Frequency estimation under stationary and non-stationary conditions - A case study of induction motor fault diagnosis

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Abstract

Signal parameters carry vital characteristic information about any physical process. Fourier bases have been of tremendous analytical potential that still spans the space of signature analysis. This thesis attempts to retrieve phase information of signals with time-varying and constant frequencies to gain insight into such processes.

We adopt a model-based approach to estimate the instantaneous frequency (IF) of multiple time-varying components using a linearized constrained Kalman-based method. The method is used for estimating the chirp-like characteristic features of gravitational waves emanated from the merging of binary black-holes. The phase abstraction property of the method is used for extracting the dominant modes of the signal. The removal of dominant modes reduces the spectral leakage for stationary frequency estimation. As a consequence, previously obscured low-magnitude frequency components are observable.

We propose two spectral estimators in the thesis for stationary conditions when the frequency is constant in the observation window. The Rayleigh-quotient-based method uses the well-known Fourier basis constructed Eigenvectors to estimate the unknown Eigenvalues of a symmetric autocorrelation matrix. The technique has high frequency and amplitude accuracy and requires low computational resources. The approach is data-driven and doesn't require any information about the underlying model. Alternatively, the proposed Bayesian spectral estimator is model-based and can incorporate knowledge of the underlying model. It is sequential and has higher accuracy than the Rayleigh-quotient spectrum. The use of an accurate model can further improve the precision of the approach.

One significant impact of this thesis is the detection and estimation of low-amplitude sinusoidal components buried under noise and masked by the presence of high-magnitude elements. A similar and practical situation arises while detecting weak induction motor faults. Hence, the case study of detecting weak SCIM faults is used to validate the proposed algorithms. Furthermore, a minimum distance-based hypothesis test is recommended for incorporating the inherent fault information. Two embedded platforms are also presented in this thesis for hardware realization of the suggested algorithms. The Simulink Real-time-based hardware is appropriate for detecting faults in a single motor. However, the hardware is costly, but its flexibility for initial feasibility studies is advantageous. On the other hand, the Internet-of-things-based system has been tailor-made for dedicated fault detection in a multiple-motor scenario.

Keywords:

Bayes theorem, closely spaced sinusoids, constrained Kalman filter, current analysis, fault diagnosis, Gauss-Markov process, gravitational waves, hypothesis testing, incipient faults, induction motor, instantaneous frequency estimation, Internet of things, non-stationary signal, Rayleigh-quotient, signal-conditioning, Simulink Real-Time, spectral estimation, time-varying autoregressive process, vibration analysis.