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EEG GRADIENT ARTIFACT REMOVAL BY COMPRESSIVE SENSING AND TAYLOR-FOURIER TRANSFORM

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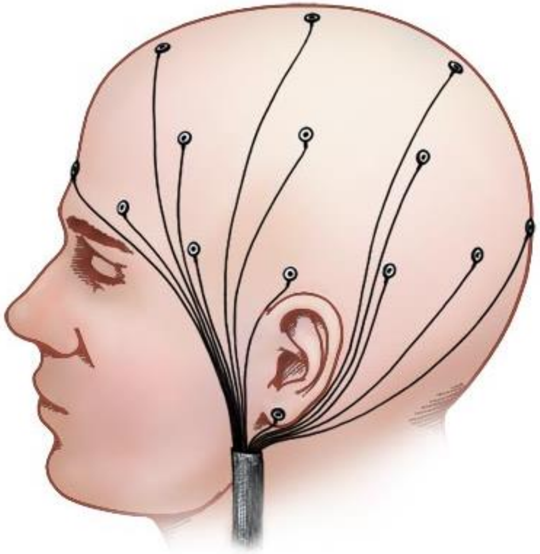
Brain Activities Measuring Techniques

- Neurophysiology **measuring approaches** can be classified in **two main classes**:

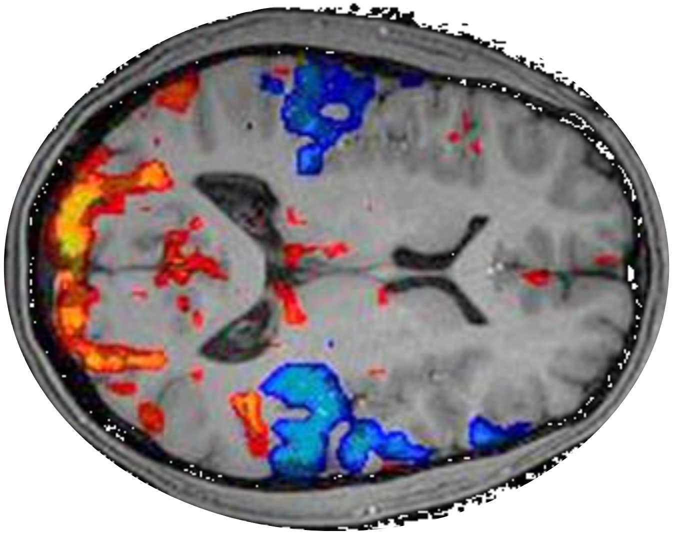
DIRECT

- Electroencephalography Recording (**EEG**)



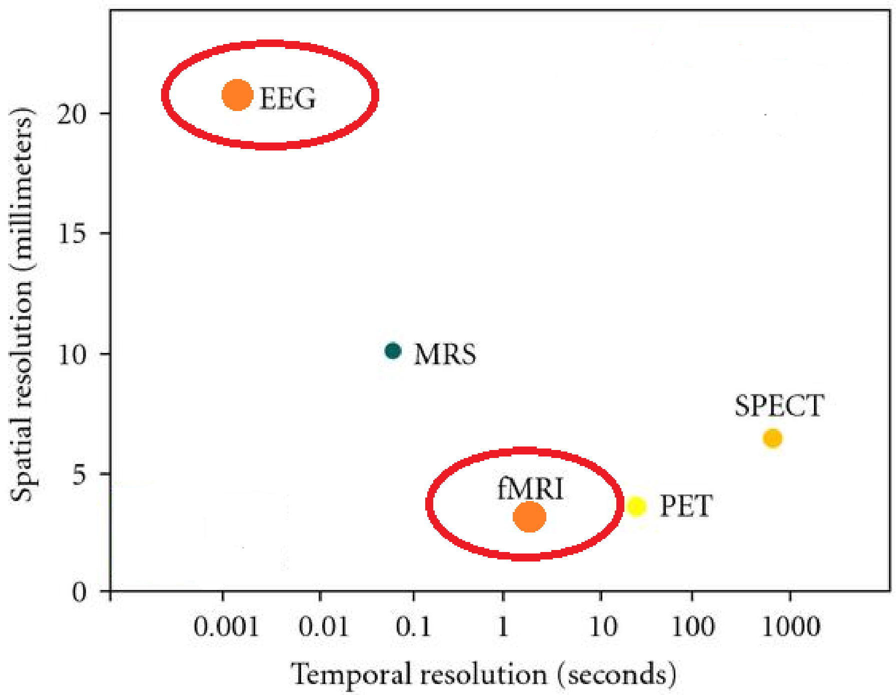
INDIRECT

- Functional Magnetic Resonance Imaging (**fMRI**)



Concurrent Acquisition

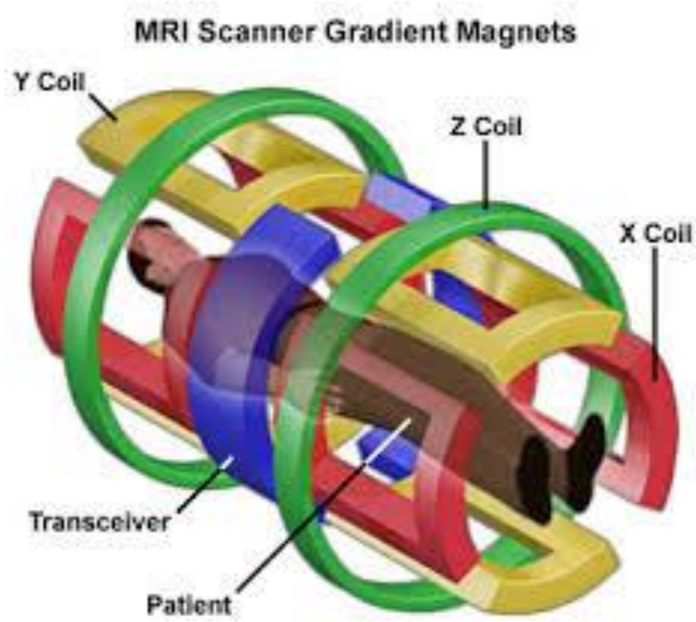
- A **synchronous acquisition** combines:
  - ***HIGH TEMPORAL RESOLUTION*** given by **EEG**
  - **HIGH SPATIAL RESOLUTION** given by **fMRI**



Gradient Artifact

- EEG leads and head tissues form **a loop**…

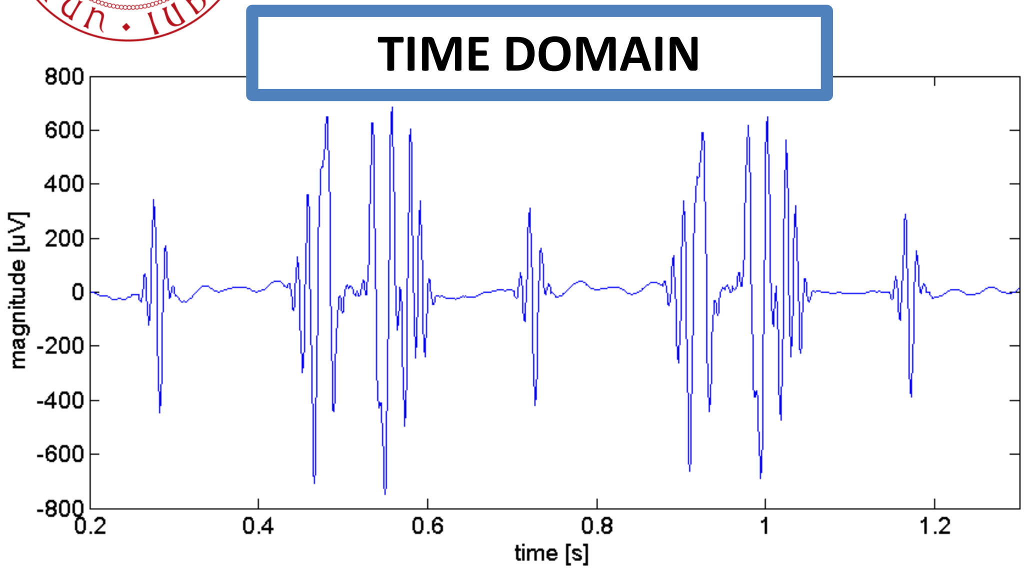
… while **magnetic field gradients** are periodically imposed and inverted

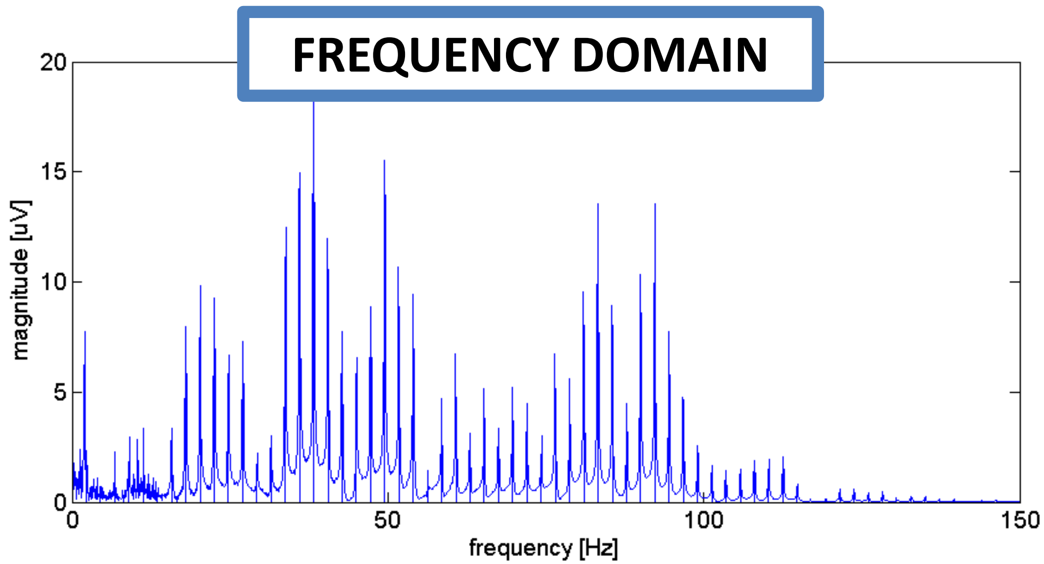


- Induced current produces

a large artifact, aka ***GRADIENT ARTIFACT (GRA)***

GRA Properties

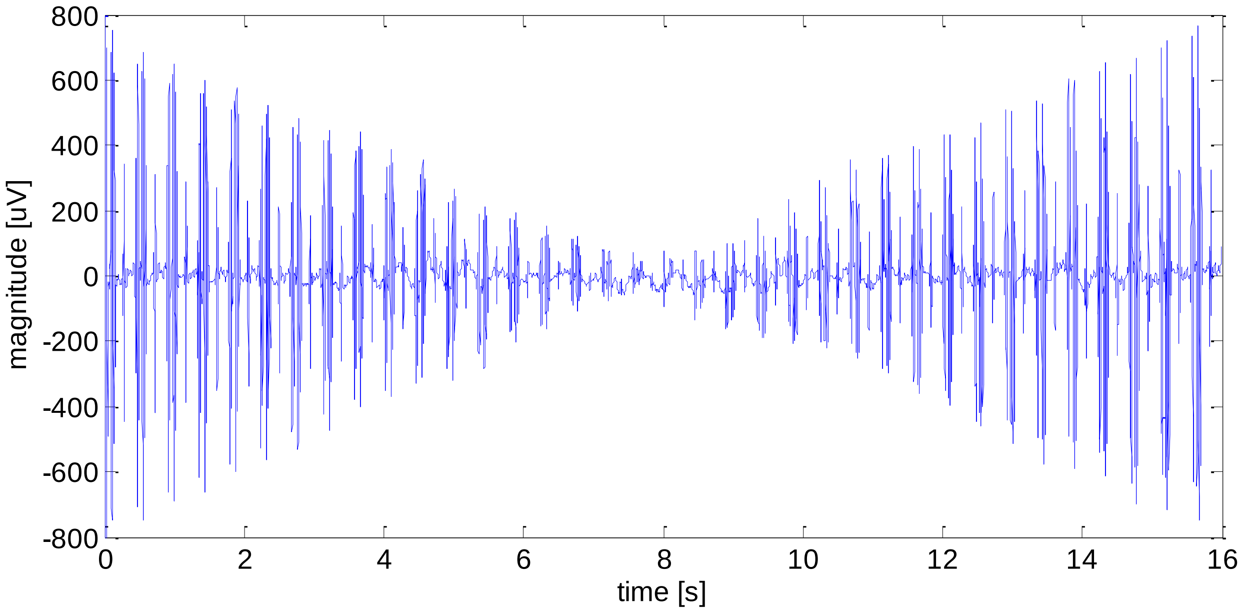




- ❖ train of occurrences
- ❖ two orders larger
- ❖ inherent periodicity
- ❖ irregular trend
- ❖ wideband

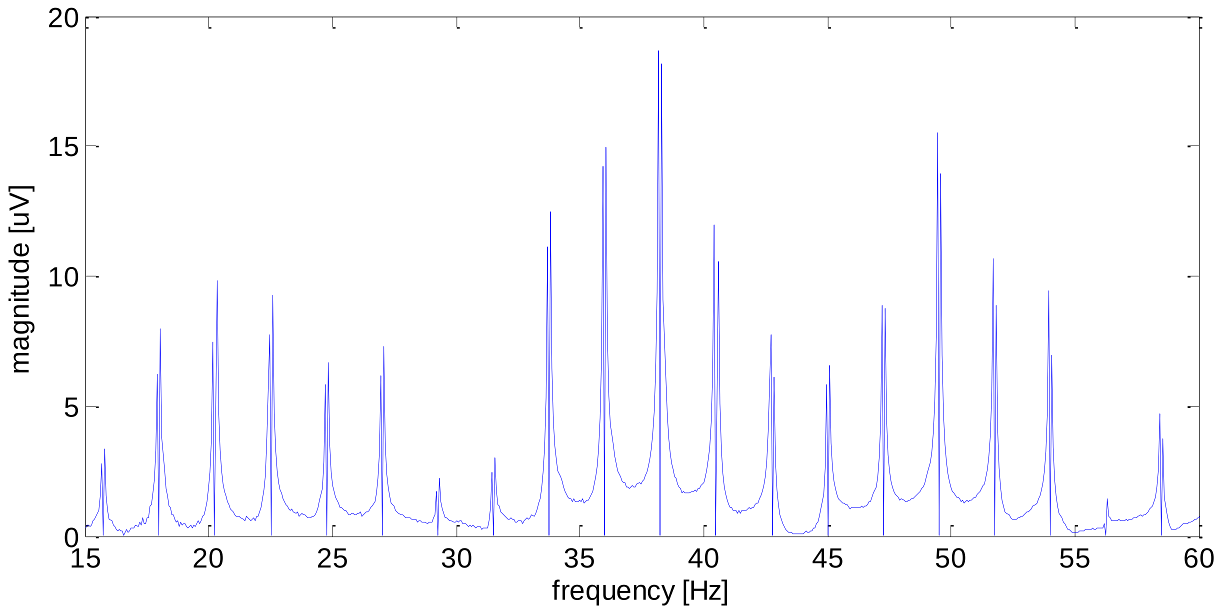
Water Phantom (1)

- **water phantom**, **only GRA** contribution
- in the time domain:
  - ***NO COINCIDENCE*** between artifact occurrences
  - low frequency ***ENVELOPE MODULATION***



Water Phantom (2)

- in the frequency domain:
  - peaks with ***INDEPENDENT AMPLITUDE AND PHASE***
  - almost ***EQUALLY SPACED*** frequencies $f_0 = \frac{N_v}{T_v}$



Problem Statement

ARTIFACT MODEL

$$x(t) = \sum_{h=1}^{H} A_h(t) cos(2\pi h f_0 t + \phi(t))$$

SAMPLED SIGNAL MODEL

$$y[n] = \sum_{h=1}^{H} A_h[n] cos(2\pi h f_0 n + \phi[n]) + e[n]$$

EEG *from informative to noisy* contribution

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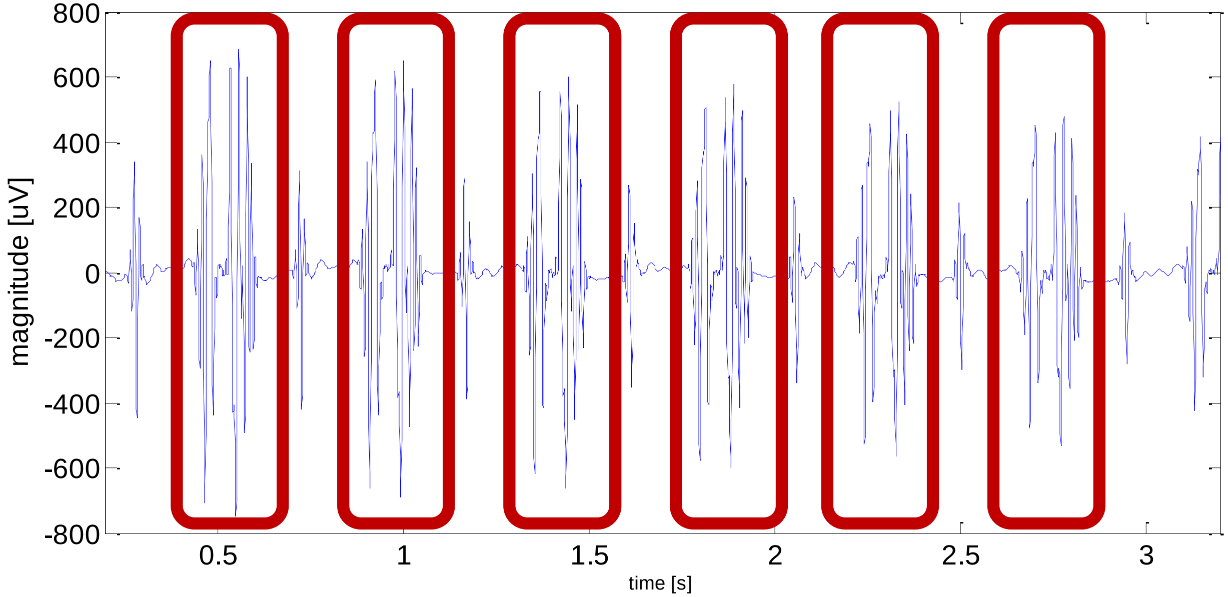
Artifact Removal

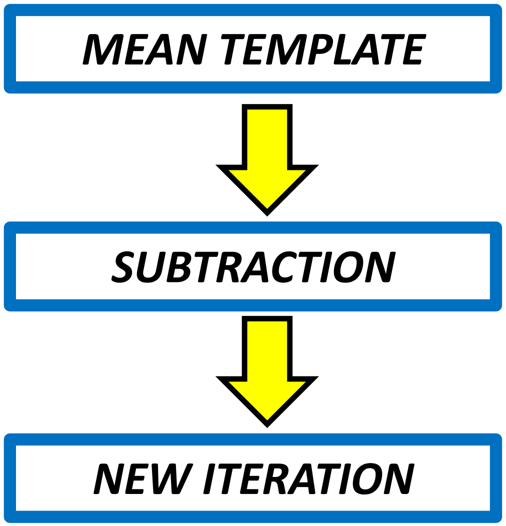
- ***WORK HYPOTHESIS***: artifact is **simply superimposed** to EEG signal

- ***REMOVAL APPROACH***
  1) Detect signal portions affected
  2) Generate an artifact template
  3) Subtract the template

- ***CRITICAL POINT***: **template generation**

Average Artifact Subtraction (AAS)





- All occurrences from all channels
- EEG treated as **uncorrelated white noise**

AAS Issues

- Based upon a ***STATIC MODEL***
  - ***no dynamics*** *included*
- Only a ***MEAN TEMPLATE*** is computed
  - *need of* ***more iterations***
- Occurrences are ***NOT COMPARABLE***
  - ***mutual similarity*** *classification*

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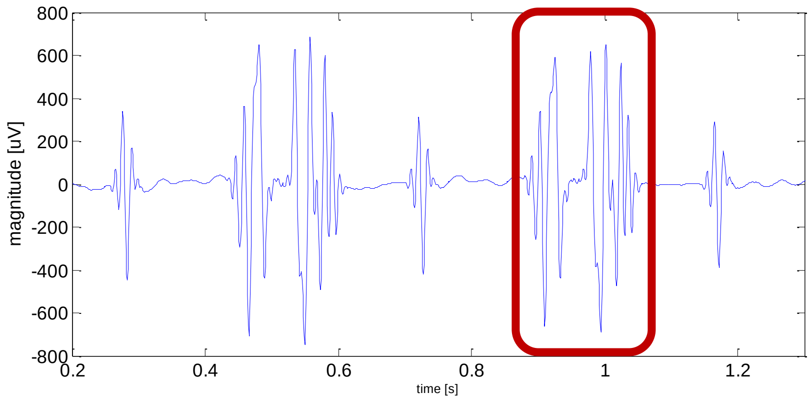
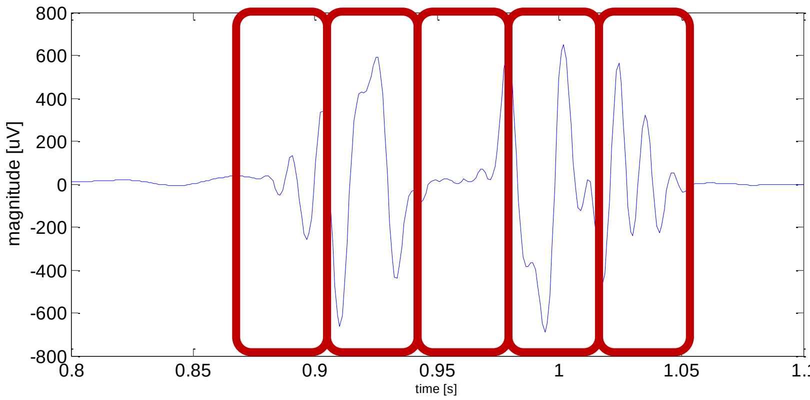
Our Proposal

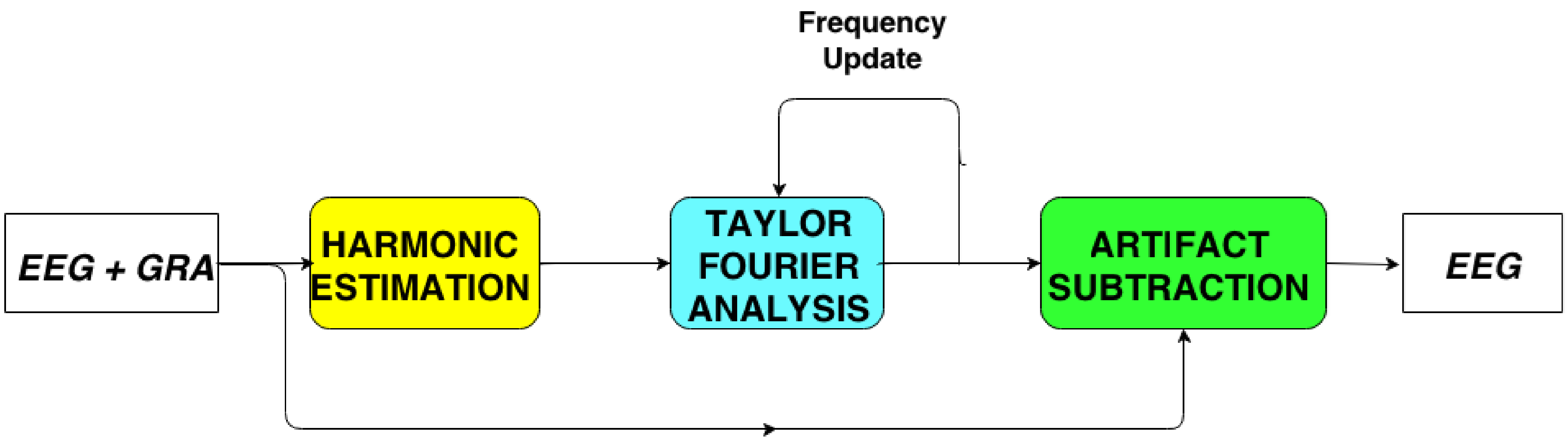
- each occurrence is treated ***SINGLY***...
  - ***specific template computation***





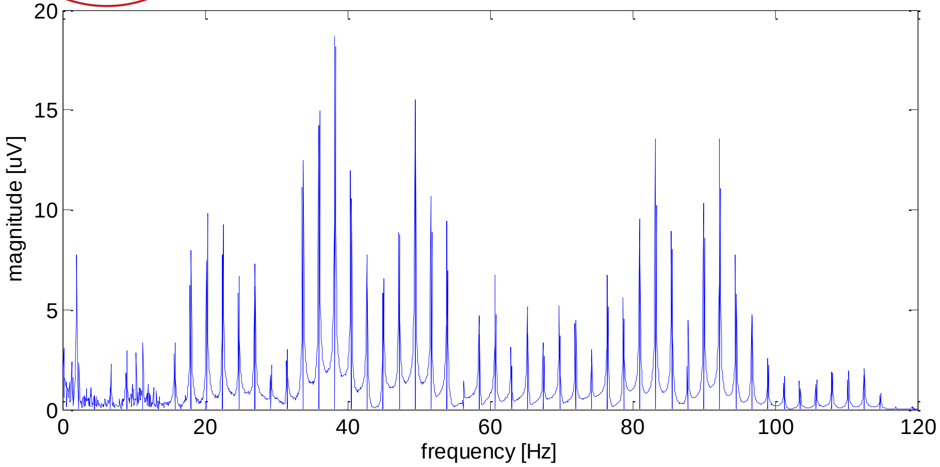
- ... and divided into ***SHORT INTERVALS***
  - ***reduced dynamic effect***

Main Steps



- **No prior** information needed
    - ***signal independent*** *approach*

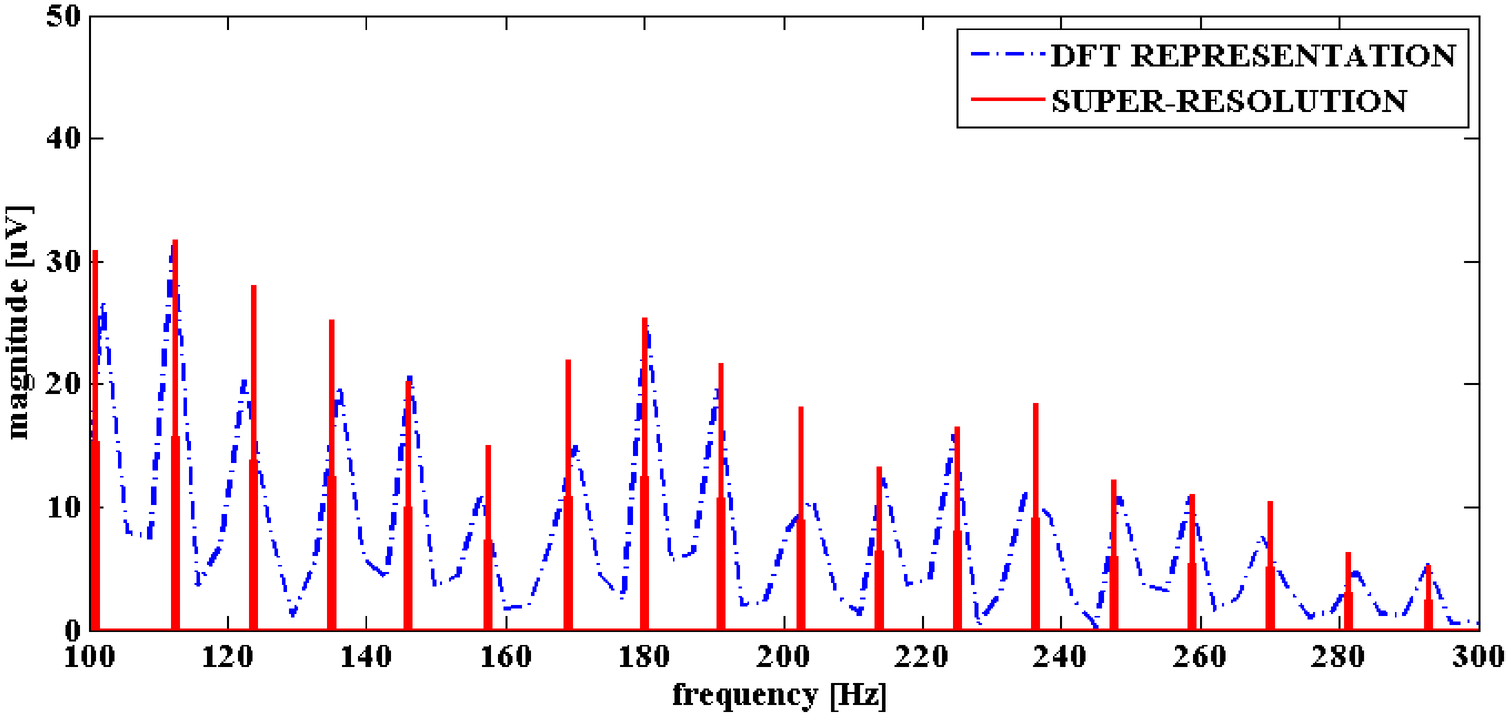
Harmonic Frequencies



$$\sum_h A_h[n]\cos(2\pi f_h n + \phi[n])$$

- **signal portion** consisting of $\boldsymbol{N}$ **samples**
  - *DFT normalized resolution of* $\Delta_f = 1/N$
- **super-resolution** needed
  - ***ZERO-PADDING***: *too computational costly*
  - ***COMPRESSIVE SENSING*** (CS): *efficient*

Resolution Enhancement



- CS **resolution gain** equal to $\boldsymbol{P \sim 10}$
- Peak **frequencies resolution** $\boldsymbol{\Delta_f = 1/(NP)}$

Taylor-Fourier Transform (TFT)

$$\sum_{h} A_h[n]\cos(2\pi f_h n + \phi[n])$$

- ***DFT***: only **averaged estimates**
- ***TFT***: suited for **dynamic conditions**
  - *transform kernel* $\psi_{(k,h)}(t) = t^k e^{-j2\pi f_h t}$
  - *transform coefficient*

$$\theta_{(k,h)} = \frac{T_s^k}{k!}\frac{d^k A_h(t) e^{j\phi_h(t)}}{dt^k}$$

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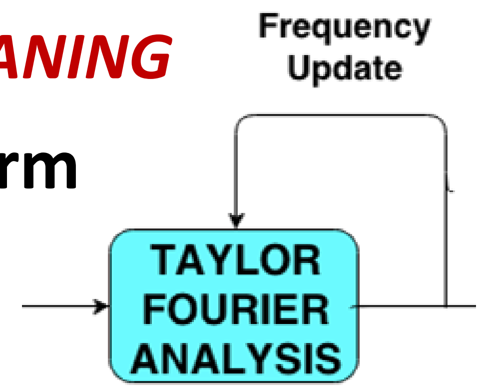
TFT Advantages

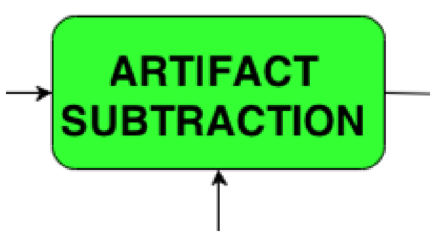
- TFT coefficients have a ***PHYSICAL MEANING***
  - **phase first derivative = frequency term**

$$\hat{f}_h = f_h + \frac{d\phi_h(t)}{dt}$$



Given $\hat{f}_h$ the TFT analysis provides $\hat{A}_h$ and $\hat{\phi}_h$

ARTIFACT TEMPLATE



$$\sum_h \hat{A}_h[n]\cos(2\pi\hat{f}_h n + \hat{\phi}_h[n])$$

Experimental Validation

- EEG and GRA **acquired independently** and **numerically added**

- ***EEG*** measured ***OUTSIDE THE SCANNER***
  - healthy subject with open and closed eyes

- ***GRA*** acquired on a ***WATER PHANTOM***
  - static and dynamic conditions

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Static VS Dynamic

- ***Dynamic Data Set***
  - real GRAs during T2* EPI sequences
  - **time-varying parameters** (f_h, A_h, ϕ_h)

- ***Static Data Set***
  - numerically simulated GRAs
  - **stationary parameters** $f_h = hf_0$

$$A_h \sim \mathcal{N}(1 \times 10^4, 5 \times 10^2)$$
$$p_h \sim \mathcal{U}(0, 2\pi)$$

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Algorithm Parameters

- Sampling frequency $F_s = 1024$ Hz
- Hardware band-pass filter $0.5 \ - 269.5$ Hz

- ***Observation interval*** of $N = 301$ samples corresponding to $\mathbf{0.294}$ **seconds**

- Enhancement factor $P = 13$ corresponding to $\boldsymbol{\Delta_f = 0.26}$ **Hz** of ***Frequency resolution***

Performance Indices

- For each data set and each conditions ***10 GRA*** have been removed
  - ***MEAN RESULTS*** are here presented:

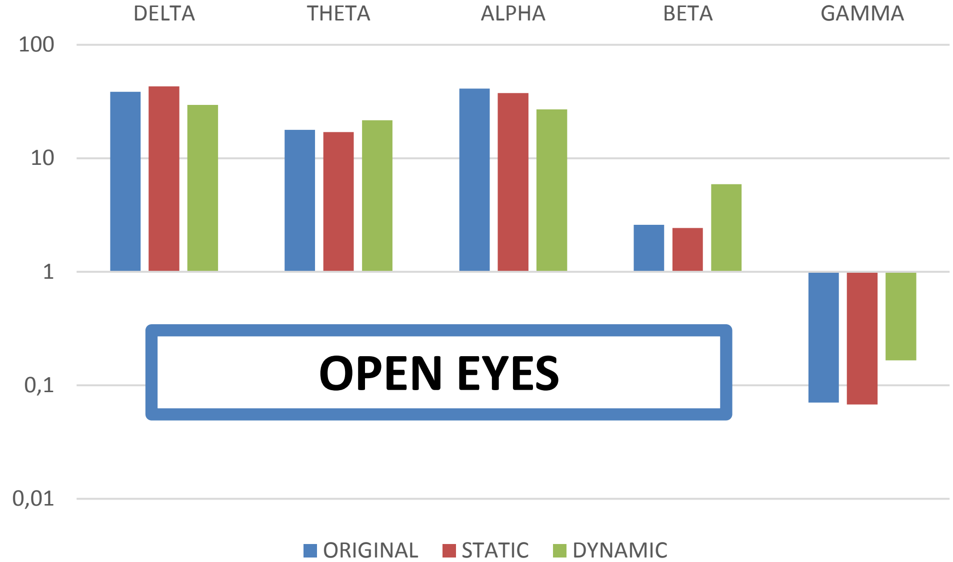
PATIENT STATE	DATA SET	SNR IN [dB]	SNR OUT [dB]
OPEN EYES	*static*	-39.5	13.10
	dynamic	-38.7	3.77
CLOSED EYES	*static*	-36.9	11.79
	dynamic	-37.1	5.23

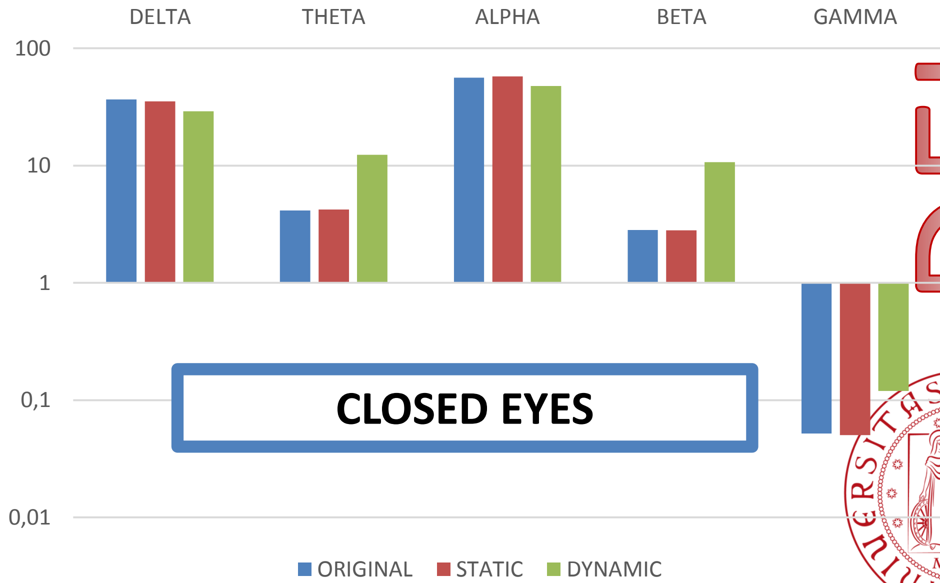
  - Significant **SNR gain** in all cases

Band Power Distribution

- ***Percentage power distribution*** over clinical significant bands **not distorted**

ORIGINAL
STATIC
DYNAMIC





Conclusions

- ✓ Signal **model accounting** for **dynamics**
- ✓ ***QUICK ESTIMATION***: **short observation interval**
- ✓ ***REDUCED ARTIFACT INTERFERENCE***: **SNR gain**
- ✓ ***RESULTS RELIABILITY***: **no significant distortion** in power distribution

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Thank You!

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