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The Accuracy of Time Series Analysis for Laser-Doppler Velocimetry

P.M.T. Broersen, S. de Waele and R. Bos
Department of Applied Physics,
Delft University of Technology
P.O.Box 5046, 2600 GA Delft
The Netherlands
tel. +31 15 2786419,
fax +31 15 2784263,
email broersen@tn.tudelft.nl

ABSTRACT

Four approaches for the processing of unequally sampled data are known, each with many variants. The Lomb-Scargle approach uses the precise time information in computing spectra and is a useful method for the detection of harmonic peaks and much less for the spectral slope or other details. The second approach consists of several different slotting methods which determine an equidistant covariance estimate of the data. Unfortunately, none of the slotting covariance estimators has the important positive semi-definite property that is required for a valid covariance estimate. Hence, spectral estimates become negative at some frequencies and the logarithm of the spectrum is not defined there. Theoretically, no useful interpretation can be given to the estimates, because they no longer give the distribution of the total power over the frequencies. Many local peaks appear in the log spectral density between the negative spectral estimates if the negative estimated values are replaced by zero. The third category fits parametric spectral models to raw data. It imposes a spectral shape, independent of the data, and it can only be useful if that shape is known a priori.

The fourth method first resamples the irregular data on an equidistant time base. Nearest Neighbor takes the nearest original observation for each resampled value. Afterwards, it uses the familiar and accurate equidistant signal processing algorithms for the evaluation. Time series models can give an accurate spectral representation for turbulence data, if the model type and the model order are selected properly. This is demonstrated by the fact that the spectral density is retrieved accurately with the spectrum of time series models in simulations. Resampling causes a distortion of the estimated spectrum, that increases strongly with frequency. Therefore, nearest neighbor resampling is limited in disclosing spectral details at higher frequencies. Although strongly filtered, peaks can be retrieved at frequencies up to the average sampling rate, so two times the Nyquist frequency that would belong to equidistant sampling. For still higher frequencies, even very strong peaks in the original irregular signal do not give rise to any ripple in the estimated spectral density after resampling.
For frequencies above the average sampling rate, the Lomb-Scargle method can detect the presence of narrow large peaks, if the power of the noise is not too high.