Kourtogram

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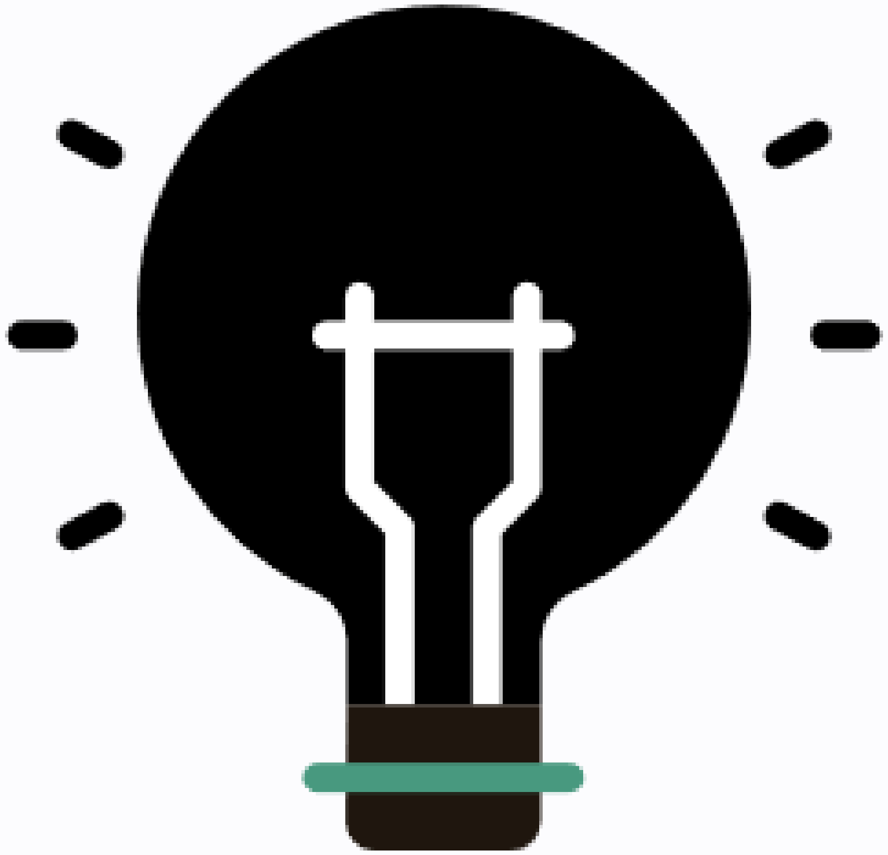
Fraunhofer
LBF

Introduction



Kourtogram

Limitation

Solutions

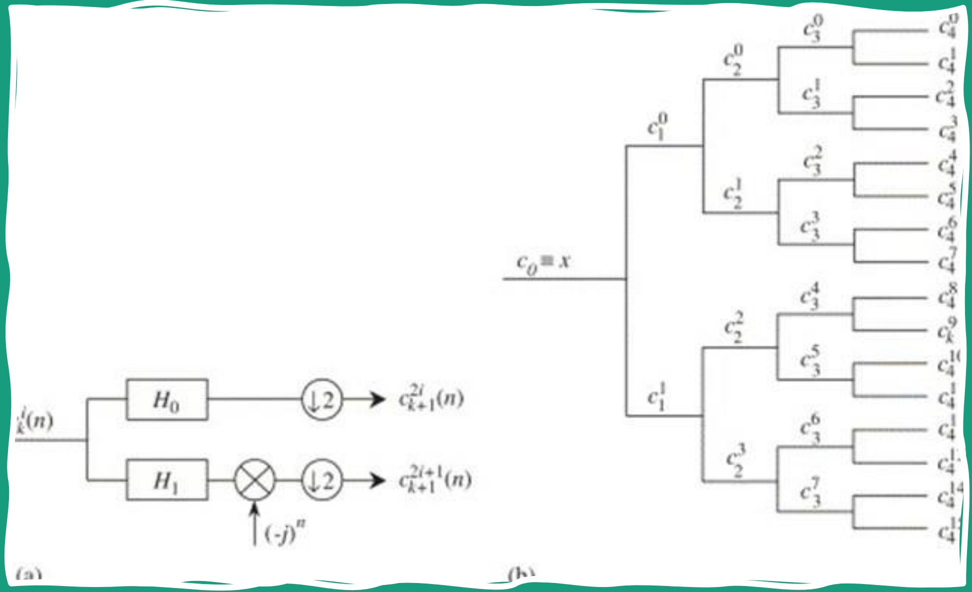
Case study

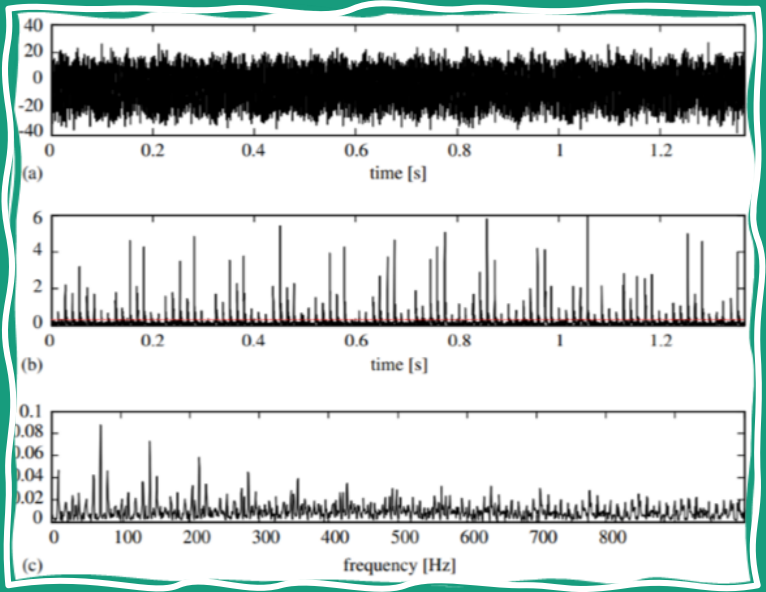
Fraunhofer LBF

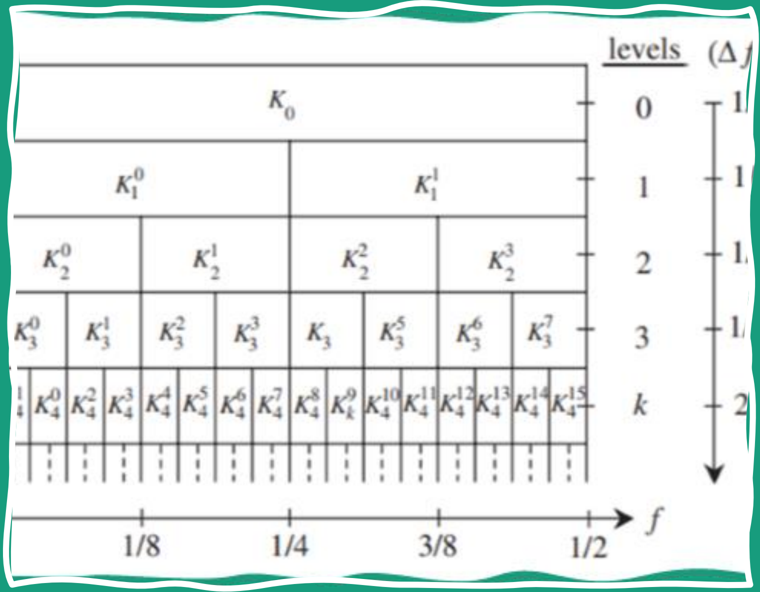
Kourtogram

- Purpose
  - Transient detection
  - Non stationarity
- Why not Global Kurtosis
- Algorithm
- Filter Window detection
- Application on bearing and gearbox

Source: Fast computation of the kurtogram for the detection of transient faults , Antoni(2006)







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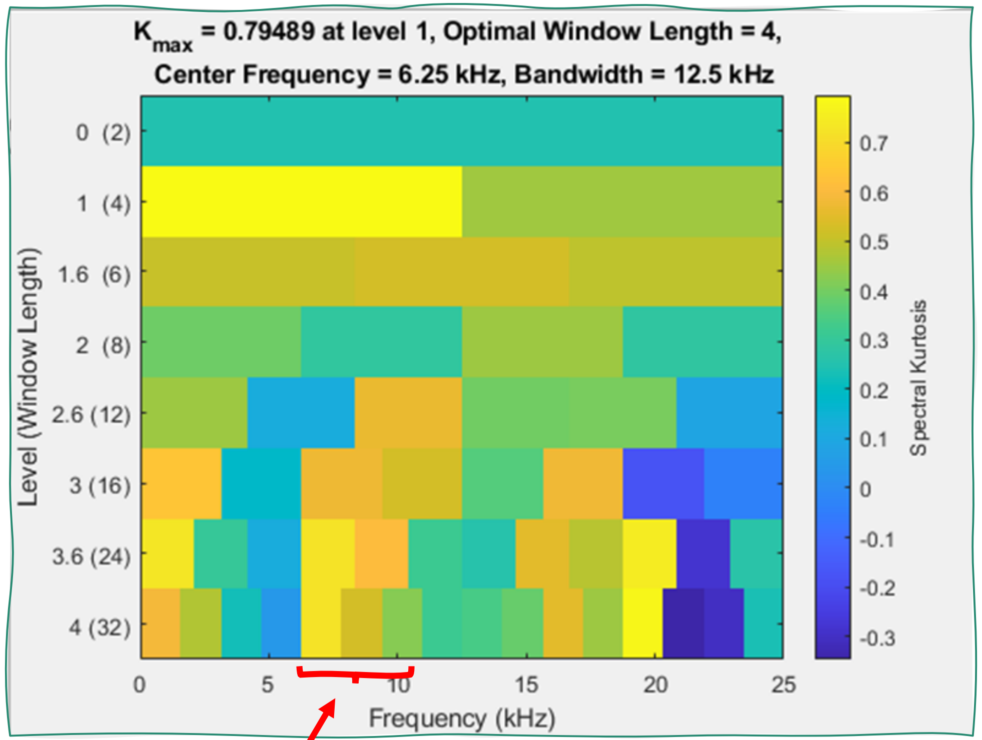
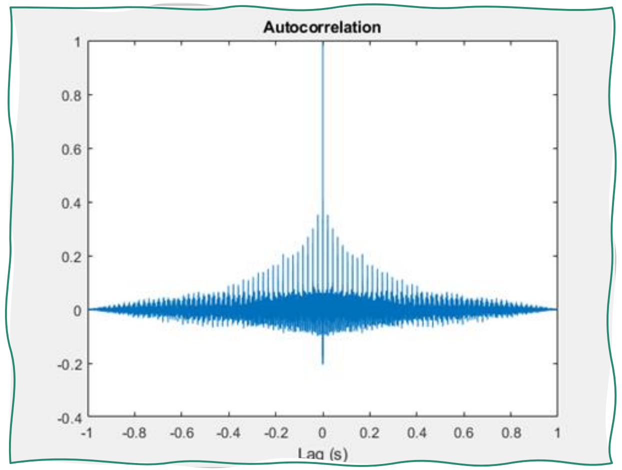
Ambiguous Kourtogram (first case)

Excessive filter bandwidth (Accelerometer Data from bearing with outer race fault (MAFAULDA). RPM= 48 rev/s)

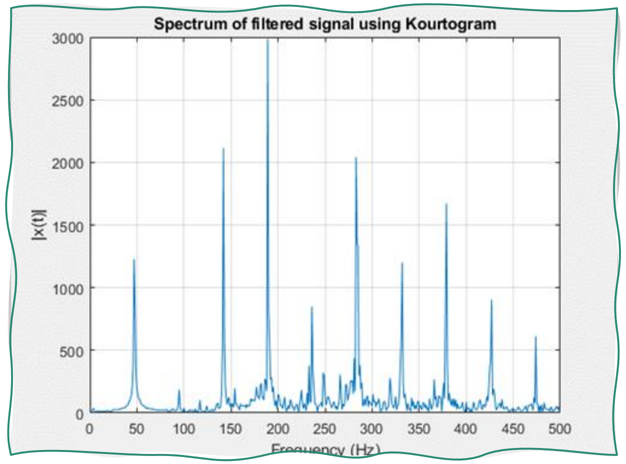


Damage Bandwidth

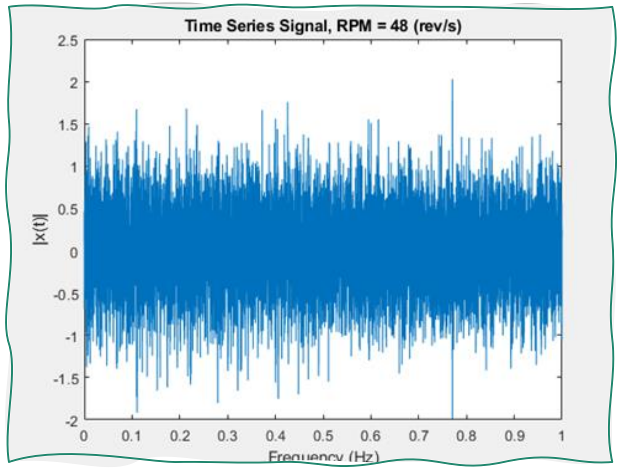
Autocorrelation



Filtered Spectra using Kourtogram

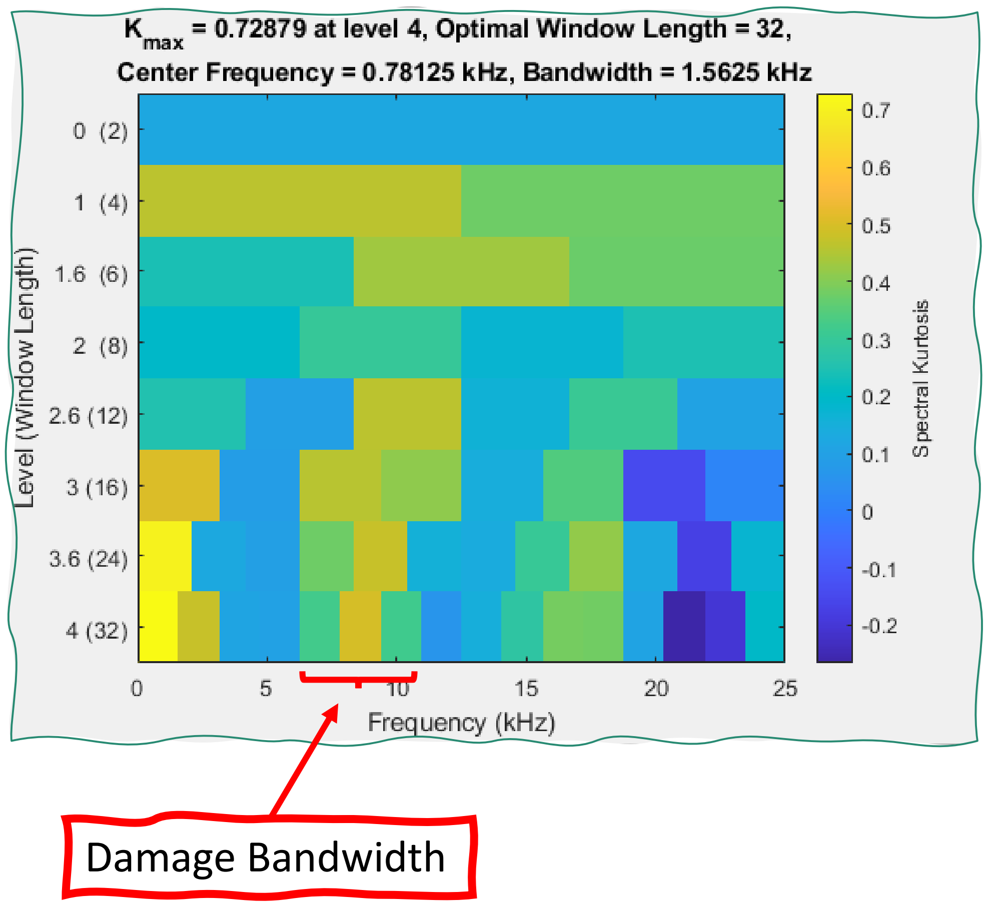


Time Series

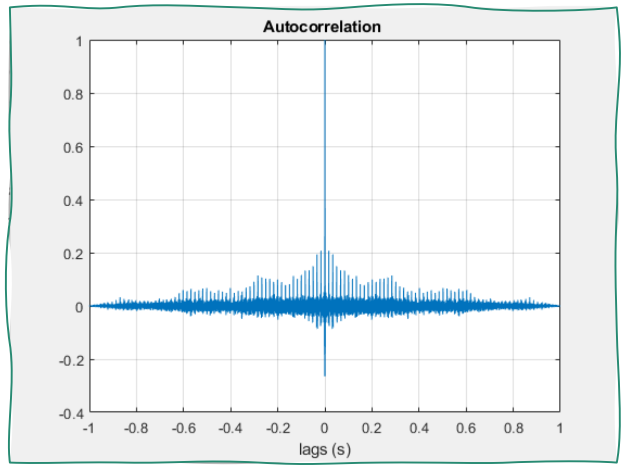


Ambiguous Kourtogram (second case)

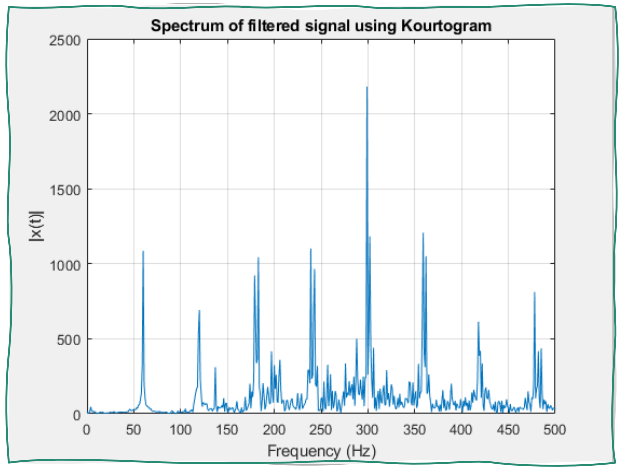
Extremely low frequency filter bandwidth (Accelerometer Data from bearing with outer race fault (MAFAULDA). RPM= 61 rev/s)



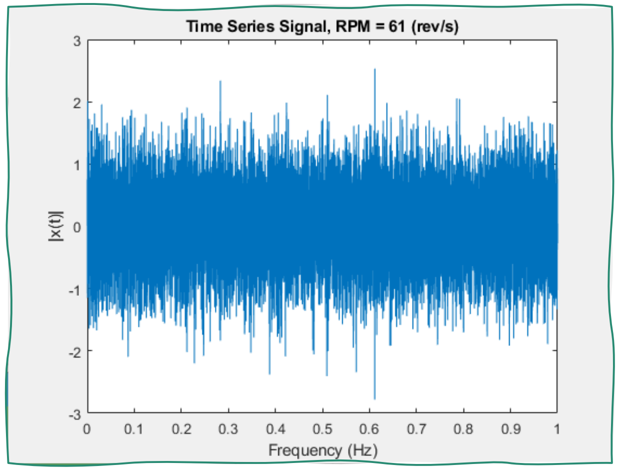
Autocorrelation

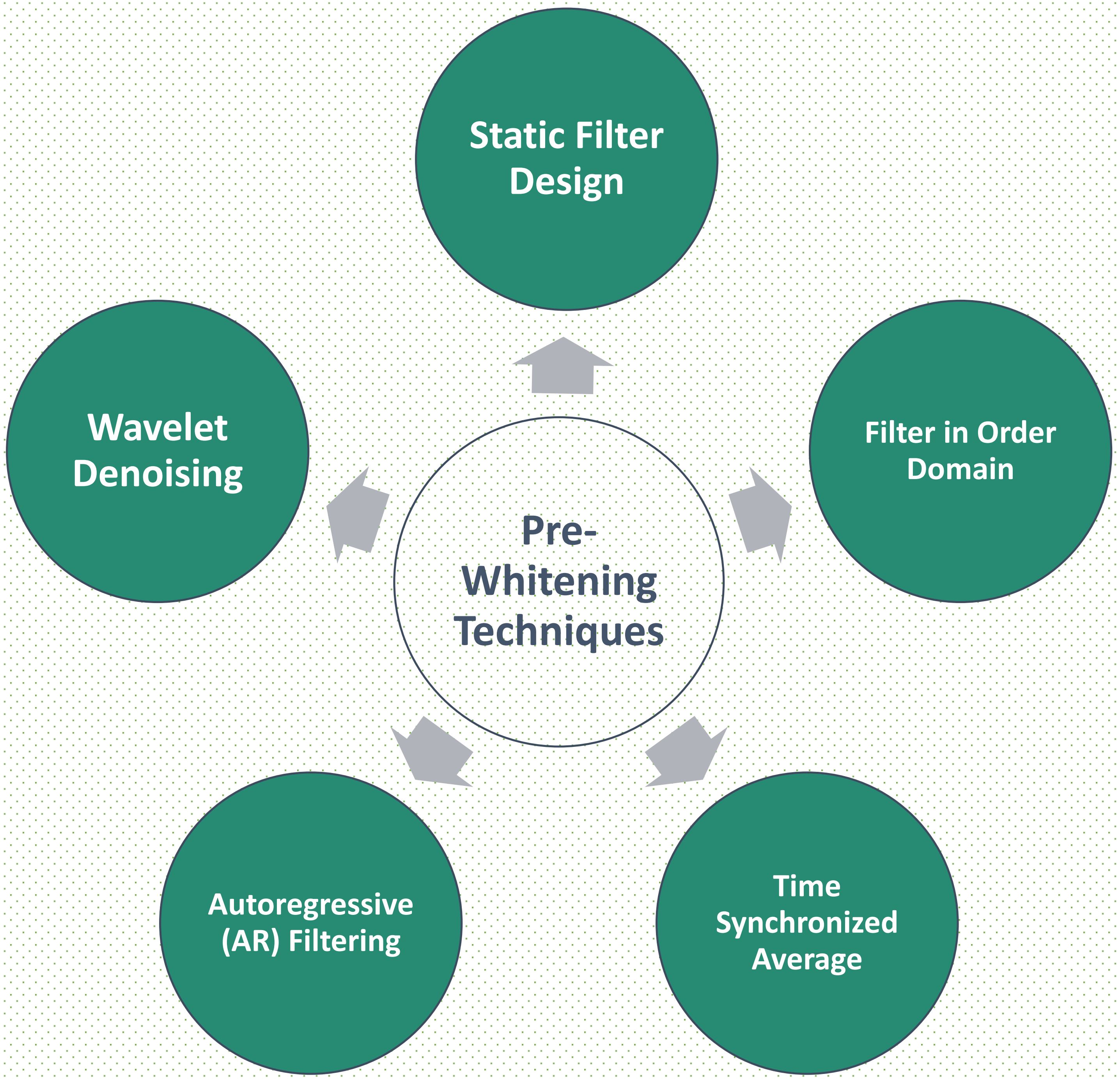


Filtered Spectra using Kourtogram



Time Series




Static Filter Design
Filter in Order Domain
Wavelet Denoising
Pre-Whitening Techniques
Autoregressive (AR) Filtering
Time Synchronized Average
Fraunhofer LBF

Static Filter Design

- **Steps:**

1- Compare the spectra of the signal in presence and absence of the fault
2- Look for a separation between the two signal
3- Set a threshold from which separation is meaningful (6-8dB suggested by Randall (1985))
3- Design a filter to extract amplified part of the signal
4- calculate Kortugram

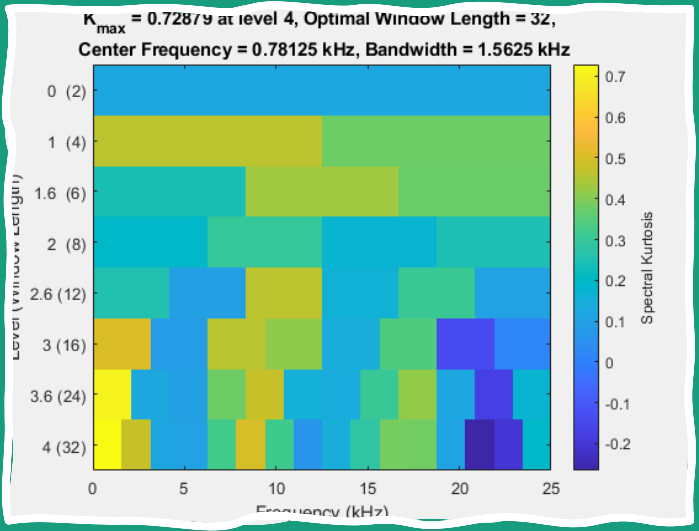
How I have done it (after filtering)

- **Pros and Cons:**

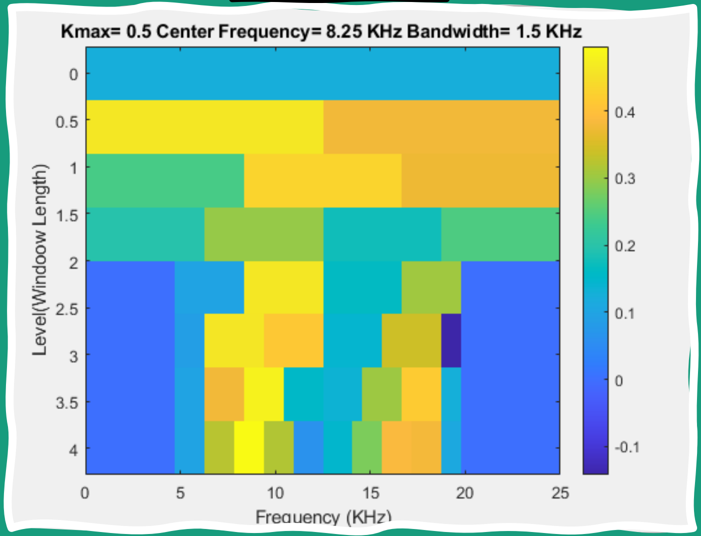
1- Simple
2-Not accurate
3- Prefiltering can cause spurious values
4- Slow
5- Necessity of base line

6-8dB separation
(see: Randall (1985))

Before



After



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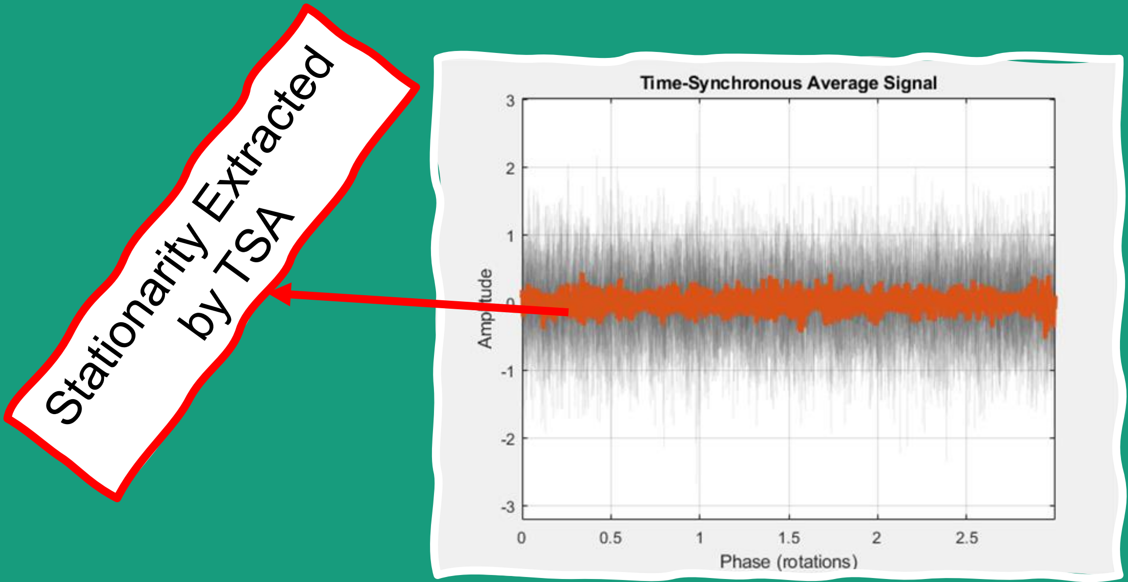
Time synchronized average

- **Steps:**

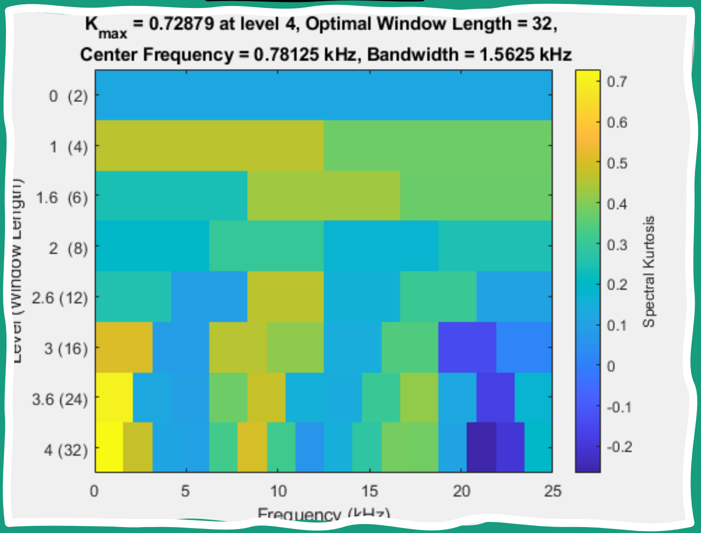
1- Angular Resampling
2- Segmenting signal into the revolutions
3- Summing up and averaging out, over revolutions
4- Bring back to time domain
5- subtract the averaged signal

- **Pros and Cons:**

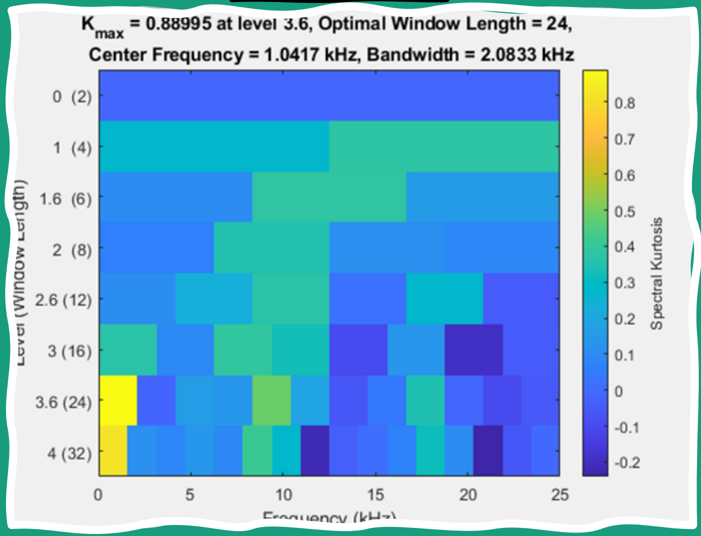
1- Complexity
2-not stable
3-the most known technique
4- removes cyclo-stationary signatures such as bearing fault
5- prone to noise



Before



After



Wavelet Denoising

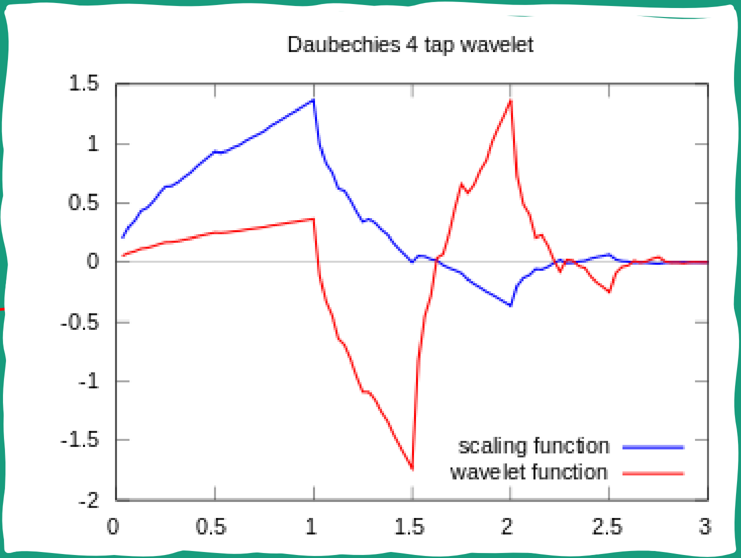
- **Steps:**

1- Find the suitable wavelet and wavelet parameters
2- Denoise the original signal using wavelet
3- Subtract the Denoised signal from original signal.
4-The residual of Denoised signal, in fact is a representation of the noise and the nonstationary part of the signal.

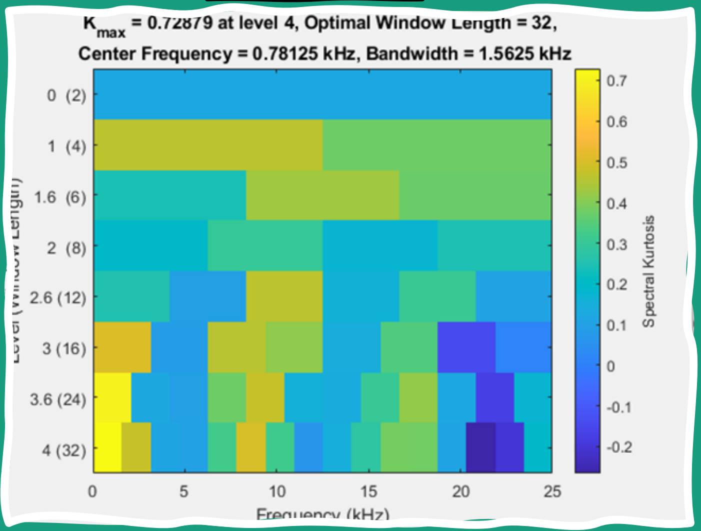
- **Pros and Cons:**

1- not suitable for low SNR signals
2-Experties Needed
3- Can be Atomized

Residual signal from Denoising process using db-4 wavelet for 12 level, BlockJS method



Before



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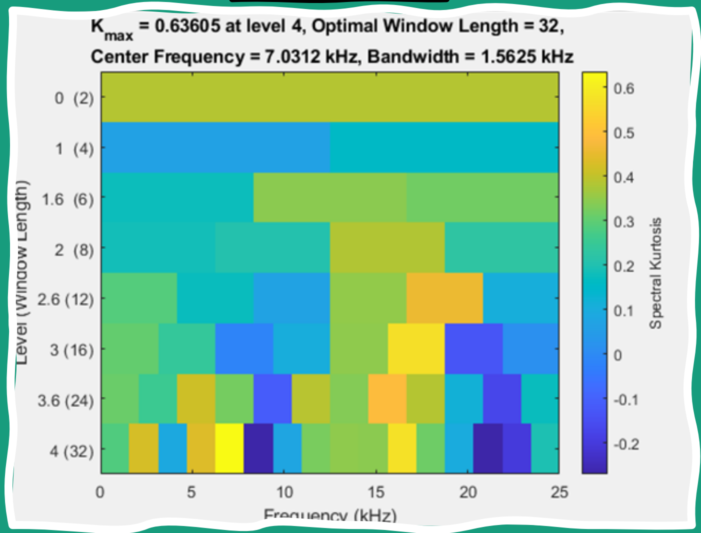

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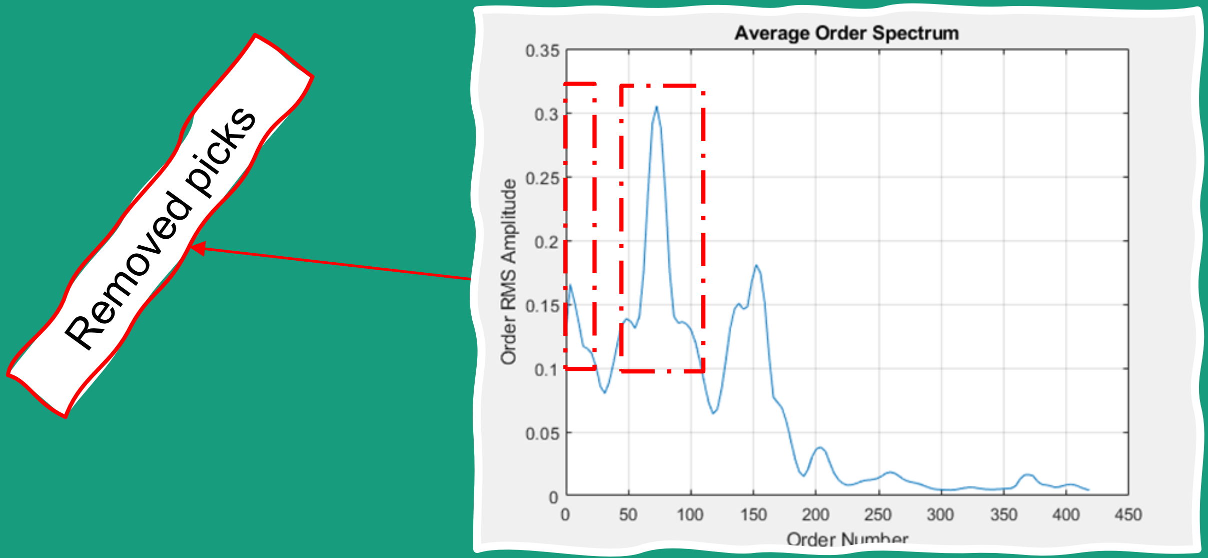
Filter in order domain

- **Steps:**

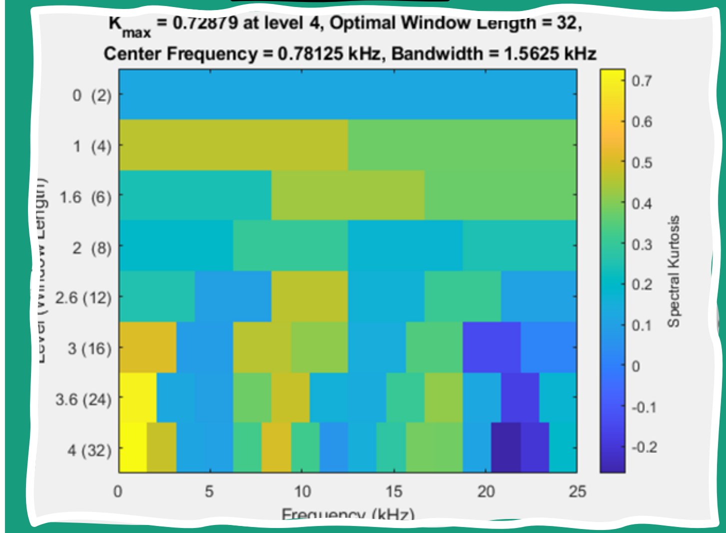
1- Angular Resampling
2- Calculate the order spectra
3- set the threshold
4- Remove the order picks

- **Pros and Cons:**

1- sensitive to the threshold
2-Experties Needed
3-important information might be removed



Before



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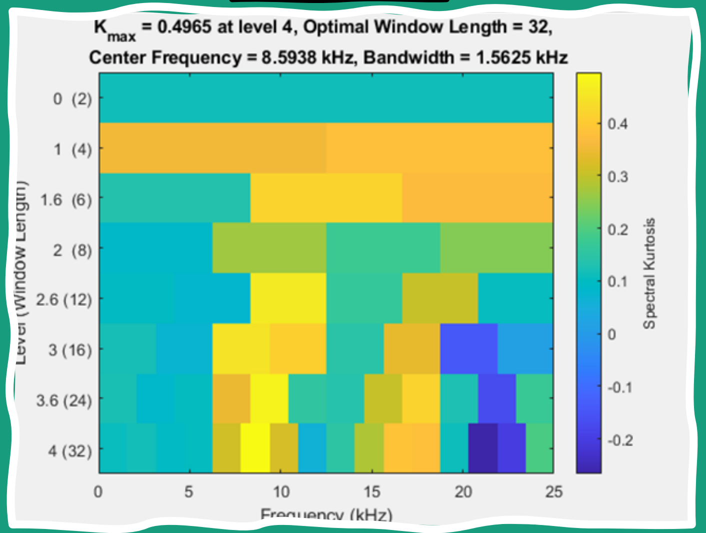

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Autoregressive (AR) Model

- **Steps:**

1- Find the suitable AR Model
2- Optimizing the order
3- Generating the model
4- Estimating the stationary signal
5- Computing the error

- **Pros and Cons:**

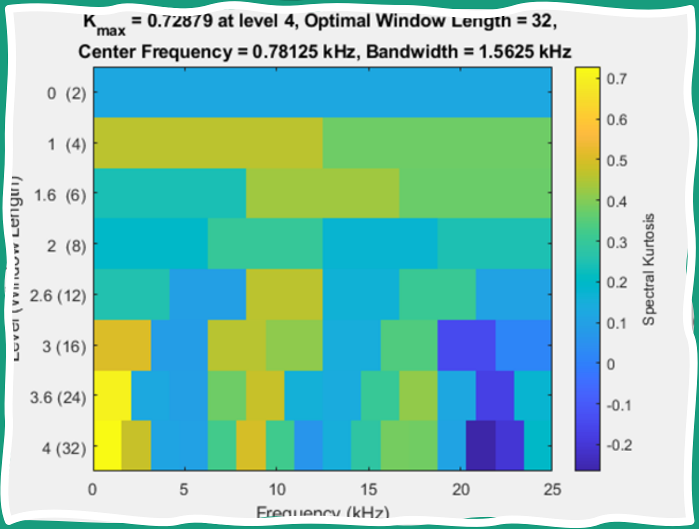
1- Expertise needed in modeling
2- prone noise

Mathematical Representation

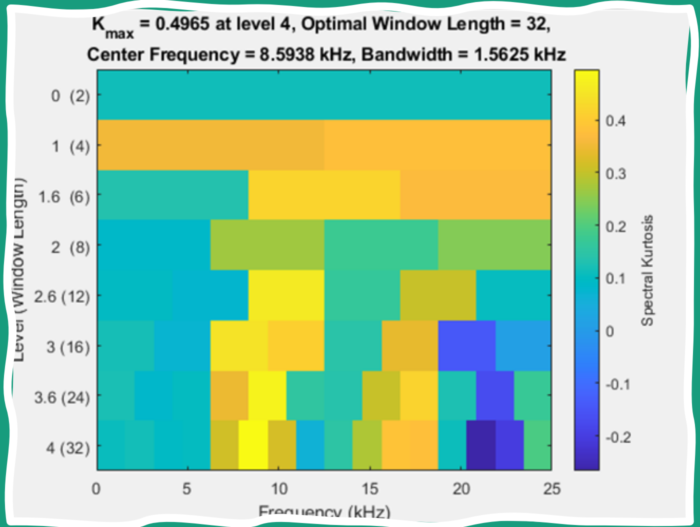
$$X_t = \Sigma_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t$$

p : *Model order (number of lag)*
X_{t-i}:*Lagged Value*
$\boldsymbol{\varepsilon_t}$: *Prediction error* ***(noise + non stationarity)***
φ: *Model parameter*

Before



After



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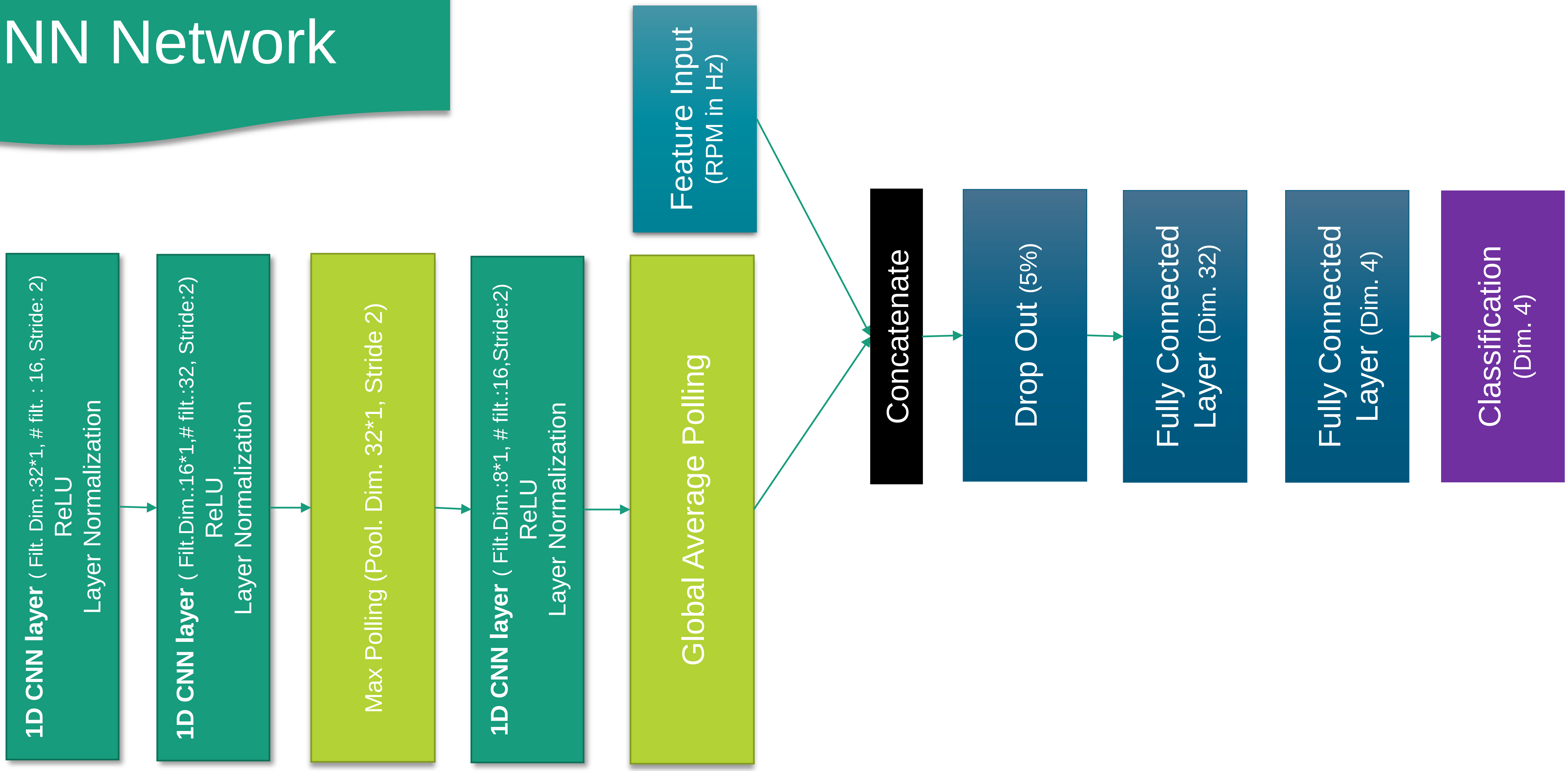
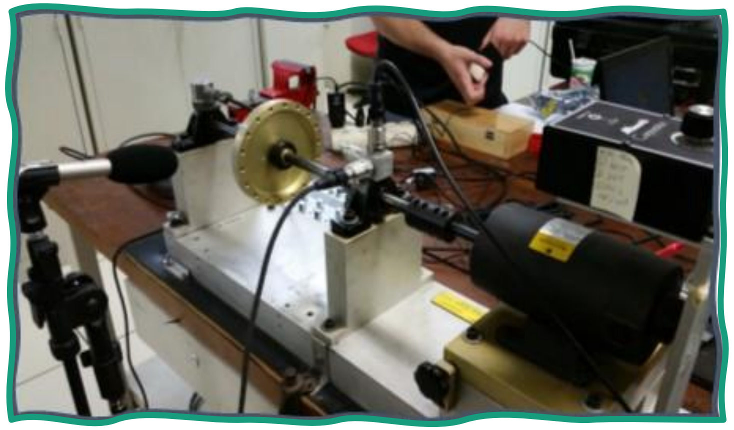
CNN Network



Feature Input (RPM in Hz)
1D CNN layer (Filt. Dim.:32*1, # filt. : 16, Stride: 2)
ReLU
Layer Normalization
1D CNN layer (Filt.Dim.:16*1,# filt.:32, Stride:2)
ReLU
Layer Normalization
Max Polling (Pool. Dim. 32*1, Stride 2)
1D CNN layer (Filt.Dim.:8*1, # filt.:16,Stride:2)
ReLU
Layer Normalization
Global Average Polling
Concatenate
Drop Out (5%)
Fully Connected Layer (Dim. 32)
Fully Connected Layer (Dim. 4)
Classification (Dim. 4)

MAFAULDA Dataset

- Test bench: SpectraQuest's
- Bearings: two ABVT 8 rolling ball
- RMP range: 700 – 3600rpm
- Sensors:
  - Tachometer
  - Two tridimensional accelerometer
  - Microphone
- Sampling Frequency: 50 KHz
- Measurement duration: 5s
- Outer/Inner/cage fault scenario



SpectraQuest's Machinery Fault Simulator (MFS)

Weight (g)	Measurements
6	49
10	48
15	48
20	49
25	47
30	47
35	45
Total	**333**

Imbalance Load details

Tachometer '	'Underhang Bearing Accelerometer Axial'	'Underhang Bearing Accelerometer Radiale '	'Underhang Bearing Accelerometer Tangential '	'Overhang Bearing Accelerometer Axial'	'Overhang Bearing Accelerometer Radiale '	'Overhang Bearing Accelerometer Tangential '	'microphone'
-0.56205	0.49038	-0.047927	0.048199	0.16672	0.034679	0.78593	0.10149
-0.56537	-1.5267	-0.11375	0.017286	0.16381	0.035058	0.73414	-0.0027973
-0.56313	0.971	0.23181	0.063505	0.1694	0.037785	0.80038	-0.01078
-0.5625	-1.5916	-0.44822	0.010677	0.16446	0.036373	0.68713	0.14934
-0.56661	1.0665	0.35208	0.10047	0.1659	0.03672	0.74835	-0.13203
-0.55848	-0.97374	-0.45289	0.0046073	0.16389	0.032985	0.68246	0.13768
-0.56572	0.3661	0.35023	0.030267	0.1682	0.03722	0.72353	-0.15036
-0.56366	-0.28867	-0.10572	-0.031329	0.16652	0.034628	0.67451	0.13157
-0.55979	-0.90231	0.22798	-0.00416	0.17068	0.041341	0.64372	-0.096815
-0.56708	0.66282	0.15316	-0.001411	0.17285	0.042277	0.66084	0.075668
-0.55558	-1.7188	-0.14494	-0.04	0.17252	0.045813	0.58502	0.048239

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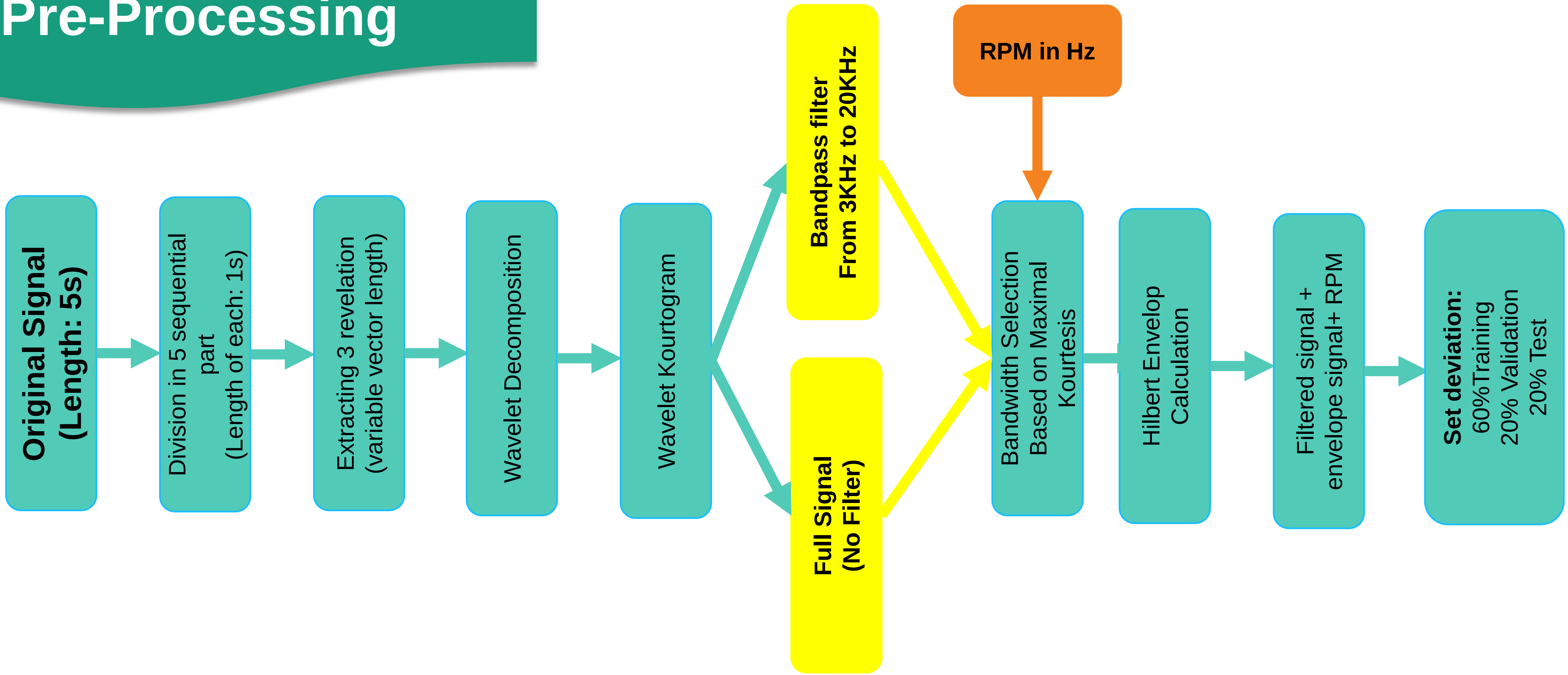
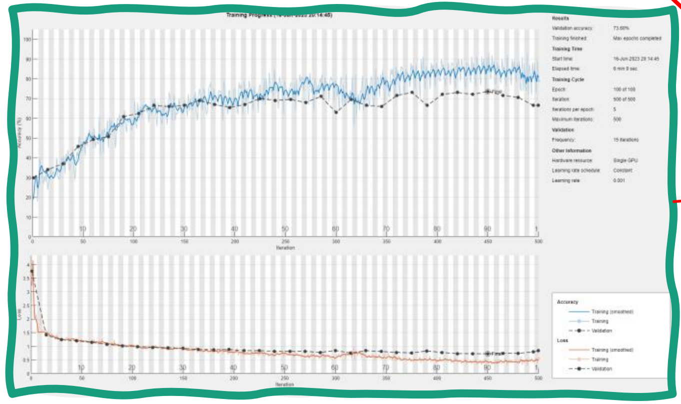
Data Handling
&
Pre-Processing



Case Study

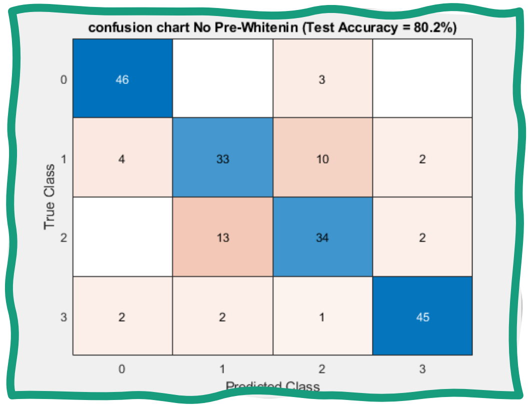
No Pre-Whitening

Learning Curve

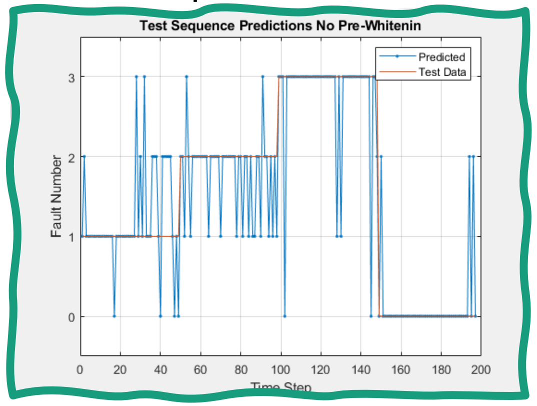


Test Accuracy = 80.2%

Confusion Chart

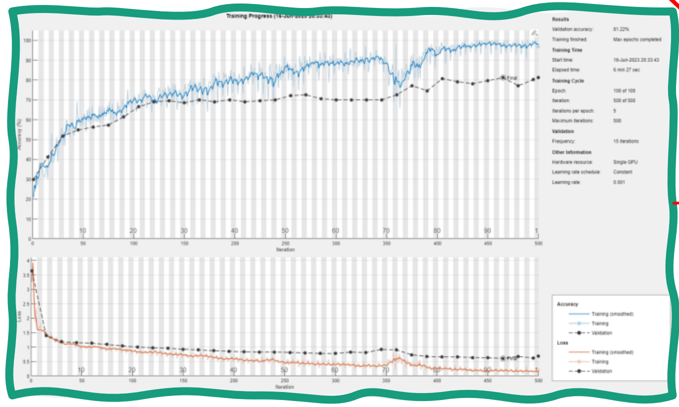


Test Sequence Predictions



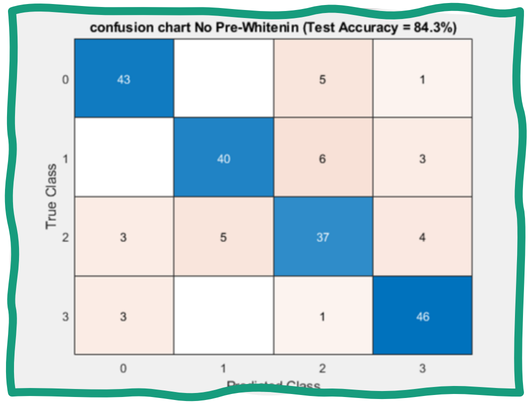
Bandpass Filter

Learning Curve



Test Accuracy = 84.3%

Confusion Chart



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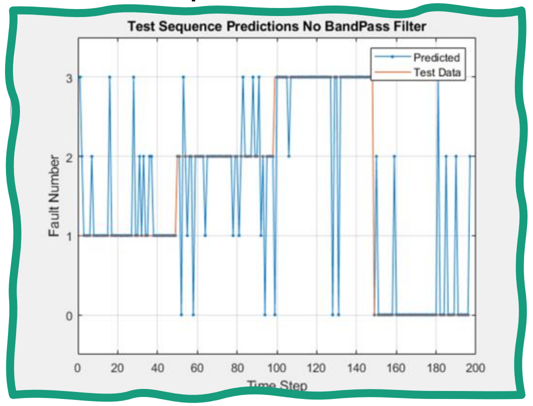

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Thank you!

DO YOU HAVE ANY QUESTIONS?

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