Introduction and Background

Objective
Characterization of rhythmic temporal dynamics in naturally-occurring random processes, such as:
- Underwater propeller cavitation
- Human speech
- Music
- Machine noise
- Helicopter noise

Propeller Cavitation as a Rhythmic Process

Cavitation noise is caused by the periodic-like generation and collapse of air bubbles on the rotating blades of an underwater propeller. The images below show examples of lip-vortex cavitation (left) and sheet cavitation (right).

Cavitation noise is audibly and visually rhythmic. However, the power spectrum fails to capture the low-frequency propeller rhythm.

None of the Fourier components directly relates to the rhythm of the signal. An alternative representation for rhythm is a modulation product model, as described below.

Modulated Random Processes

Signal Model: $x(t) = m(t) \cdot c(t) + w(t)$

- Periodic, low-bandwidth
- Wide-sense stationary, broadband

Define:
- Covariance: $R_x(t, t') = \mathbb{E} \{ x(t) x(t') \}$
- Looève spectrum: $\Gamma_x(f, \lambda) = \mathbb{E} \{ X(f) \cdot X(f + \lambda) \}$

From the above definitions, $x(t)$ is periodically correlated [2] and therefore consists of correlated frequency increments. The figures below show synthetic examples of the time and frequency correlation functions for such a process.

Synthetic Test Signals

Signal 1: 2-Hz amplitude-modulated Gaussian noise (-6dB SNR):

$x(t) = m(t) \cdot c(t) + w(t)$

Signal 2: Output of a 2-Hz periodically-varying AR(1) system:

$x(t) = \sum_{k=-b}^{b} m_k(t) \cdot c(t)$

Conclusions

New multiband DEMON: An improved modulation estimator for colored rhythmic processes, using subband normalization and averaging.

Key finding:
Subband expansion reveals dynamics that require more sophisticated signal models and estimators.

References