AIRCRAFT ENGINES TIME-FREQUENCY ANALYSIS REALLOCATION ERRORS

—

12/09/2024

ESR 15

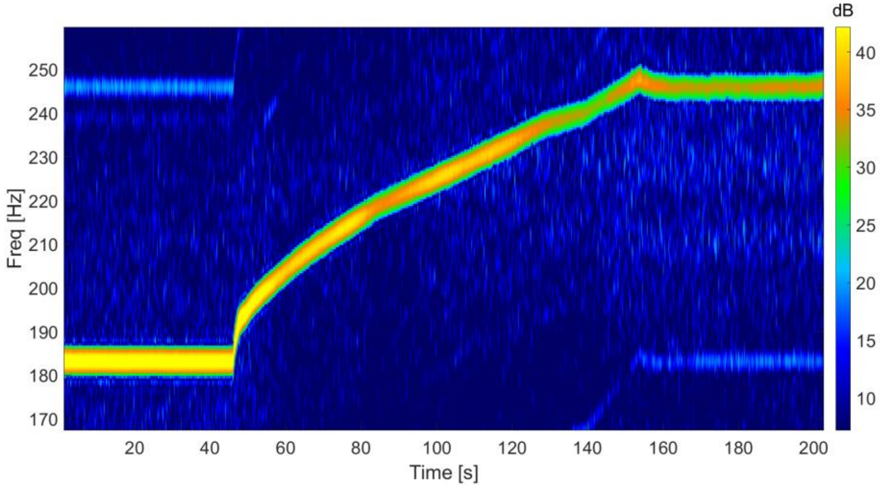
Fadi KARKAFI

Marie Skłodowska-Curie Project, MOIRA – H2020

UNIVERSITÉ DE LYON
SAFRAN
INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

Introduction

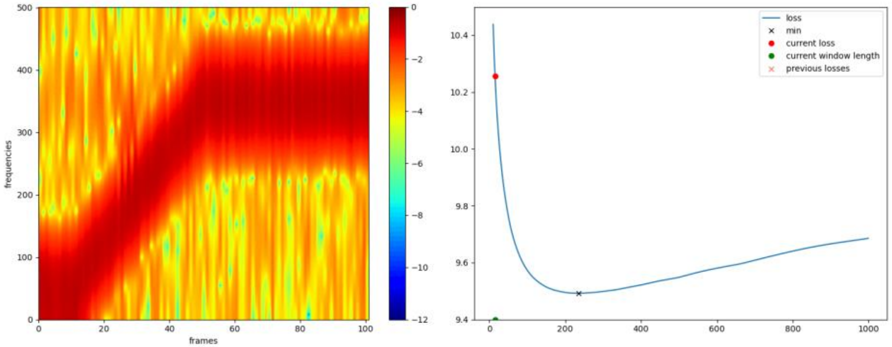
- Aircraft engines operate under varying conditions
  - Importance of analyzing the acquired signals in Time-Frequency Representation (TFR)
- Multiple challenges
  - AM/FM signals, multi interferences within components, noisy varying phase, …
- Varying signal characteristics over time
  - Need for an adaptation to maintain reliable time and frequency resolution



Frequency Reallocation

- Short-Time Fourier Transform (STFT)
  - Provide information about frequencies energies evolution along time
- Time-Frequency (TF) trade-off
  - Smaller window lengths provide better T resolution but poor F resolution
- Heisenberg-Gabor Uncertainty Principle
  - TF resolution is limited by the choice of the window size
- Fixed window size unsuitable for varying regimes
  - Small temporal window for fast varying regimes and longer ones for stationary modes.

→ Need for frequency reassignment

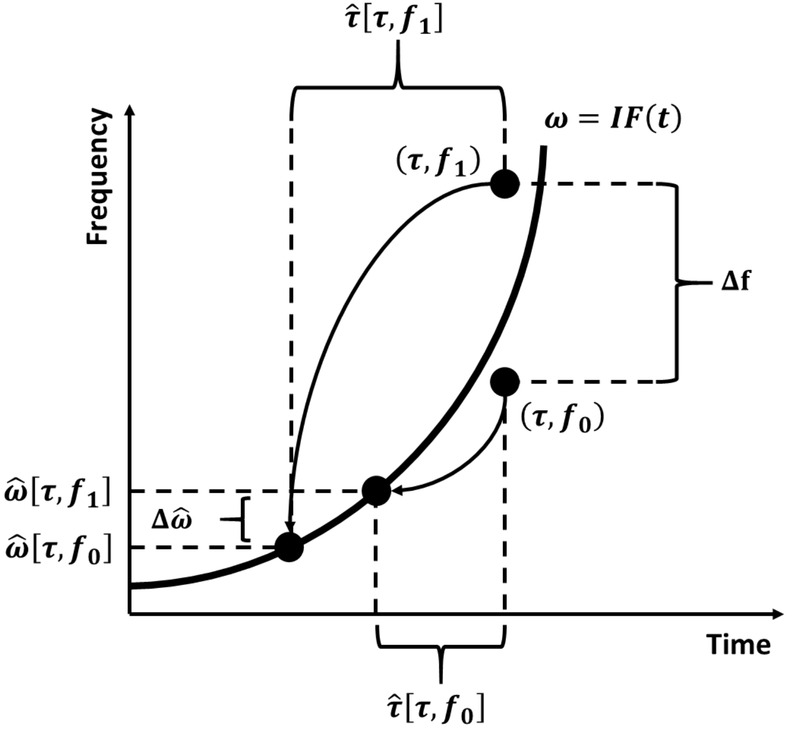


First Order Synchrosqueezing Transform (SST-1)

- Redistributing frequency components within TFR
  - Need to compute an initial rough estimate of the instantaneous frequency channel
- The STFT is a complex number
  - $S_x^g[\tau,f] = X[\tau,f]e^{2\pi j\phi[\tau,f]} \rightarrow \widehat{\omega} = \Delta_\tau \phi[\tau,f] = \frac{1}{\Delta t}\arg\{S_x^g[\tau,f] \times S_x^g[\tau-\Delta\tau,f]^*\}$
- Reassignment operation

$$\tilde{T}[\tau,f] = \sum_{\omega:|\widehat{\omega}[\tau,f]-\omega|\leq\frac{\Delta f}{2}} S_x^g[\tau,\omega]$$

- Rough assumption
  - $\Delta_\tau^{[2]}\phi[\tau,f] \approx 0$



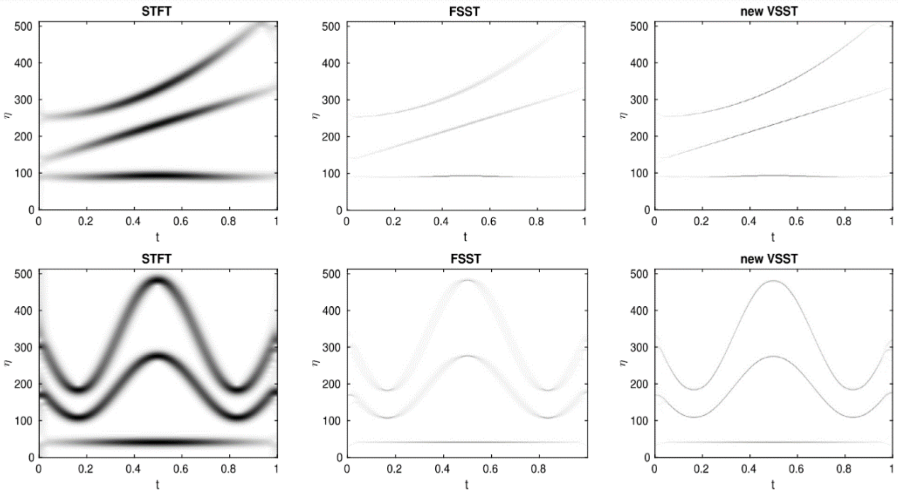
Second Order Synchrosqueezing Transform (SST-2)

- High speed fluctuations
  - Reallocations errors → need to consider fast variations of the speed

- Need to adapt the speed operator of SST-1
  - $\widehat{\omega}_x^{[2]}[\tau,f] = \widehat{\omega}_x^{[1]}[\tau,f] + q[\tau,f] \times (\tau - \tau_x[\tau,f])$
  - $q[\tau,f] = \frac{\Delta_\tau \widehat{\omega}_x^{[1]}[\tau,f]}{\Delta_\tau \tau_x[\tau,f]}$

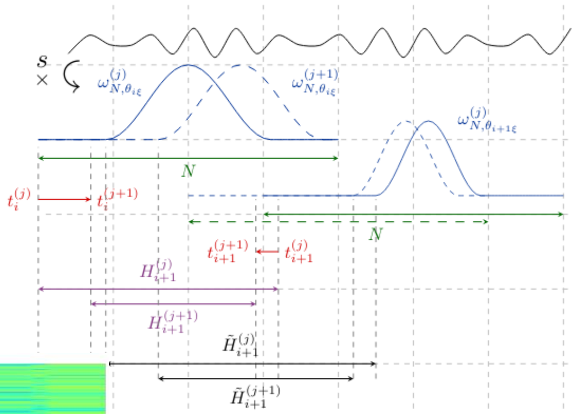
$$v = v_o + a \times t$$

$$a = \frac{\Delta v}{\Delta t}$$

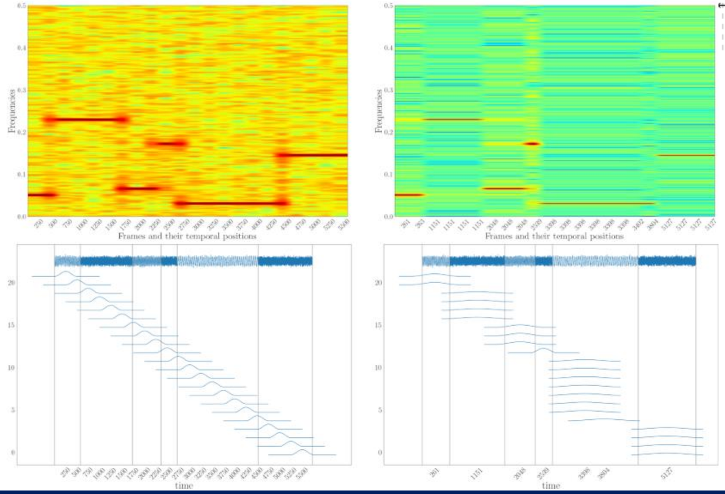


- Theoretically this is correct …
  - But if the considered phase is noisy and the noise is uncorrelated, the ratio of differences will amplify the noise
  - Need to consider those varying regimes without the limitation of noise amplification

Differentiable Short-Time Fourier Transform (DSTFT)

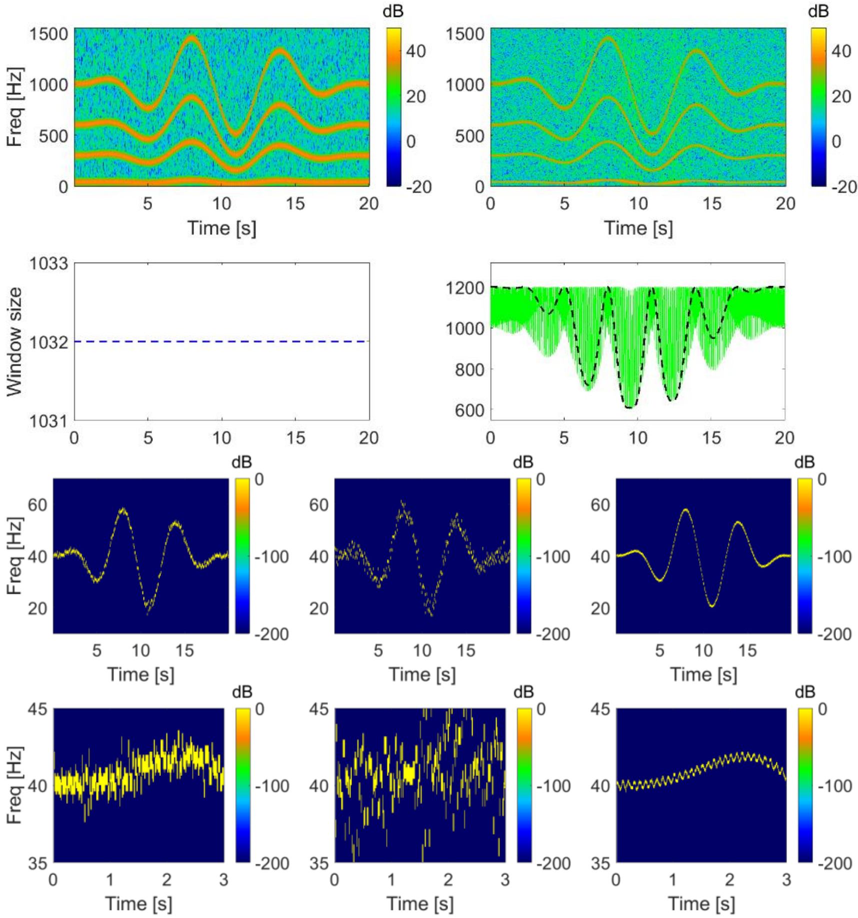


- Extension for the STFT
  - Enables the gradient-based optimization of the parameters
- Another perspective of STFT
  - $S_x^g[\tau, f] \rightarrow S_x^{g_N}[i, f]$
- Defined criterion
  - Evaluation Goal: Extract frequency components
  - Maximizing the kurtosis for each frame



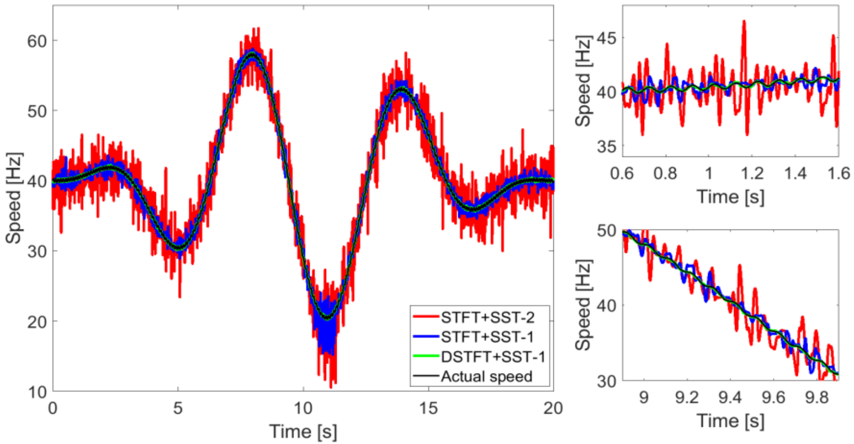
Simulation Case

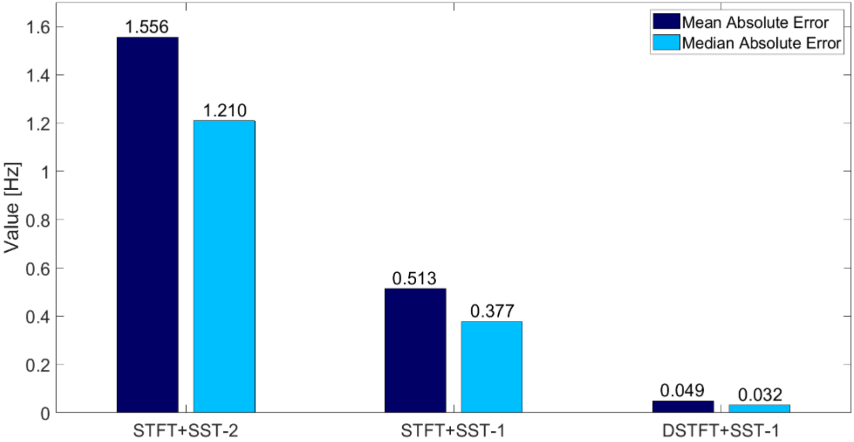
- Simulated data with varying regime
  - Spectrograms comparison
- DSTFT window distribution
  - Proportional to $\frac{1}{\ddot{\theta}^2(t)}$
  - If $\ddot{\theta}^2(t) \gg \rightarrow \Theta \ll$ to consider high speed fluctuations
- Multiple methods comparison
  - STFT + SST-1 / STFT + SST-2 / DSTFT + SST-1



Simulation Case

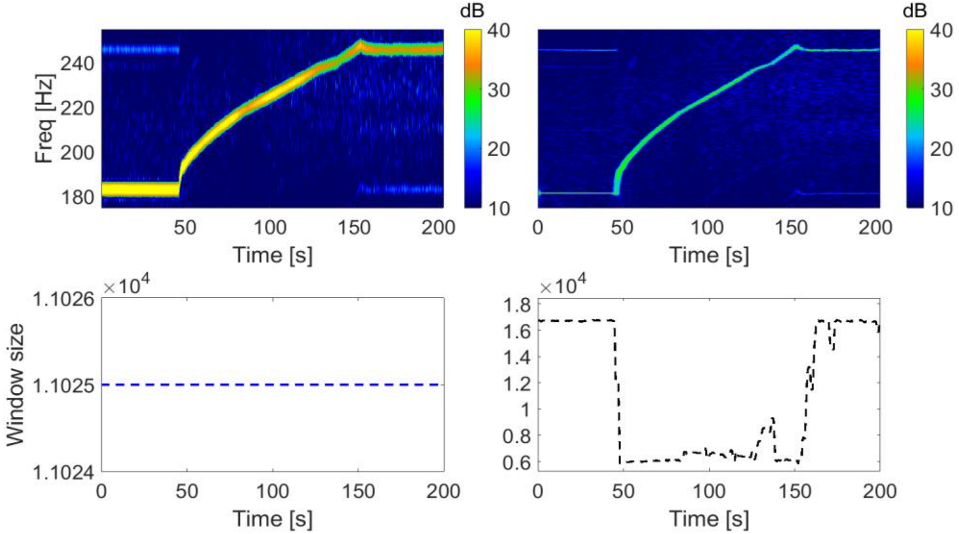
- IF estimation
  - Expected value of each STFT within the speed frequency band
- Close observation
  - Most variance/error caused by conventional methods is clear within a certain regime of the speed
- Methodology outperformance
  - Considering the varying regime results a better performance





Experimental Case

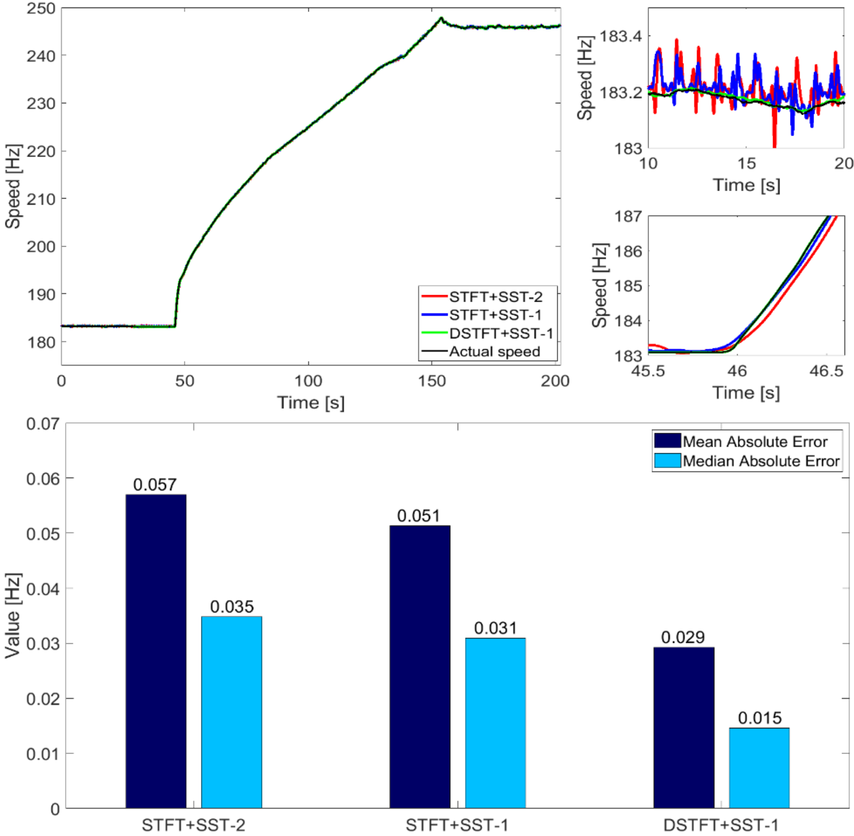
- Aircraft engines operate under varying conditions
  - Spectrograms comparison
- DSTFT window distribution
  - Higher window length corresponds to stationary regimes
  - Lower window lengths starts at the first hop frame



Experimental Case

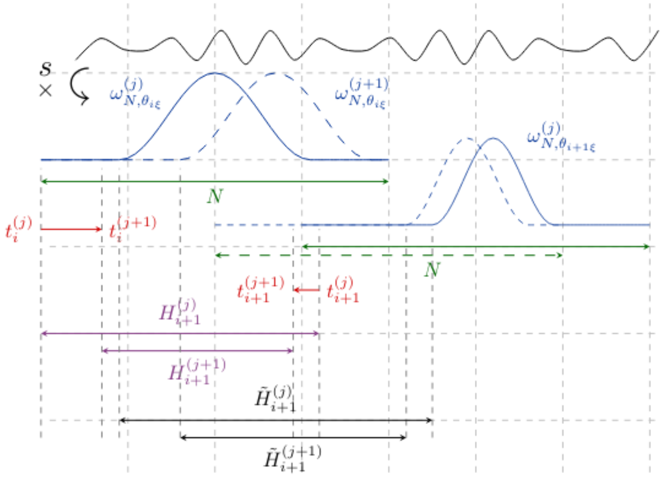
- IF estimation
  - Expected value of each STFT within the speed frequency band

- Methodology outperformance
  - Considering the varying regime results a better performance



Discussion and Perspectives

- Regime tracking
  - Information about the system's behavior
- Speed fluctuations
  - AM and FM objectives
- Window shape
  - Extension of gradient-based parameters
- Defined criterion
  - Modify the loss function according to the desired goal

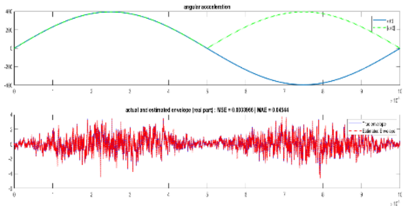


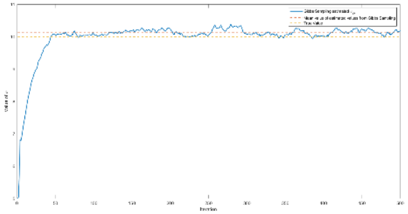
Timeline

Multi Order Synchro-squeezing Transform (MOST)

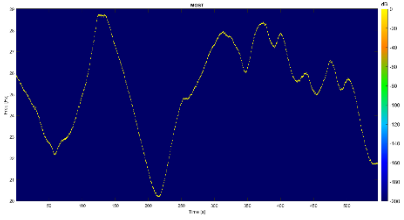
DSTFT + SST-1

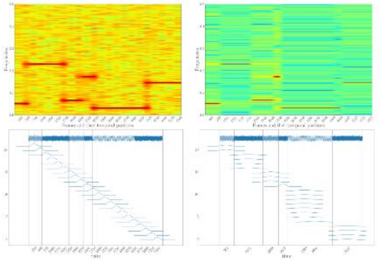
ISMA 2024





…





CNS component separation

PHME 2024

Speed-dependent VKF

Fully automated adaptation

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement n° 955681.