Frequency Tracking for Speed Estimation

Estimating the frequency of a periodic signal, or tracking the time-varying frequency of an almost periodic signal, is an important problem that is well studied in literature. This thesis focuses on two subproblems where contributions can be made to the existing theory: frequency tracking methods and measurements containing outliers.

Maximum-likelihood-based frequency estimation methods are studied, focusing on methods which can handle outliers in the measurements. Katkovnik's frequency estimation method is generalized to real and harmonic signals, and a new method based on expectation-maximization is proposed. The methods are compared in a simulation study in which the measurements contain outliers. The proposed methods are compared with the standard periodogram method.

Recursive Bayesian methods for frequency tracking are studied, focusing on the Rao-Blackwellized point mass filter (RBPMF). Two reformulations of the rbpmf aiming to reduce computational costs are proposed. Furthermore, the technique of variational approximate Rao-Blackwellization is proposed, which allows usage of a Student's t distributed measurement noise model. This enables recursive frequency tracking methods to handle outliers using heavy-tailed noise models in Rao-Blackwellized filters such as the RBPMF. A simulation study illustrates the performance of the methods when outliers occur in the measurement noise.

The framework above is applied to and studied in detail in two applications.
The first application is on frequency tracking of engine sound.
Microphone measurements
are used to track the frequency of Doppler-shifted variants of the engine sound of a vehicle moving through an area. These estimates can be used to compute the speed of the vehicle. Periodogram-based methods and the RBPMF are evaluated on simulated and experimental data. The results indicate that the RBPMF has lower RMSE than periodogram-based methods when tracking fast changes in the frequency.

The second application relates to frequency tracking of wheel vibrations, where a car has been equipped with an accelerometer. The accelerometer measurements are used to track the frequency of the wheel axle vibrations, which relates to the wheel rotational speed. The velocity of the vehicle can then be estimated without any other sensors and without requiring integration of the accelerometer measurements.
In situations with high signal-to-noise ratio (SNR), the methods perform well.
To remedy situations when the methods perform poorly, an accelerometer input is introduced to the formulation. This input is used to predict changes in the frequency for short time intervals.