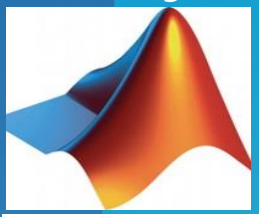
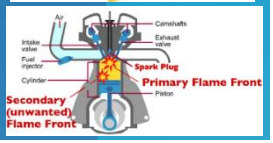
Optimizing Diesel Engine Technology using Data Analysis in MATLAB





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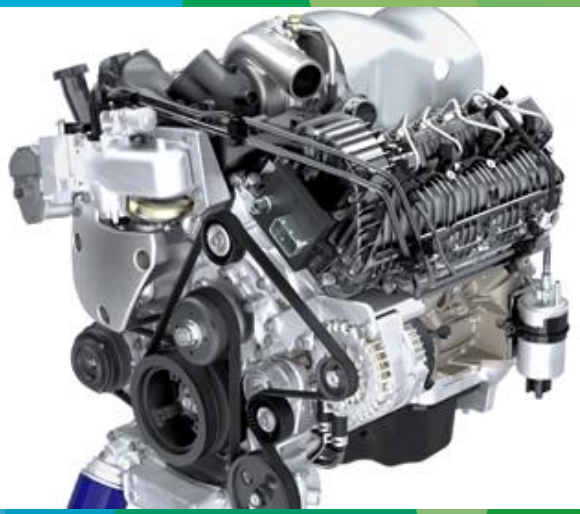

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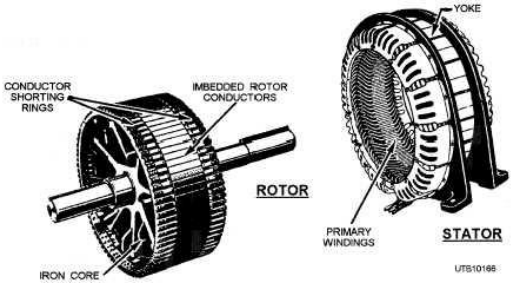
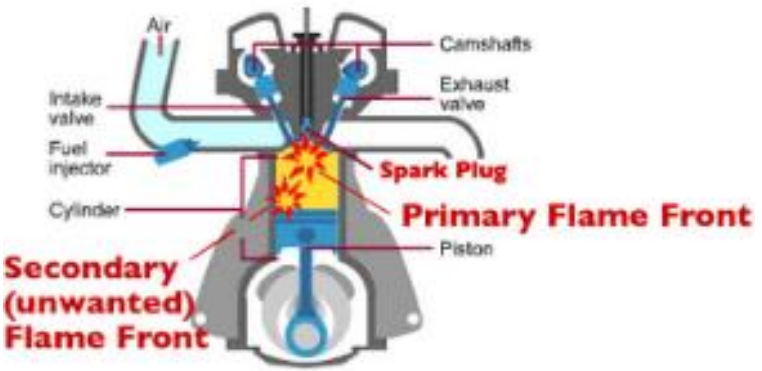
Noise – Data Sources



Industrial Machinery & Processes



Diesel Engine

Tones?

Tones are noises with a narrow sound frequency composition

Pure Tones are waveforms that occur at a Single Frequency

Tones can be identified subjectively by listening.

Annoying tones source: machinery with rotating parts
such as motors, gearboxes, fans and pumps often create tones

The human ear functions as a dynamic band pass filter. Only one tone can be distinguished within a critical band.

Psychoacoustic metrics such as PROMINENCE RATIO

Psychoacoustic metrics such as TONE TO NOISE RATIO

Psychoacoustic metrics such as the Tonality

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Knocking?

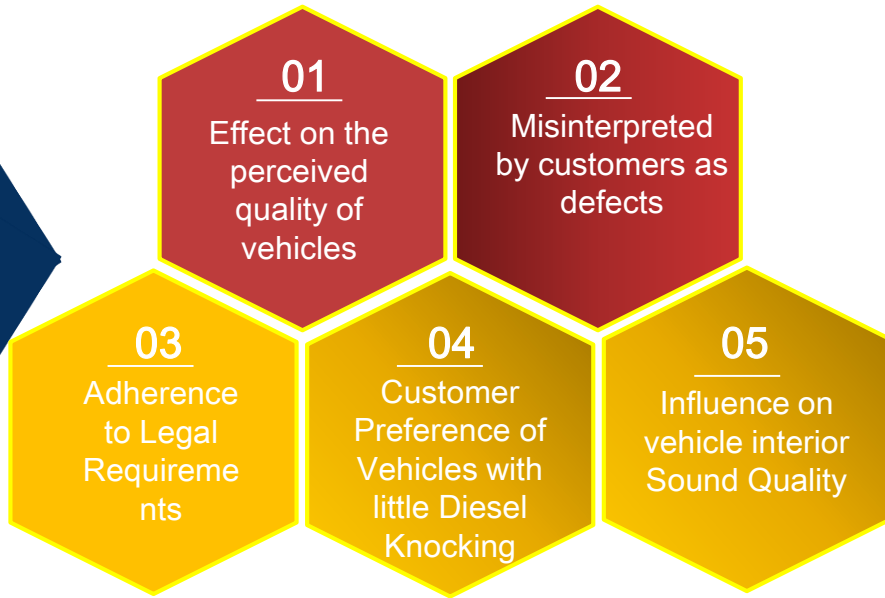
Diesel knock is the clanking, rattling sound emitted from a running diesel engine.

Diesel Engines are becoming extremely popular due to its good fuel economy

Knocking index : impulsive noise analysis parameter for engine sound quality

The ability to maximize power and fuel economy by optimizing spark timing for a given air/fuel ratio is limited by engine knock

Tuning vehicle NVH Parameter is a key aspect of the powertrain development process



Introduction

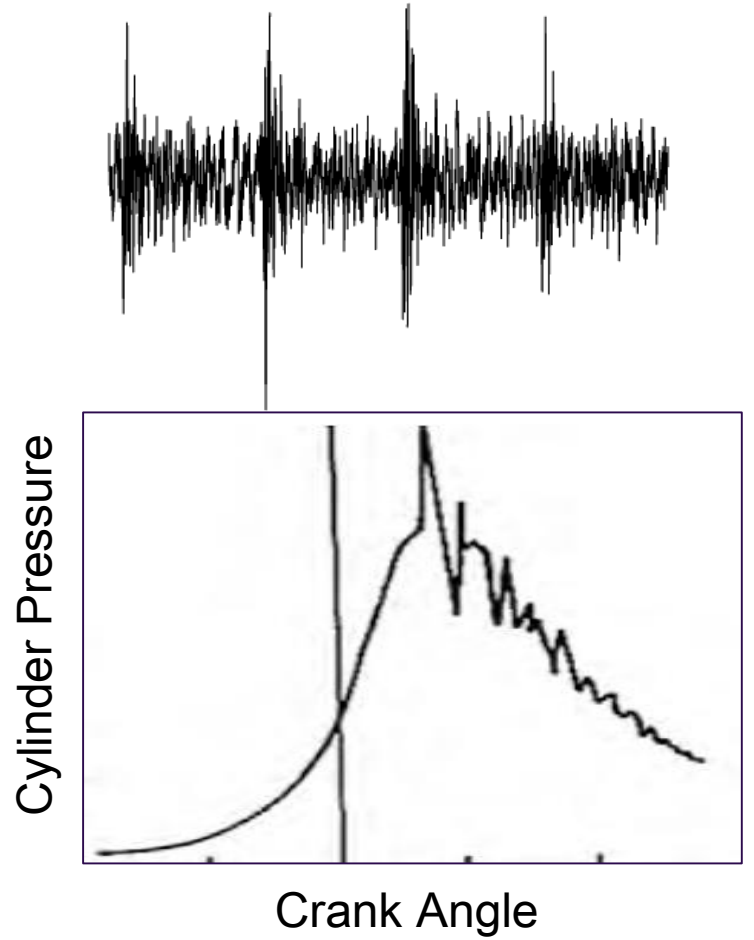
Knocking Effects

Knocking Index : Impulsive Noise

Impulse noise is a category of (acoustic) noise which includes unwanted, almost instantaneous (thus impulse-like) sharp sounds.

Knocking Index is an impulsive noise analysis parameter for engine sound quality

Noise consisting of random occurrences of energy spikes having random amplitude and spectral content.



Impulsive Noise Definition

Impulsive Engine Noise Signature

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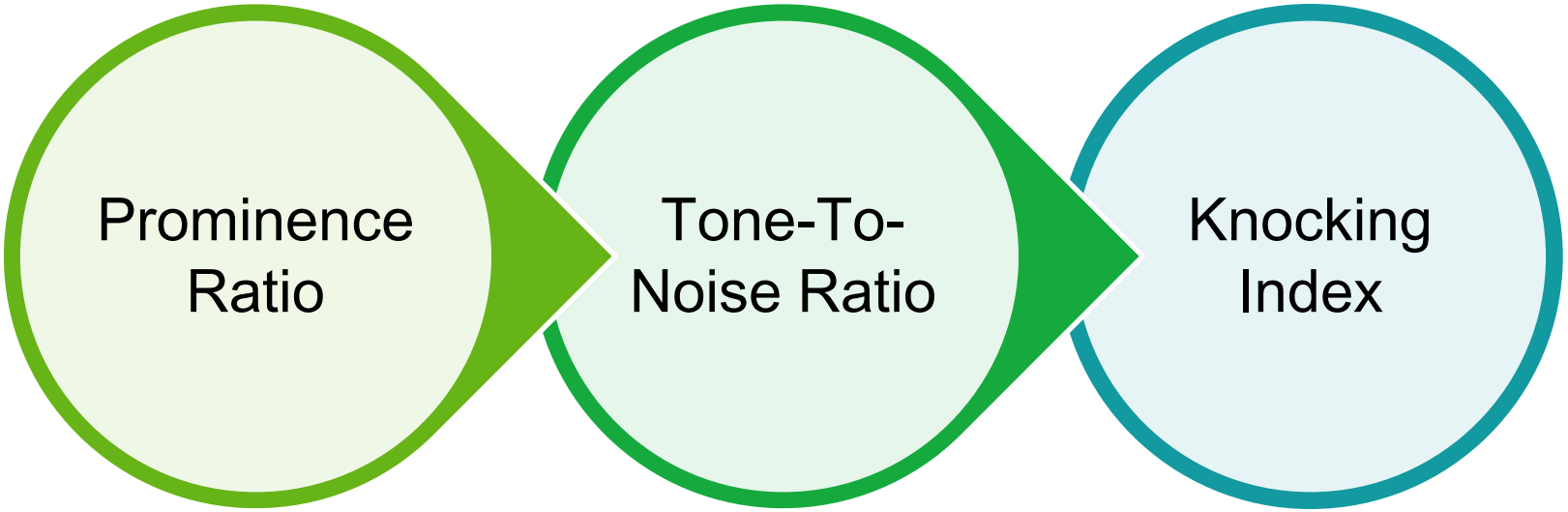
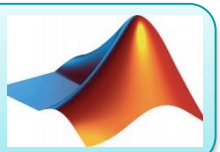
Noise Vibration Harshness : Psychoacoustics



Software Demo



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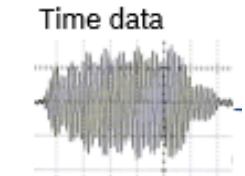
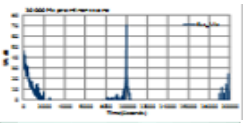
Prominence Ratio



FFT analysis [Configurable Parameters]

FFT(data), Data Windowing



SPL Spectrum

20log(FFT /0.00002)

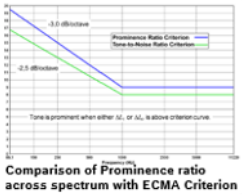
Calc. Critical Band

Calc. overall SPL in Middle Critical Band

Calc. overall SPL in Lower Critical Band

Calc. overall SPL in Upper Critical Band

Determine PR for the given tone


Comparison of Prominence ratio across spectrum with ECMA Criterion

Design & Analyze Hamming, Kaiser, Gaussian, Hanning & other windows done using Matlab Signal Processing Toolbox

SPL : Sound Pressure Level : PR : Prominence Ratio

Prominence Ratio Results

For $f_t \le 500\,\text{Hz}$:

$$f_{1,M} = f_t - \frac{\Delta f_M}{2}$$

and

$$f_{2,M} = f_t + \frac{\Delta f_M}{2}$$

For $f_t > 500\,\text{Hz}$:

$$f_{1,M} = -\frac{\Delta f_M}{2} + \frac{\sqrt{(\Delta f_M)^2 + 4 f_t^2}}{2}$$

and

$$f_{2,M} = f_{1,M} + \Delta f_M$$

$$\Delta L_P = 10\lg\left(10^{0,1L_M}\right) - 10\lg\left[\left(10^{0,1L_L} + 10^{0,1L_U}\right) \times 0{,}5\right]\,\text{dB for } f_t > 1714\,\text{Hz}$$

$$\Delta L_P = 10\lg\left(10^{0,1L_M}\right) - 10\lg\left[\left([100/\Delta f_L] \times 10^{0,1L_L} + 10^{0,1L_U}\right) \times 0{,}5\right]\,\text{dB}$$
$$\text{for } f_t \le 1714\,\text{Hz}$$

Spectral Analysis & Signal Modeling is done using Matlab Signal Processing Toolbox

Determination of Level of Middle critical band : ECMA 74 Standard

Determination of Prominence Ratio : ECMA 74 Standard

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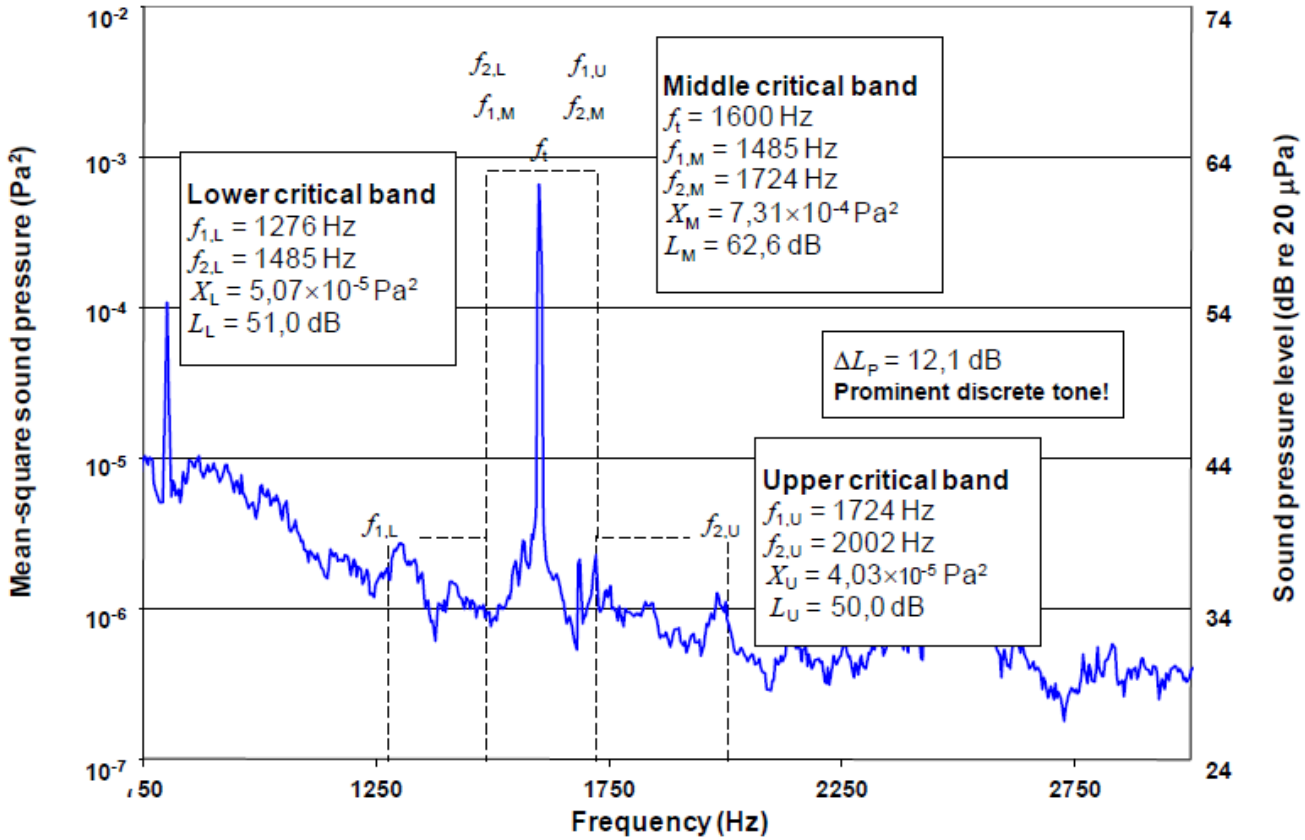
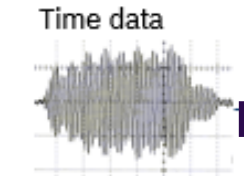
Prominence Ratio Results



PR : Discrete Tone Identification

Workflow Tone to Noise Ratio

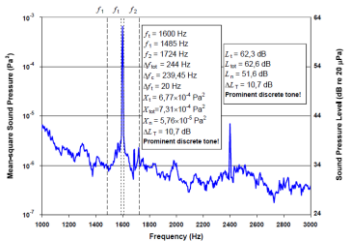


FFT analysis [Configurable Parameters]

Calculate Discrete Tone Level

Determination of Masking noise level

Determination of Tone-to-noise ratio



Parallel Processing of Data of various measurement file done using Parallel computing Toolbox

Workflow Tone to Noise Ratio

$$X_n = (X_{tot} - X_t)\frac{\Delta f_c}{(\Delta f_{tot} - \Delta f_t)}$$

$$L_n = 10\lg\left(10^{0,1L_{tot}} - 10^{0,1L_t}\right)\text{dB} + 10\lg\left(\frac{\Delta f_c}{\Delta f_{tot} - \Delta f_t}\right)\text{dB}$$

Masking Noise Level

$$\Delta L_T = 10\lg\frac{X_t}{X_n}\,\text{dB}$$

$$\Delta L_T = L_t - L_n\ \text{dB}$$

Tone to Noise Ratio : ECMA-74

$\Delta L_T \geq 8{,}0 + 8{,}33 \times \lg(1\,000/f_t)$ dB for 89,1 Hz $\leq f_t \leq$ 1 000 Hz

$\Delta L_T \geq 8{,}0$ dB for $f_t >$ 1 000 Hz

Prominent Discrete for TNR method

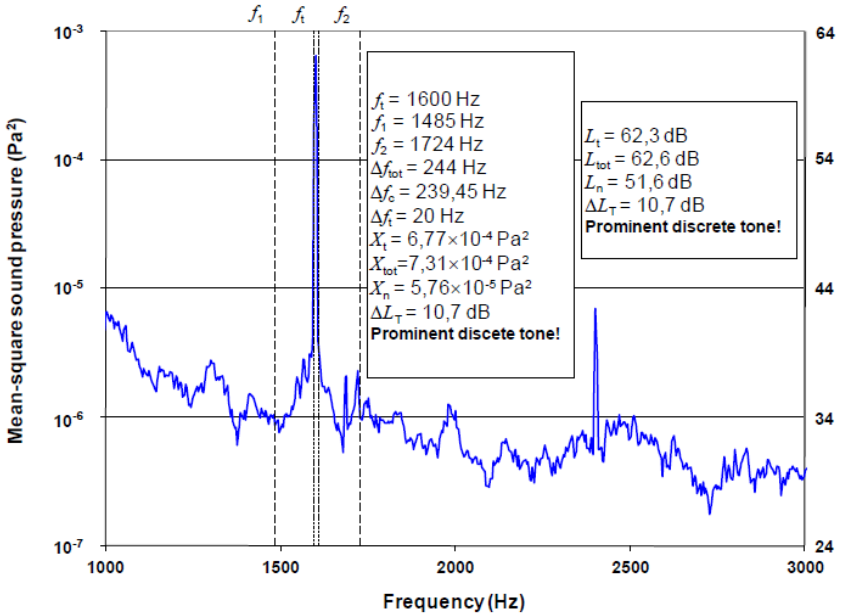
$$L_t = 10\lg\left(10^{0,1L_{t,p}} + 10^{0,1L_{t,s}}\right)\text{dB}$$

$$X_n = \left[X_{tot} - (X_{t,p} + X_{t,s})\right] \times \left[\frac{\Delta f_c}{\Delta f_{tot} - (\Delta f_{t,p} + \Delta f_{t,s})}\right]$$

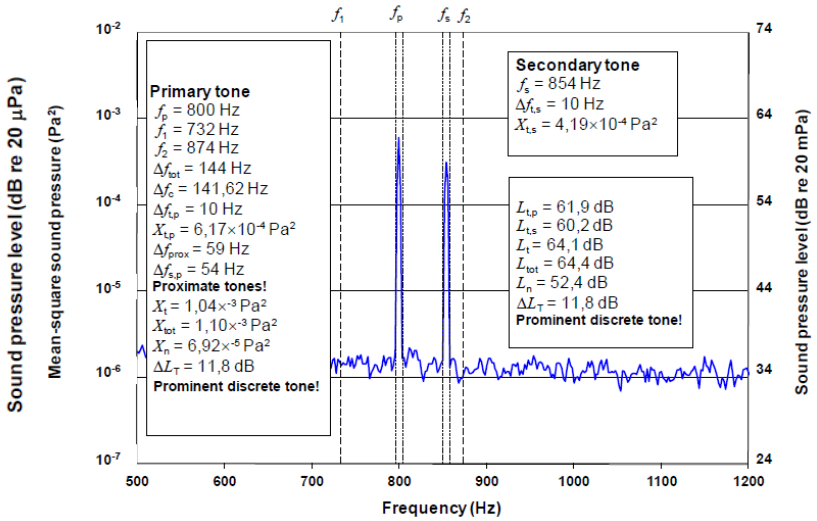
$$L_n = 10\lg\left[10^{0,1L_{tot}} - \left(10^{0,1L_{t,p}} + 10^{0,1L_{t,s}}\right)\right]\text{dB} + 10\lg\frac{\Delta f_c}{\Delta f_{tot} - \left(\Delta f_{t,p} + \Delta f_{t,s}\right)}\text{dB}$$

Multiple Tones in Critical Band: ECMA-74

Tone to Noise Ratio Results

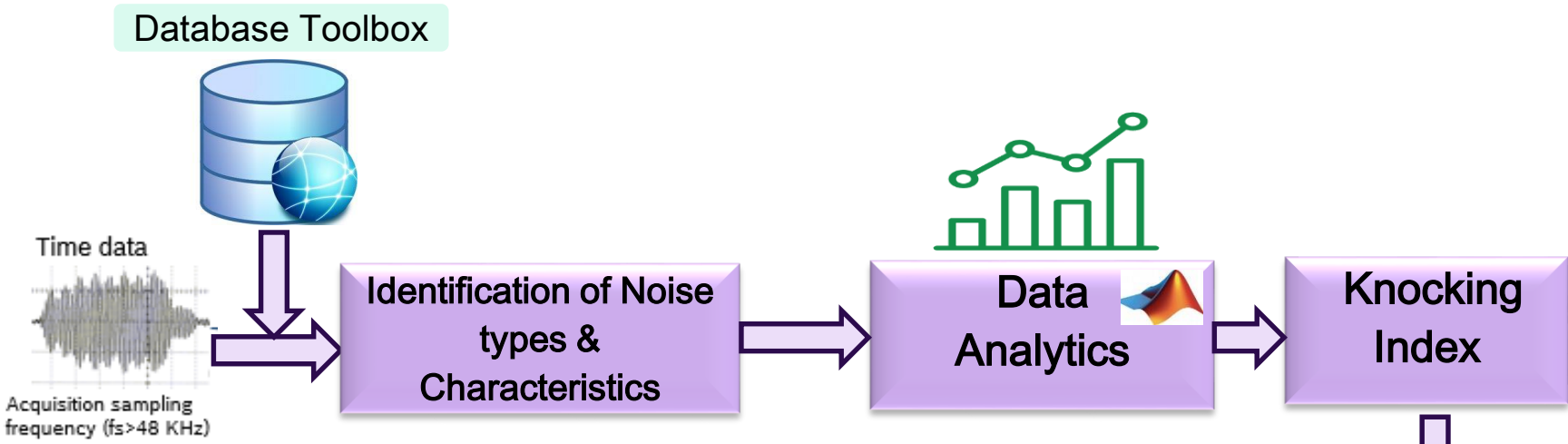


TNR : Single Tone



TNR : Multiple Tones

Knocking Index : Approach



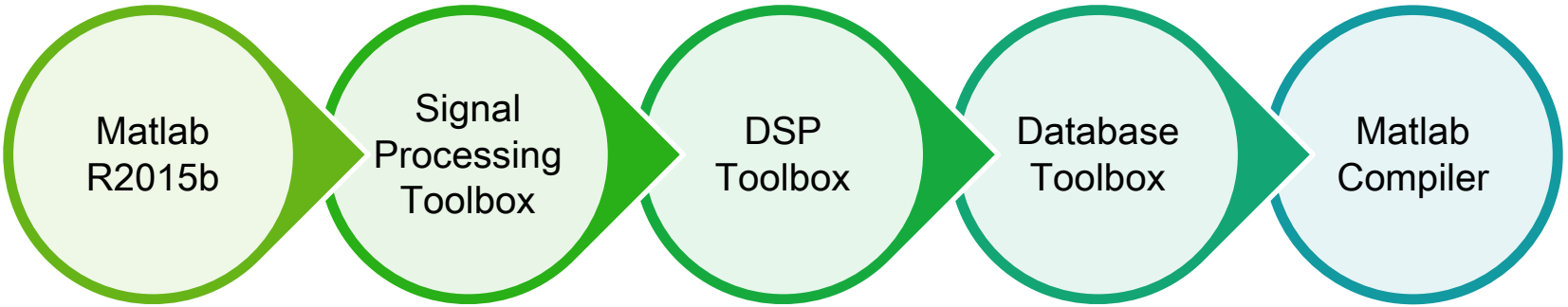
Noise Types:

1. Knocking
2. Rattling
3. Ticking(Injectors)
4. Tonal Noise

Noise Characteristics:

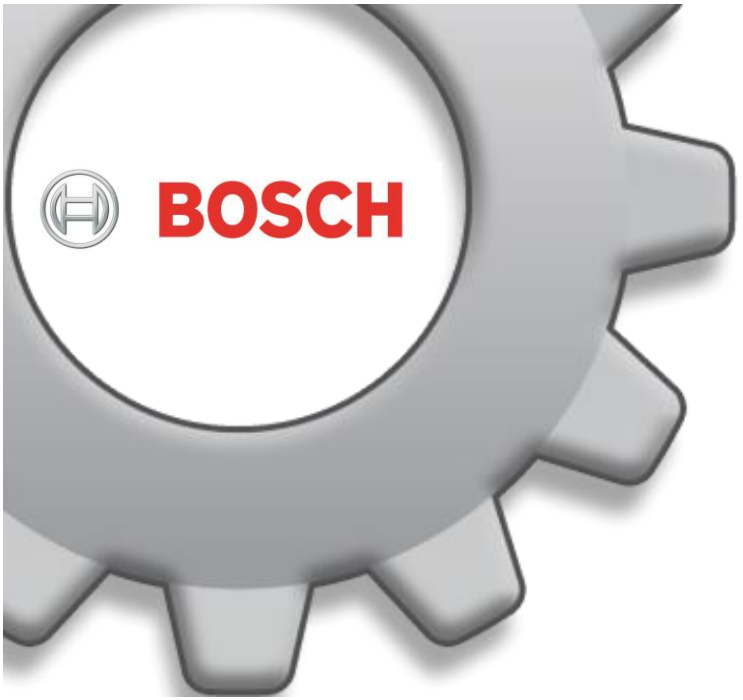
1. Impulsivness

Infrastructure



Summary

- Easy to identify & configure threshold parameters as per ECMA standard.
- Performance improvement in the validation of the components
- One platform to perform Data Preprocessing & post processing
- The characteristic features of Diesel sounds can be identified and quantified
- Separation of Engine Noise sources & Analysis of Impulsive Noise



Thank You

Images & References

- http://www.bosch.com/en/com/home/index.php
- http://in.mathworks.com/products/matlab/
- http://www.ecma-international.org/publications/standards/Ecma-074.htm