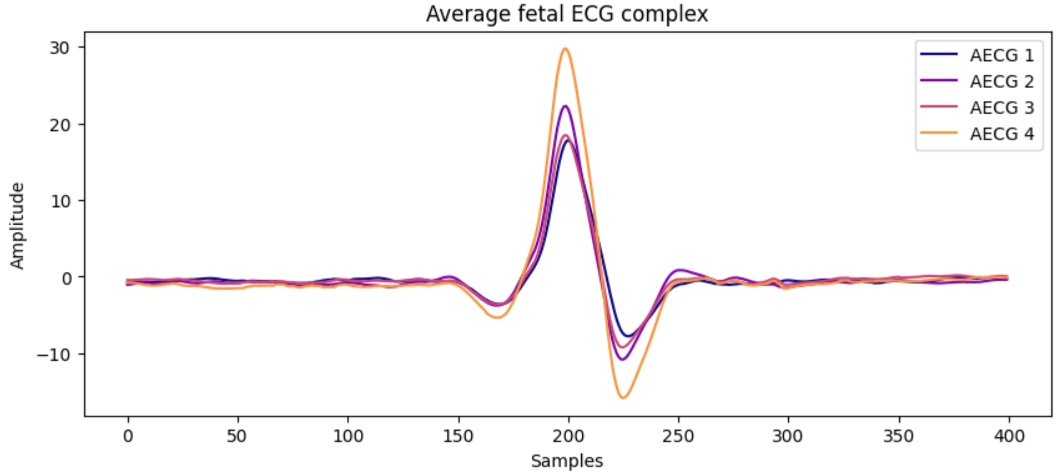


Objective: obtain a clean and reliable estimate of the fetal **cardiac waveform**

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

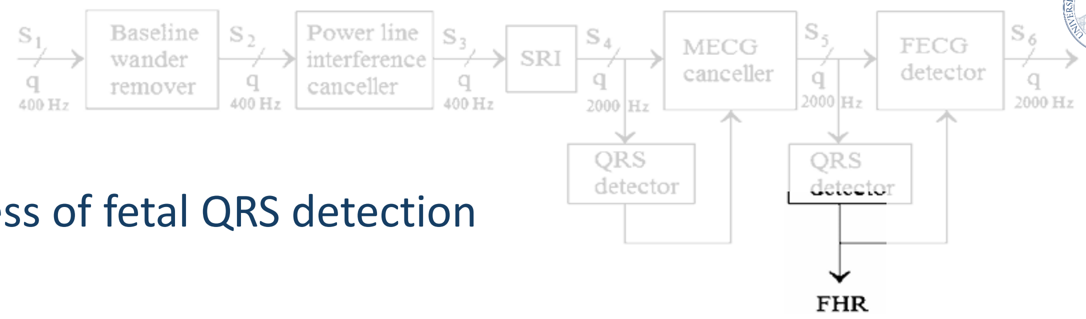
2. **Intrinsic alignment:**
   Since each window is centered on the detected QRS, all segments are aligned.

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



S5 → S6

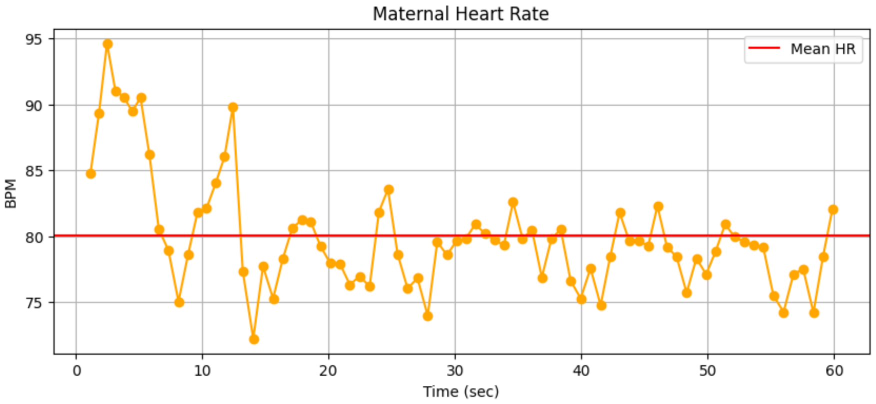
7.2 FHR

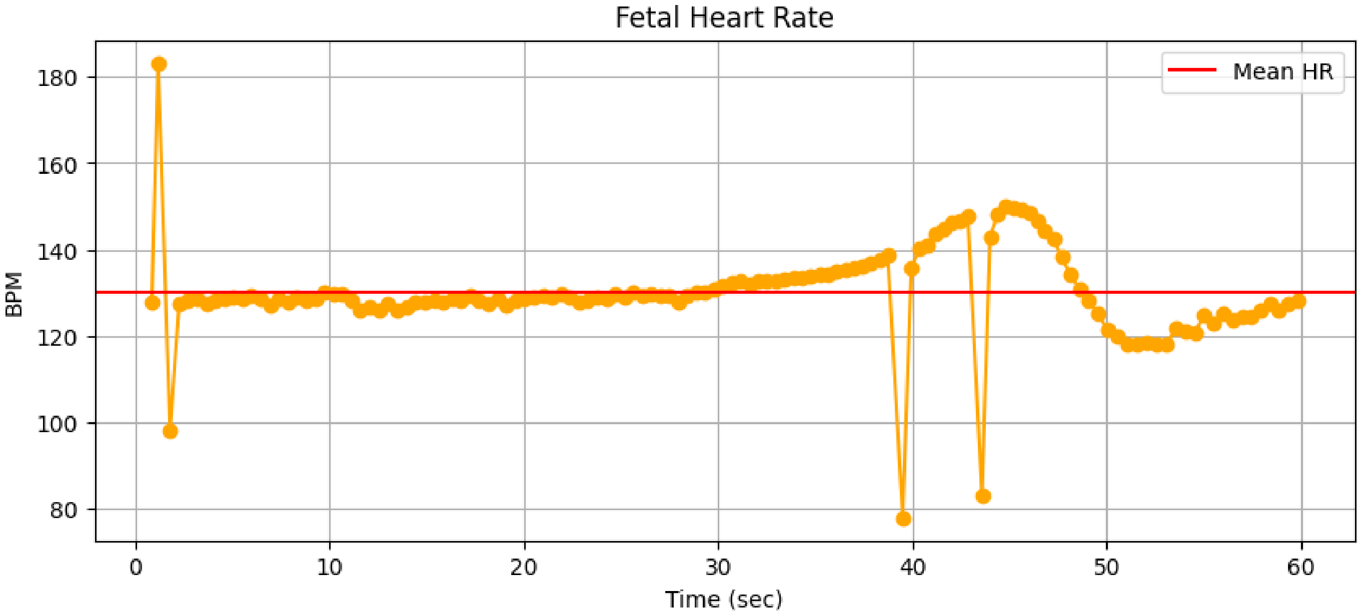


Objective: **evaluate the temporal consistency** and correctness of fetal QRS detection

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

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





Mean bpm 130.21 detected
Mean bpm 128.76 real

S5 → S6

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Dataset

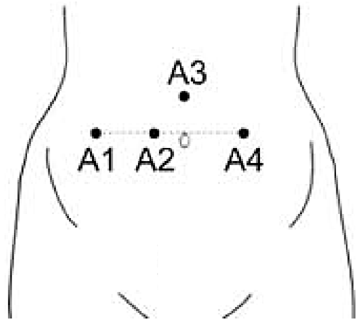
PhysioNet Challenge 2013 (Set A): https://physionet.org/content/challenge-2013/1.0.0/

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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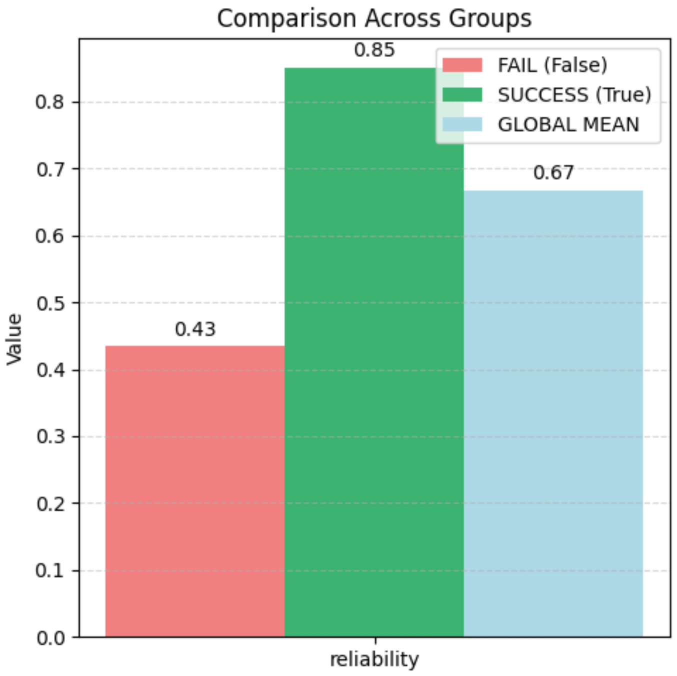
Signal quality metrics

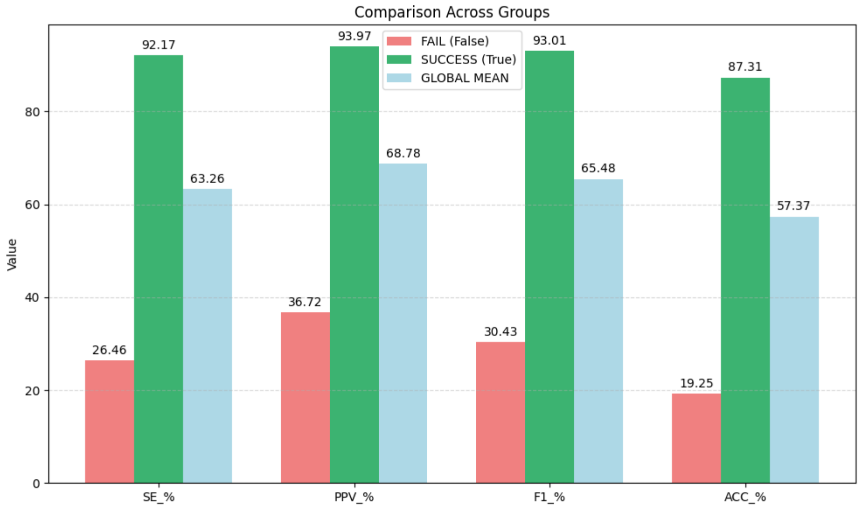
$$Reliability = 1 - \frac{num\_outliers}{total\_point\_FHR}$$

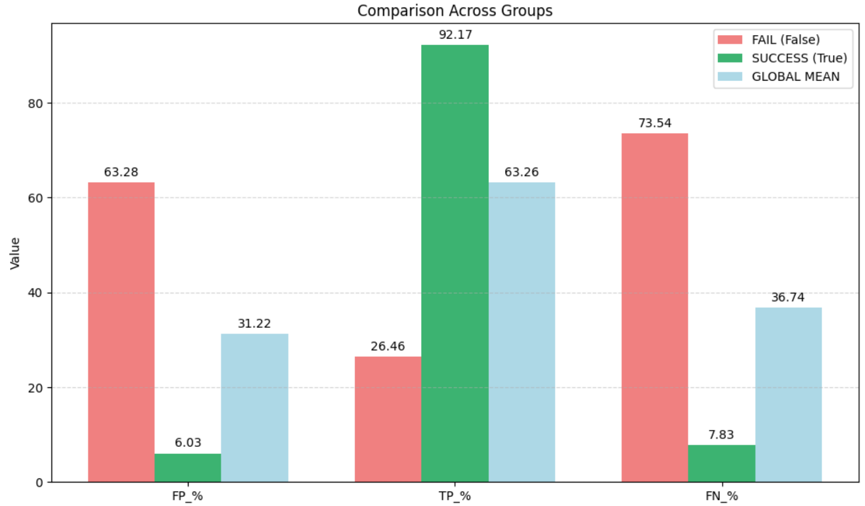
$$num\_outliers = |FHR\ i\ - median\ | > 10\ bpm$$

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



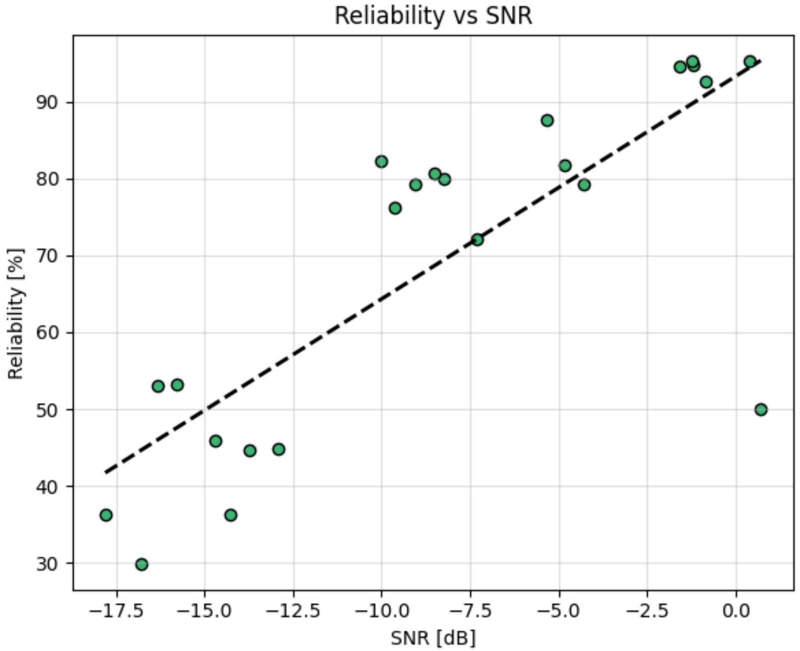
Signal quality metrics

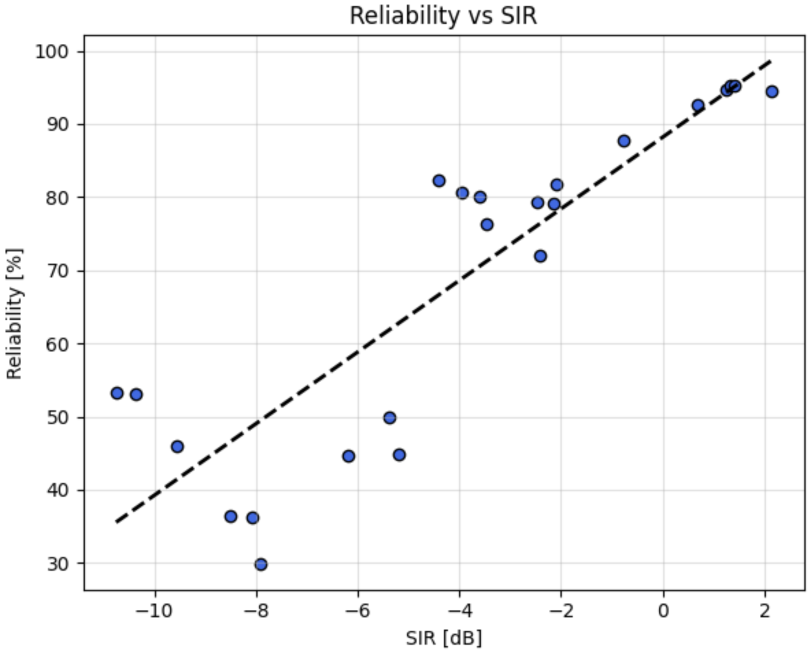




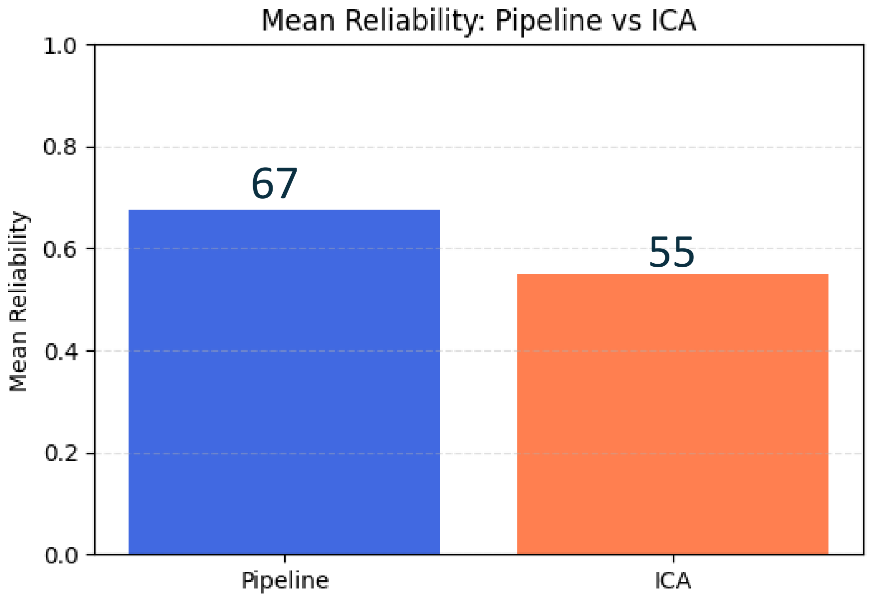
$$\mathrm{SNR}_j = \frac{P_{F_j}}{P_{M_j}} = \frac{P_{S_{6,j}}}{P_{S_{5,j}-S_{6,j}}},$$

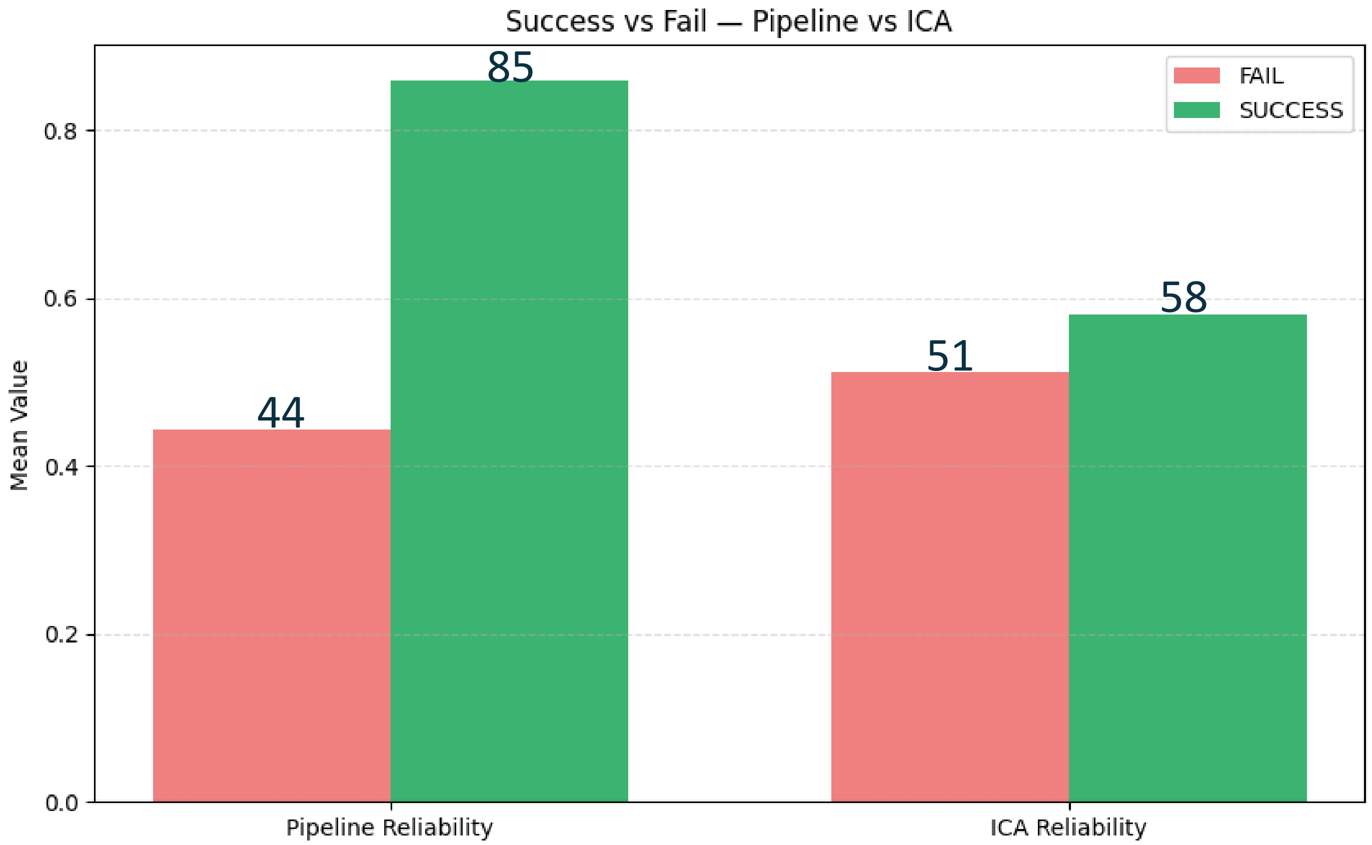
$$\mathrm{SIR}_j = \frac{P_{F_j}}{P_{N_j}} = \frac{P_{S_{6,j}}}{P_{S_{4,j}-S_{5,j}}}.$$



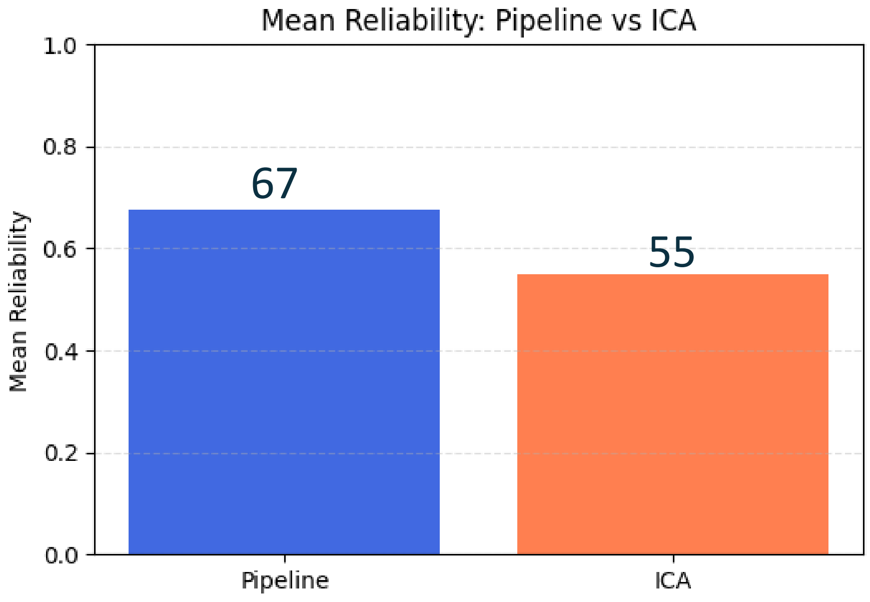


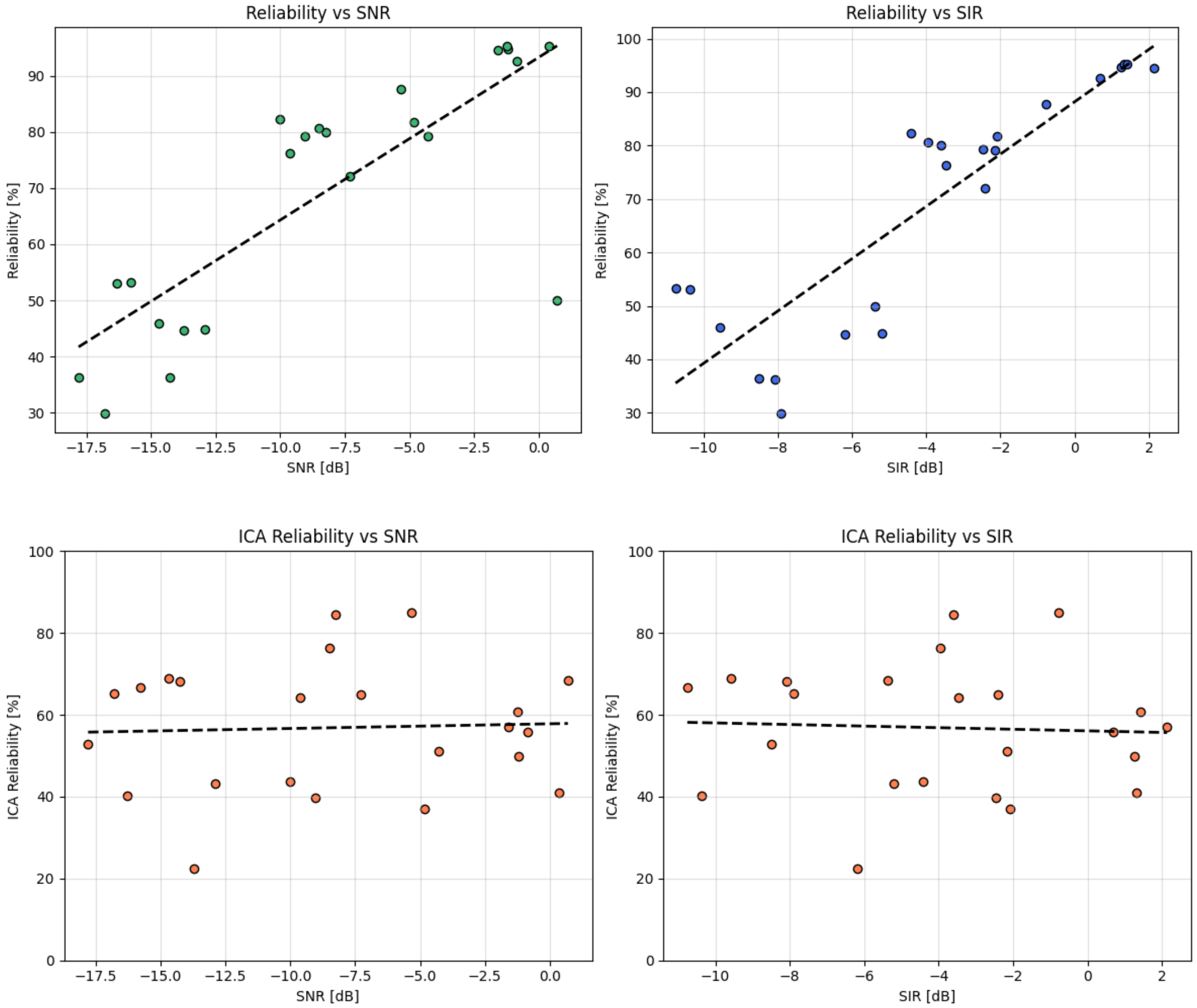
Comparison with FastICA





Comparison with FastICA





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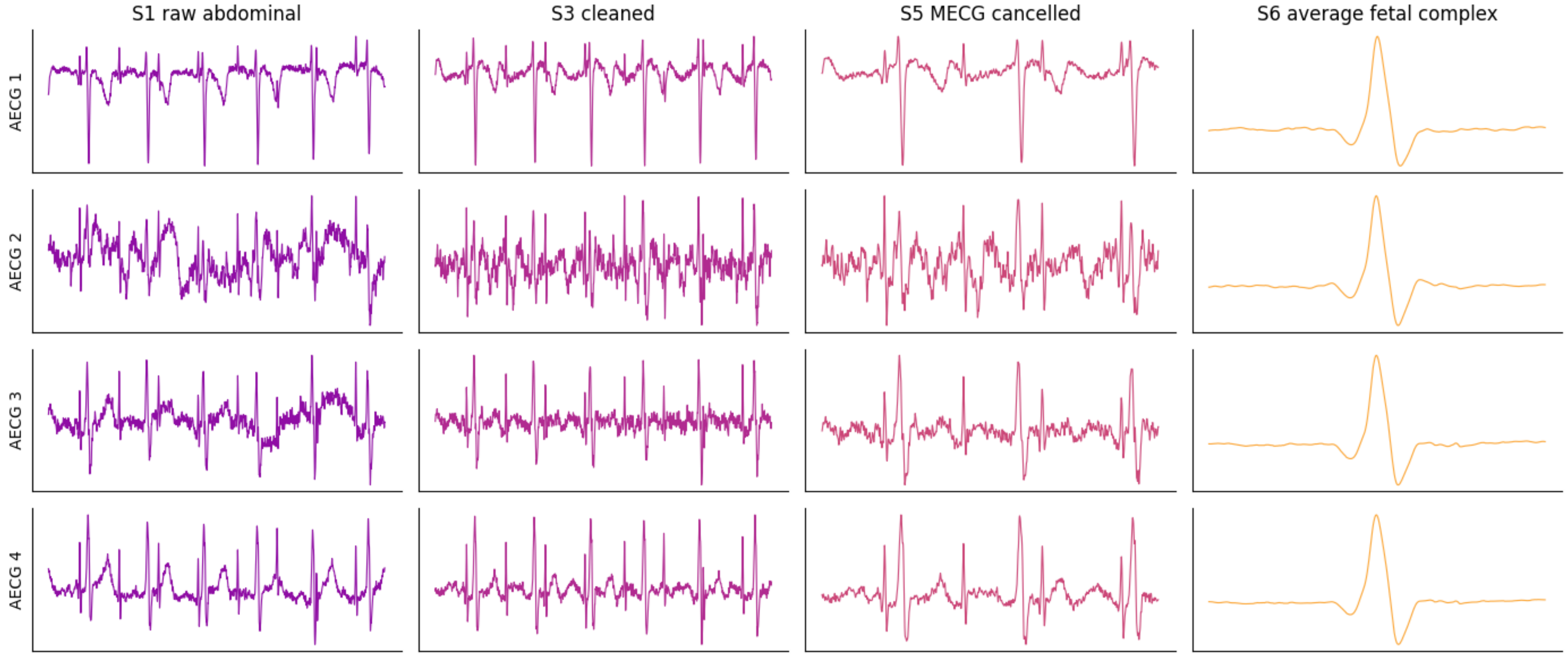
Conclusion

Non-blind methods outperform blind ICA.

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



Thanks

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