“ΑΛΓΟΡΙΘΜΟΙ ΕΠΕΞΕΡΓΑΣΙΑΣ ΓΕΩΡΑΝΤΑΡ(GPR):ΠΑΡΑΔΕΙΓΜΑΤΑ ΑΠΟ ΑΡΧΑΙΟΛΟΓΙΚΕΣ ΕΦΑΡΜΟΓΕΣ”

“GPR DATA PROCESSING ALGORITHMS : EXAMPLES FROM ARCHAEOLOGICAL PROSPECTION”

Technical University of Crete

ΙΣΝ / SNF

FORTH Institute for Mediterranean Studies

Meropi Manataki
PhD Candidate

CONTENTS

CONTENTS

επιστημονικη ΔΙΗΜΕΡΙΔΑ ΙΤΕ 2017

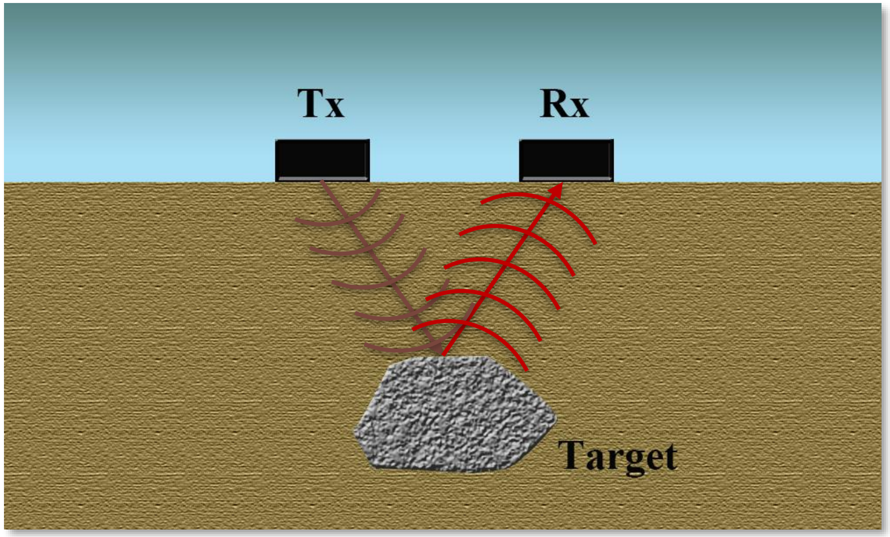
INTRODUCTION

Ground Penetrating Radar

- Non destructive ElectroMagnetic geophysical technique
- Mapping the subsurface
- It can locate artifacts and map features without any risk of damaging them
- Radio waves (10MHz ~ 2GHz)
- Real time, high resolution, cross-sectional images

11η επιστημονικη ΔΙΗΜΕΡΙΔΑ ΙΤΕ 2017

INTRODUCTION



- Injection of short pulses of EM waves into the ground
- When hits a buried object or boundary, is reflected back to the surface
- Receiver detects the returning pulses as a function of time

- Interaction of EM waves with matter
- Boundary: Contrast in materials electrical properties

INTRODUCTION

Which properties?

- Electrical properties that affect the transmitting signal:

1. Conductivity, σ (related to energy loss)
2. Permittivity, ε (related energy storage) & relative permittivity:

$$\kappa = \frac{\varepsilon}{\varepsilon_{vacuum}}$$

- Conductivity affects signal's attenuation, a:

↑ conductivity

↑attenuation

↓ depth

- Permittivity affects wave's propagation velocity, v:

↑ permittivity

↓ velocity

-Velocity is important for depth estimation

INTRODUCTION

Investigation Depth

Central frequency affects the penetration depth:

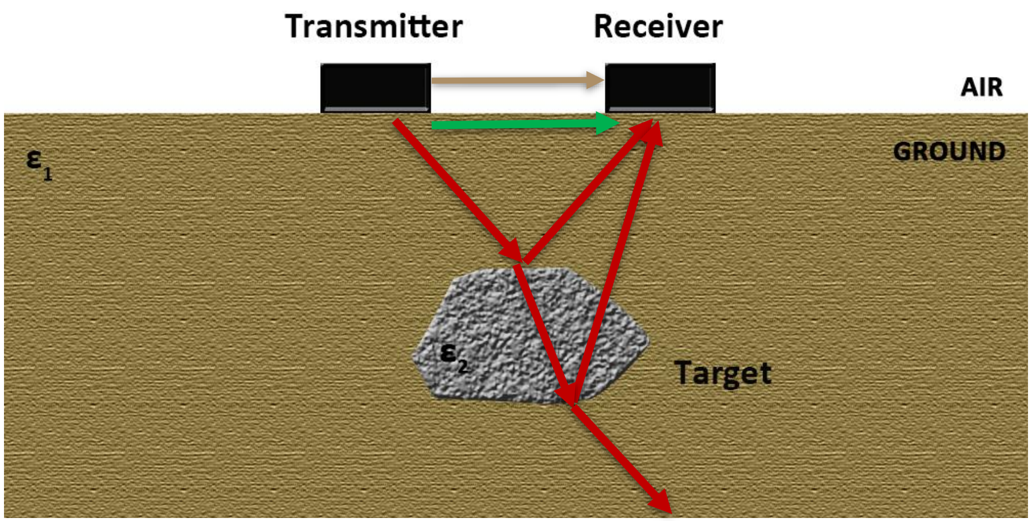
- ↑ Central Frequency
- ↓ Depth
- ↑ Resolution

Antenna should be chosen in accordance to target's expected depth

Depth (m)	Center Frequency (MHz)
0,5	1000
1,0	500
2,0	200
7,0	100
10	50
30	25
50	10

Approximate values based on the experience

INTRODUCTION



Direct Airwaves

Direct Ground waves

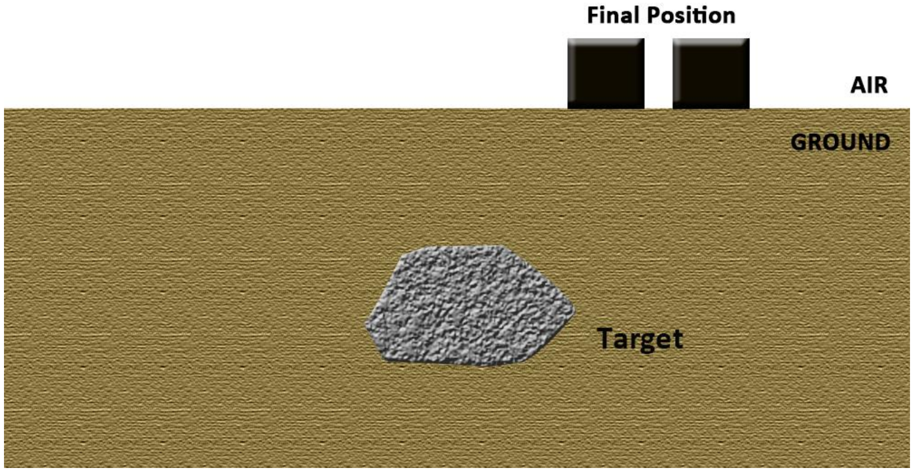
Reflected waves

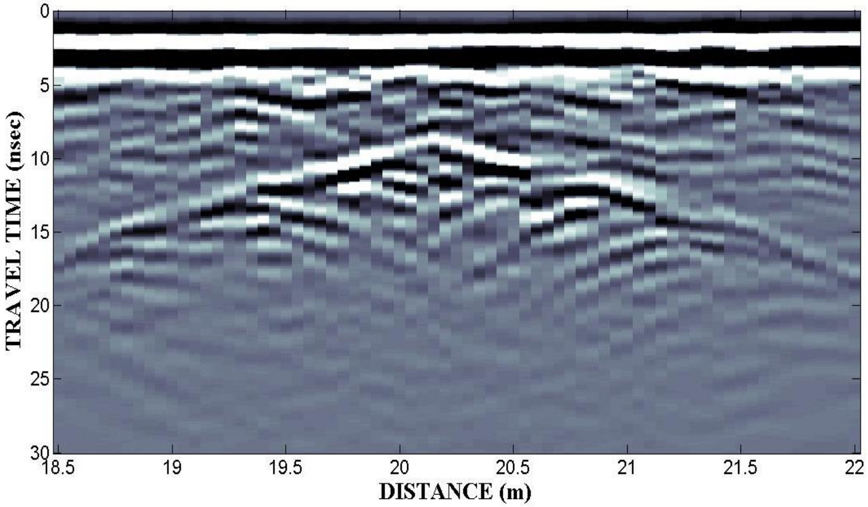
Reflected waves

Trace

INTRODUCTION

Common – offset reflection system





Radargram, Section, Bscan

CONTENTS

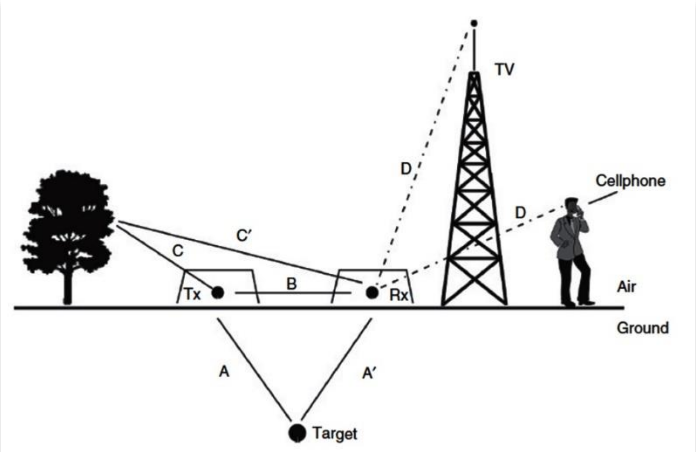
1. Introduction
2. Basic Processing
3. Decomposition Algorithms
4. Summary

CONTENTS

BASIC PROCESSING

Purpose of processing:

- Highlight the reflections related to the targets
- Remove unwanted information (i.e. noise)
- Enhance data interpretation



(Annan and Jol, 2009)

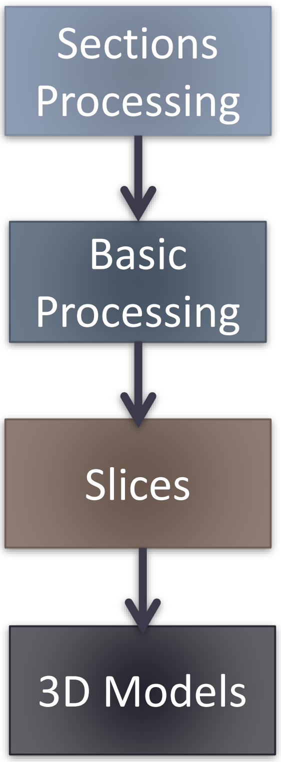
Challenges:

- GPR data processing is site-dependent
- Most the processing algorithms & techniques won't perform the same

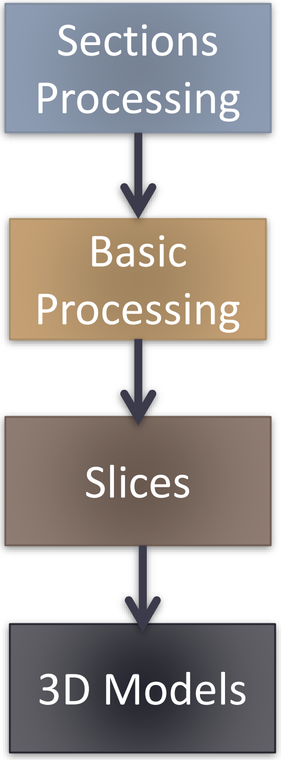
Maximize the energy on the path AA'

- minimize the direct transmitter to receiver energy on path B
- minimize the energy that escapes into the air as on path CC'
- minimize external EM noise as indicated by signals D.

BASIC PROCESSING



BASIC PROCESSING



- Dewow : Removes the initial DC signal component, or DC bias, and subsequent decay of ‘wow’ or low-frequency signal trend present in the data.
- Spatial filters like Average Background Removal: takes the mean of all traces in a section and subtracts it from each trace. Systematic noise and direct waves are removed.
- Gain to correct attenuation effect (Automatic Gain Control (AGC), Spreading & Exponential Compensation (SEC), Inverse Amplitude Decay).
- Frequency domain filters (high- , low- , band- pass filters).

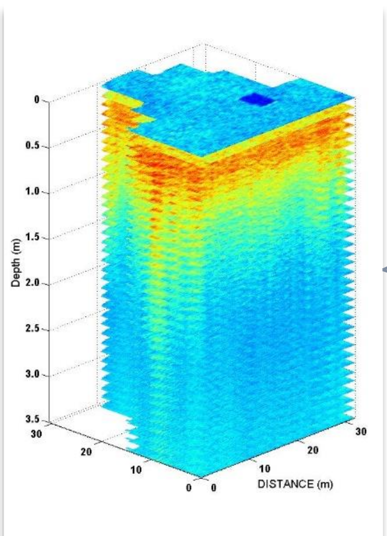
BASIC PROCESSING

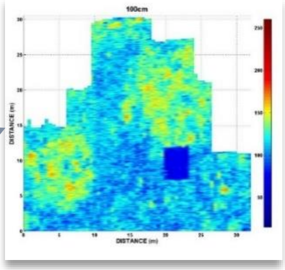
Sections Processing → Basic Processing → Slices → 3D Models

<u>Discrete Hilbert Transform</u>

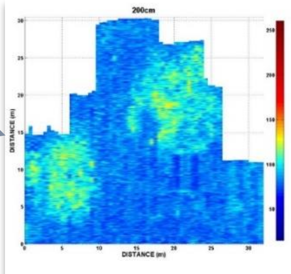
- Traces are converted to their analytical form
- Instantaneous Amplitude or Envelope shows the differences in pulse's amplitude in time and enhance the reflections

When data are collected within survey grids
a 3D volume is constructed





Slice at 20ns ~1.0m

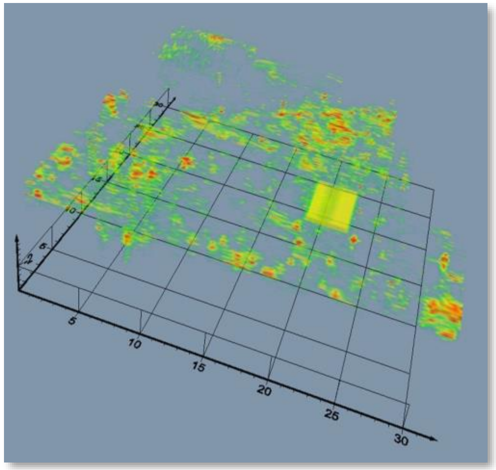


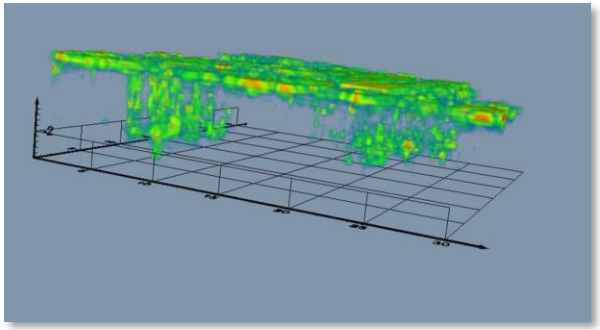
Slice at 20ns ~1.0m

BASIC PROCESSING

Sections Processing
↓
Basic Processing
↓
Slices
↓
3D Models

3D Models of the subsurface (e.g. Voxler software)



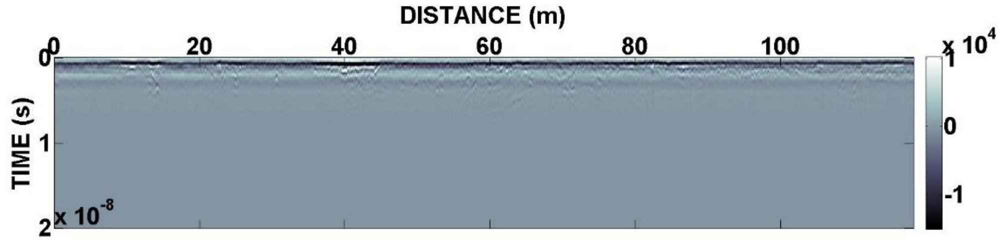


επιστημονική ΔΙΗΜΕΡΙΔΑ ΙΤΕ 2017

BASIC PROCESSING

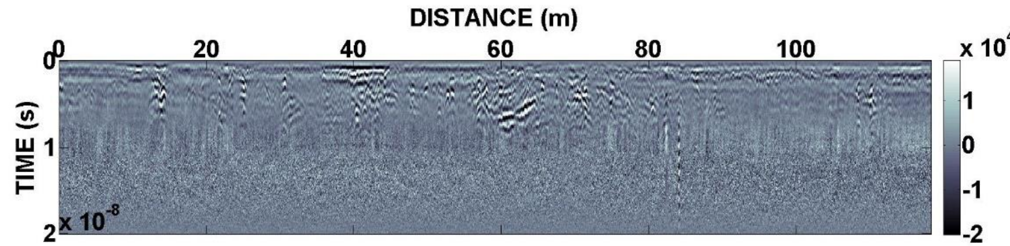
Section Processing example

- Section from Demetrias, Volos
- Hellenic period structural remaining's

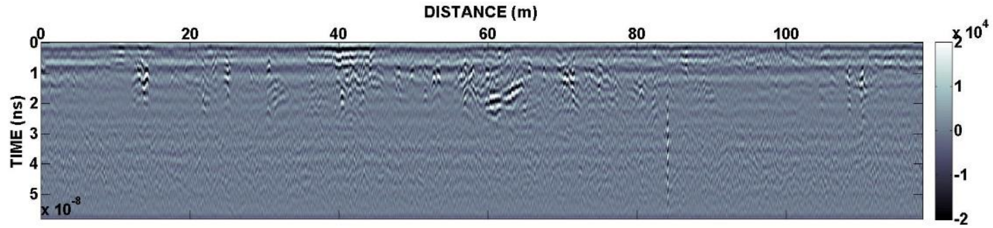


- Outcome of:

Dewow, Gain, Background Removal



- Further improvement using bandpass filter of range 100-500MHz.



BASIC PROCESSING

Magoula Almyriotiki
Survey with GPR:

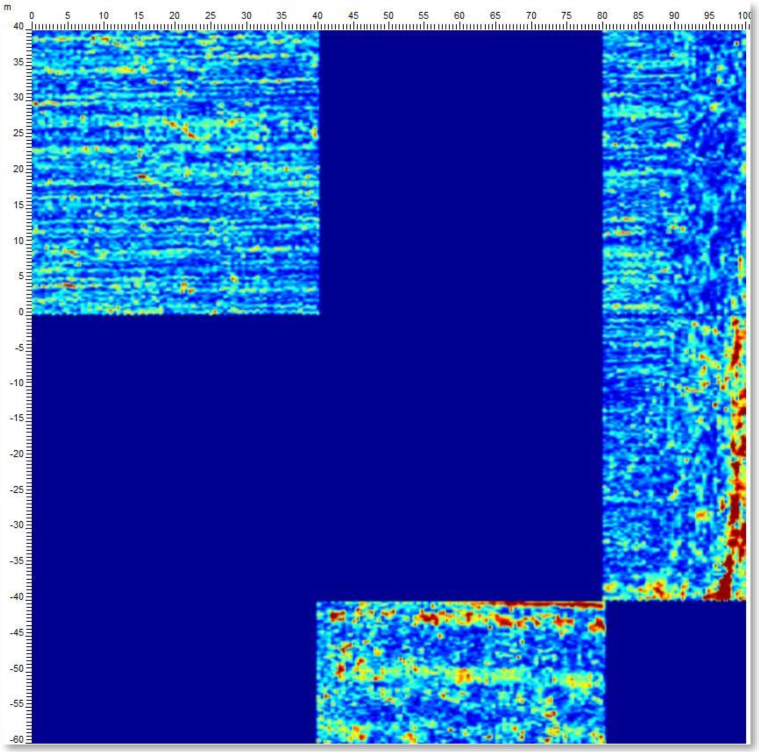
- Noggin Plus GPR, 250 MHz antenna
- 0.5m line spacing, 2.5cm sampling

Input Data:

- 41 GPR scans
- Neolithic structures were identified

BASIC PROCESSING

Magoula Almyriotiki, Thessaly

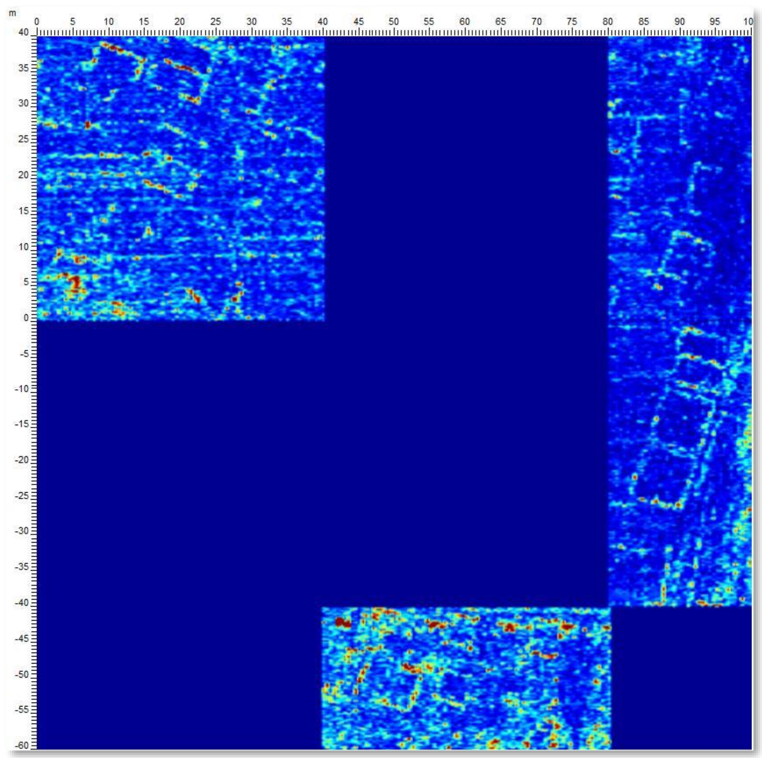


- Dewow
- SEC gain
- Average Background Removal

70-80cm

BASIC PROCESSING

Magoula Almyriotiki, Thessaly



- Dewow
- SEC gain
- Average Background Removal
- Bandpass filter

70-80cm

CONTENTS

CONTENTS

1. Introduction
2. Basic Processing
3. Decomposition Algorithms
4. Summary

DECOMPOSITION ALGORITHM

GPR operational principle is similar to Seismic reflection method:

- A general trend exists to apply Seismic processing techniques to GPR data
- Not working as intended

GPR signal:

- More complex and non-stationary.

Attenuation and dispersion effects are more extreme with GPR, and therefore, the frequency component (and phase relationship) of the signals can change markedly with recorded time and depth.

Fundamental seismic techniques that improve greatly the image such as:

- Deconvolution (improves the resolution of the section by compressing the recorded wavelets into a narrow, distinct form)
- Migration (improving section resolution and developing more spatially realistic images of the subsurface)

Need for more sophisticated processing steps to achieve similar results

DECOMPOSITION ALGORITHMS

- Empirical Mode Decomposition

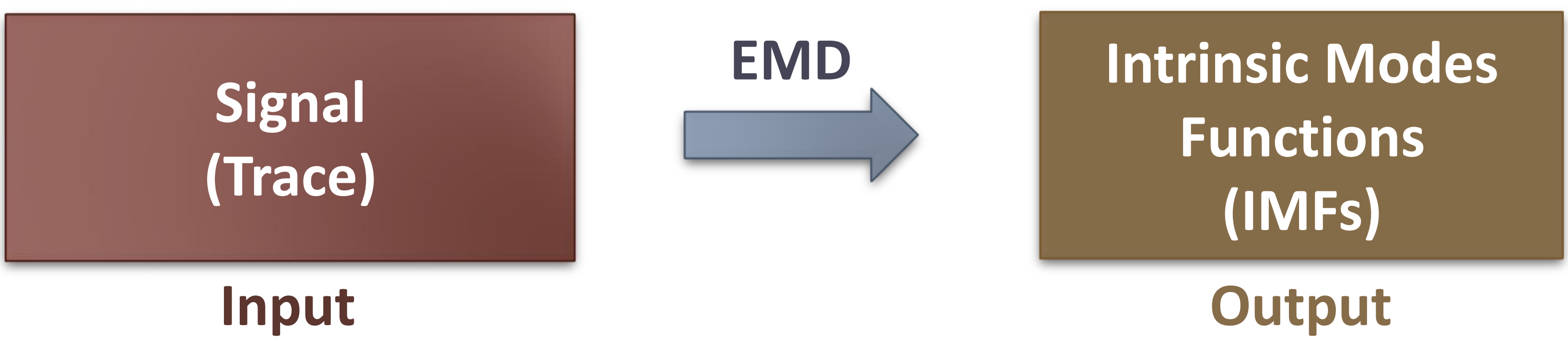
Introduced by Huang et al., (1998)

- Adaptive method
- Suitable for nonlinear and non-stationary signals

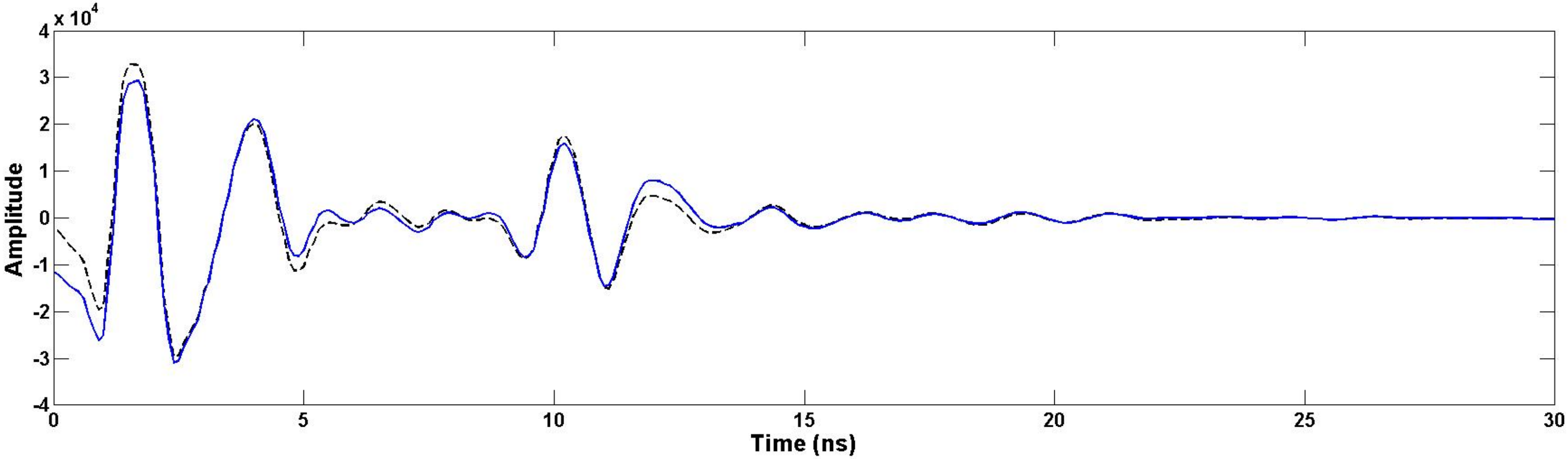
A signal is an IMF when:

(1) the total number of local extrema and the total number of zero crossings is equal or differ at most by one

(2) at any point the mean value of the two envelopes derived from local minima and local maxima equals to zero.



DECOMPOSITION ALGORITHMS



1. Identification of input signal ,$x(t)$, local extremas
2. Interpolation (cubic spline) to estimate the upper, $e_+(t)$, and lower, $e_-(t)$, envelope
3. Calculation of the mean envelope:

$$m(t) = \frac{e_-(t) + e_+(t)}{2}$$

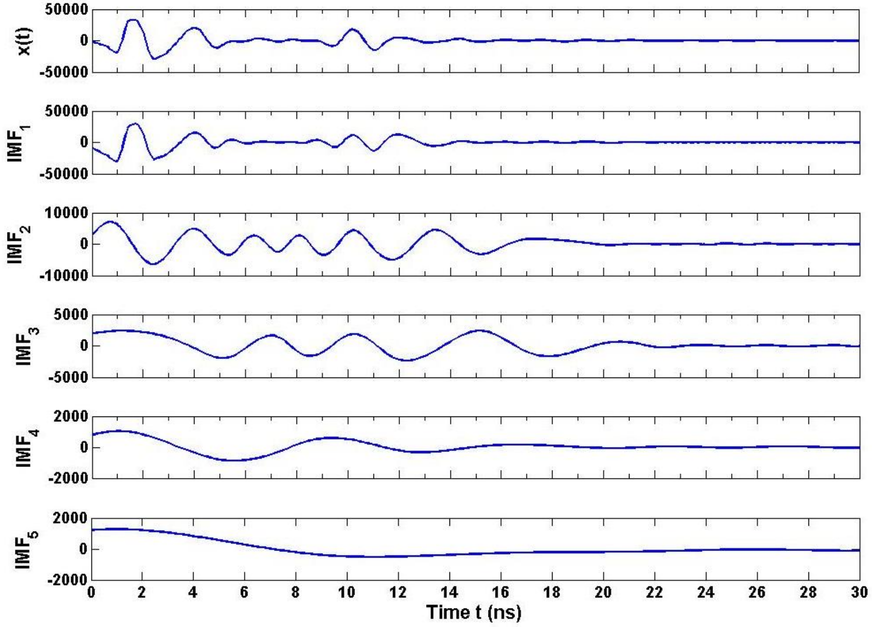
4. Extraction of local detail: $d(t) = x(t) - m(t)$

5. Check if $d(t)$ is an IMF:

- False → repeat steps 1-5 for $d(t)$ (*Sifting Process*)
- True → $d(t)$= IMF_1
- Repeat sifting for residue

$r(t) = x(t) - IMF_1$ to extract the second IMF

DECOMPOSITION ALGORITHMS



← Input: GPR trace

← Highest frequencies

← Trend of the signal

The original signal is fully reconstructed by summing all the IMFs

DECOMPOSITION ALGORITHMS

Mode Mixing Problem:

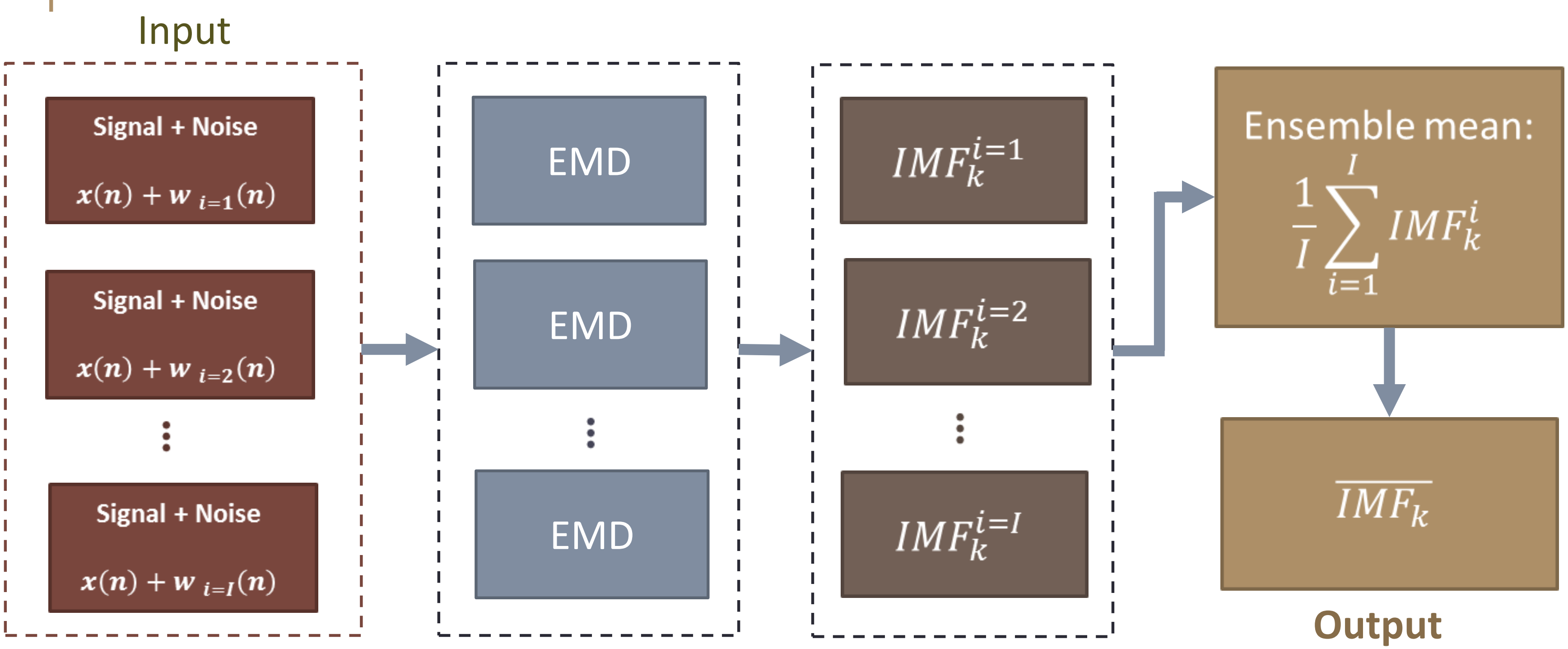
- major drawback of EMD
- limits down the frequency separation among the different modes

Appears in two forms (Wu and Huang, 2009):

1. a single IMF contains widely disparate modes,
2. similar modes are residing in different IMFs

- *Adding White Noise to input signal resolves mode mixing problem*
- Ensemble Empirical Mode Decomposition (EEMD) (Wu and Huang, 2009):
- Modification of EMD as a Noise Assisted Data Analysis method

DECOMPOSITION ALGORITHMS



1. Add different noise realizations, w_i where $i = 1,2,\dots,I$, to the input signal, $x(n)$

2. Apply EMD on each summation

3. IMFs will be extracted from each summation i, where $k = 1,2,..,K$ is the IMF order

4. Use the ensemble mean to obtain the final IMFs of the input signal, $x(n)$.

DECOMPOSITION ALGORITHMS

- White noise is canceled out when use the ensemble mean
- Improves the modes separation

Inserts new parameters:

1) Number of realizations, I

2) Level of white noise

Drawback: the signal isn't fully reconstructed by summing the resulting IMFs

Complete Ensemble Empirical Mode Decomposition (CEEMD)

Introduced by Torres et al. (2011)

Similar as EEMD

- Different noise realizations
- Ensemble mean to compute IMFs

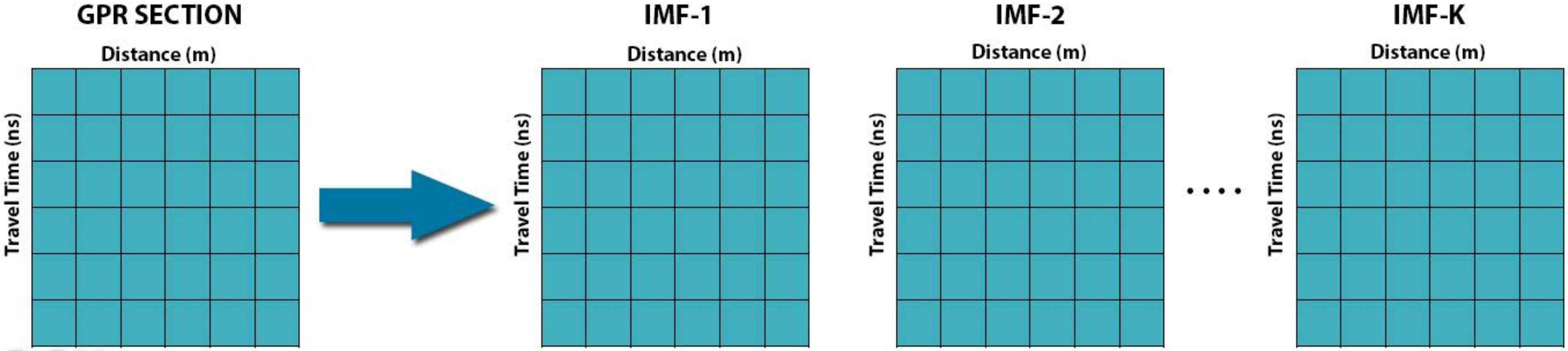
Improvement:

- A residue is retained on every step (like sifting process) so that the signal is fully reconstructed by summing the resulting IMFs

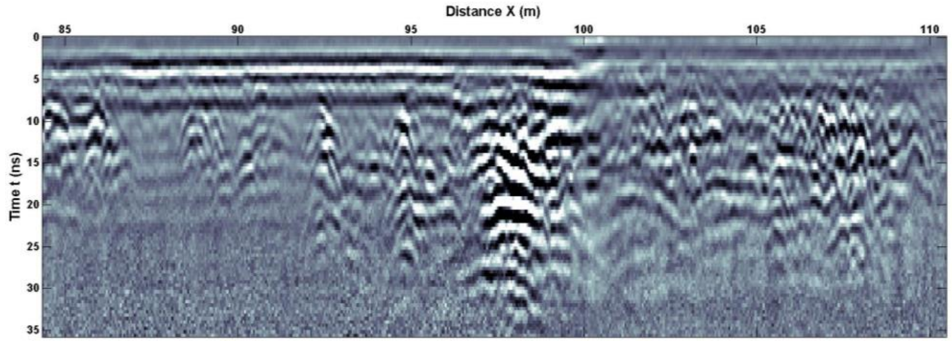
DECOMPOSITION ALGORITHMS

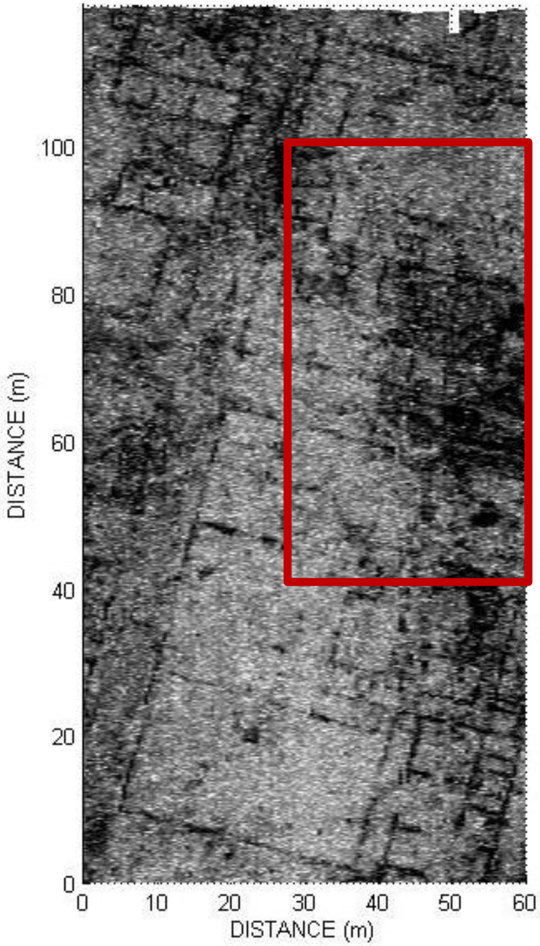
MATLAB

- Empirical Mode Decomposition toolbox (G. Rilling)
- Parallel computing toolbox
- Algorithms applied on each trace of a GPR section
- Zero-padding when the total number of modes is uneven
- IMFs are presented as images



DECOMPOSITION ALGORITHMS





Slice at 10ns

Preprocess:

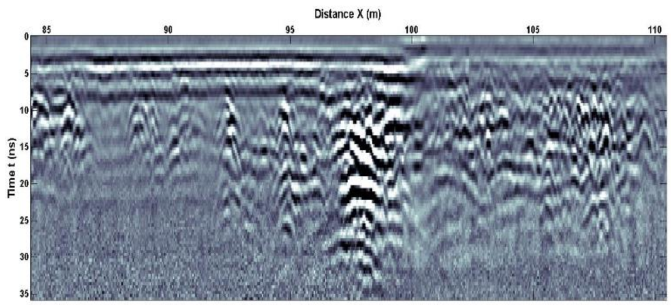
- Time zero
- Dewow filter
- Background Removal
- Inverse amplitude decay gain
- Background noise removal (Global)

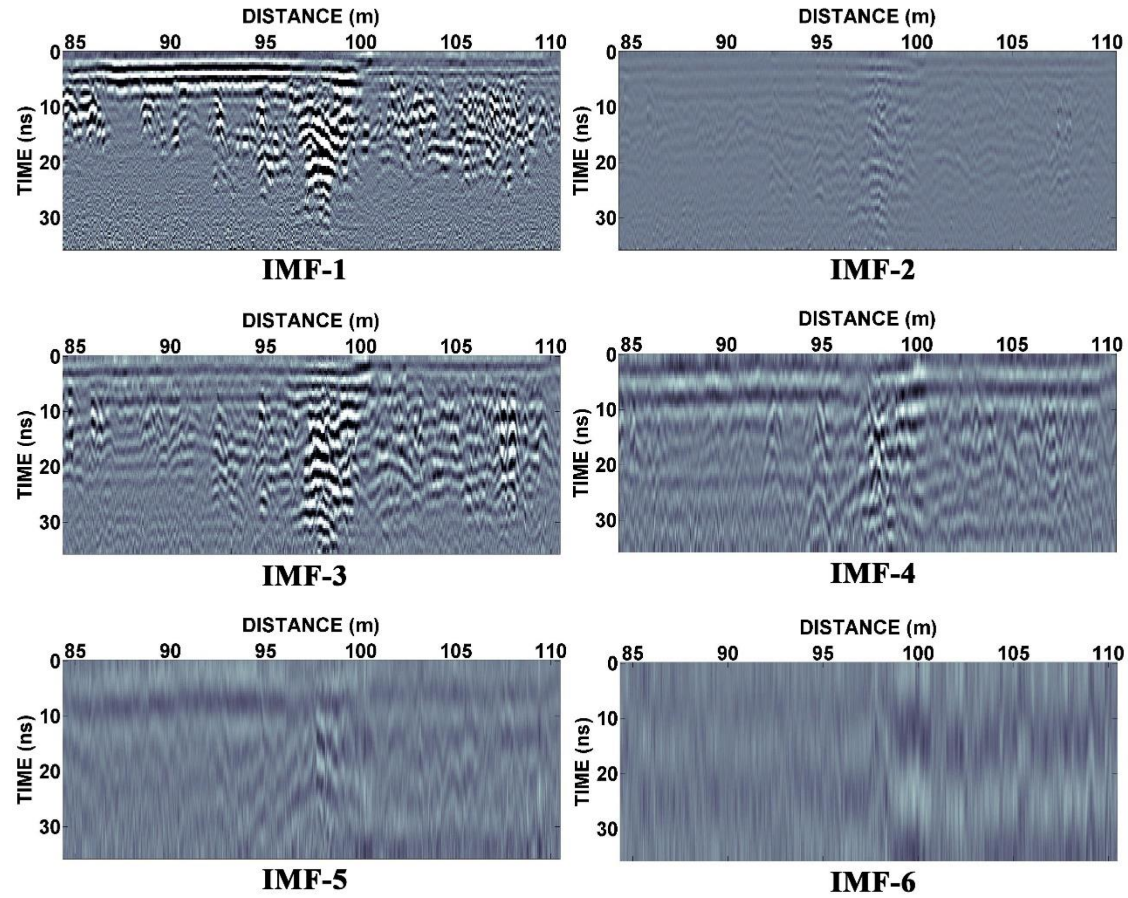
Decomposition:

- CEEMD, 100 noise realizations, 50% noise level of input signal's standard deviation

DECOMPOSITION ALGORITHMS

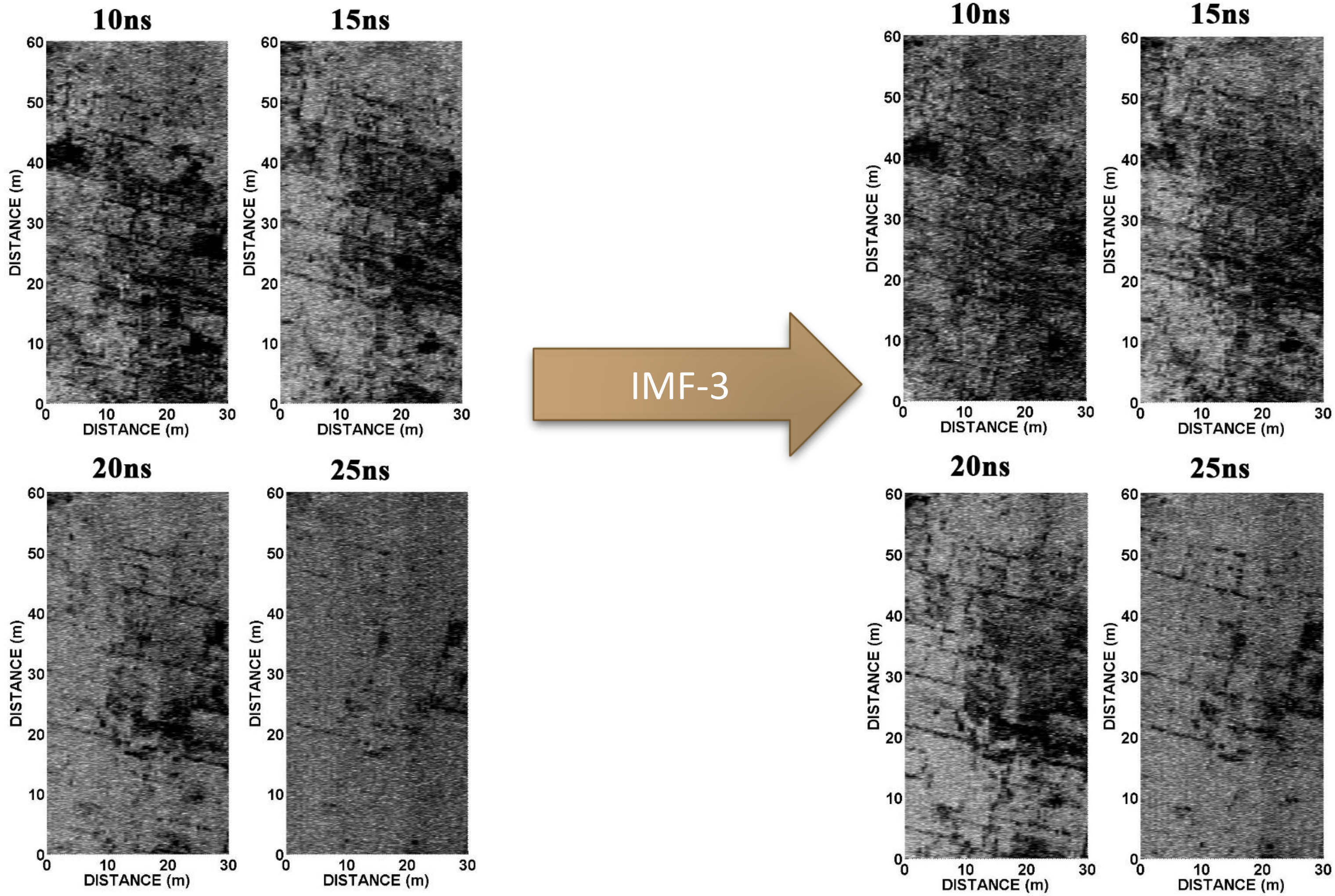
Input section





- IMF-3 seems to contain information related to walls and less noise
- Instantaneous amplitude

DECOMPOSITION ALGORITHMS



CONTENTS

CONTENTS

SUMMARY

- CEEMD returned positive results in highlighted amplitudes from late arrivals, providing more information of the buried structures
- Decomposition techniques might be a good approach for processing GPR data
- Further research is required to investigated the algorithm full potential

Need for processing techniques that take into account the nature of the GPR signal

Technical University of Crete

ΙΣΝ SNF

FORTH Institute for Mediterranean Studies

11η επιστημονική ΔΙΗΜΕΡΙΔΑ ΙΤΕ 2017

DATA PROCESSING

CEEMD

Add I noise realizations to the input signal:

- $x^i[n] = x[n] + \varepsilon_0 \times w^i[n]$

Obtain the first IMF same as EEMD:

- $\overline{IMF}_{k=1}[n] = \frac{1}{I}\sum_{i=1}^{I} E_1(x^i[n])$

Extract the second IMF:

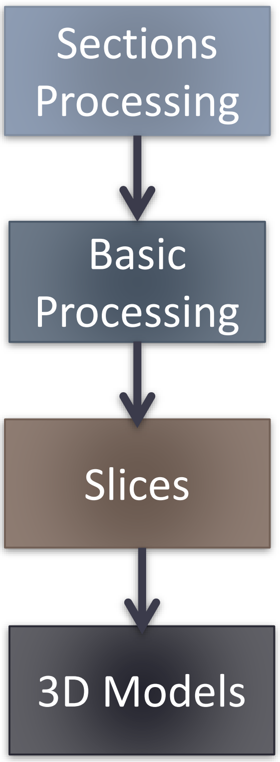
- $r_{k=1}[n] = x[n] - \overline{IMF}_{k=1}[n]$
- $R_{k=1}[n] = r_{k=1}[n] + \varepsilon_k E_1(w^i[n])$
- $\overline{IMF}_{(k+1)}[n] = \frac{1}{I}\sum_{i=1}^{I} E_1(R_{k=1}[n])$

Extract the rest IMFs for for $k = 2, \dots, K$:

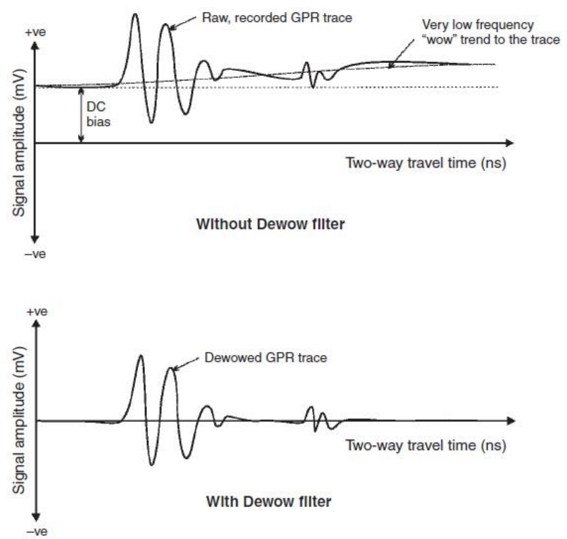
- $r_k[n] = r_{(k-1)}[n] - \overline{IMF}_k[n]$
- $R_k[n] = r_k[n] + \varepsilon_k E_k(w^i[n])$
- $\overline{IMF}_{(k+1)}[n] = \frac{1}{I}\sum_{i=1}^{I} E_1(R_k[n])$

If $r_k[n]$ doesn't have at least two extremas assign it as the last IMF.

BASIC PROCESSING



- Dewow : Removes the initial DC signal component, or DC bias, and subsequent decay of ‘wow’ or low-frequency signal trend present in the data.



11η επιστημονική ΔΙΗΜΕΡΙΔΑ ΙΤΕ 2017

DATA PROCESSING

EMD

Sifting process stopping criterion:

- is based on two thresholds, θ_1 and θ_2 (Rilling et al. ,2003):
- *mode amplitude:* $\alpha(t) = \frac{e_+(t) - e_-(t)}{2}$
- *evaluation function:* $\sigma(t) = \frac{m(t)}{\alpha(t)}$

The sifting procedure is repeated until:

$\sigma(t) < \theta_1$ for $(1 - \kappa)$

of the input signal's total duration, while for the remaining fraction:

$\sigma(t) < \theta_2$

EMD stopping criterion:

- When the residue becomes monotonic
- Not enough extremas to calculate the two envelopes
- Residue is the last IMF of the input signal