Burst detection and particle time of flight estimation with wavelets for acoustic velocity estimation

Anne Degroot, Silvio Montresor, Bruno Gazengel, Olivier Richoux and Laurent Simon

Laboratoire d'Acoustique de l'Université du Maine - UMR CNRS 6613,
Av. O. Messiaen, 72085 Le Mans cedex 9, France

Keywords: LDV processing, burst detection, acoustic velocity.

This paper presents the principle of acoustic velocity measurement in weak flow with Laser Doppler Velocimetry (LDV). It proposes and evaluates a processing technique which enables to detect and localize in time domain the presence of Doppler bursts in case of acoustic excitation. The performances of the detector are characterized with ROC (Receiver Operating Characteristic) curves. Finally, the estimator performances are studied by means of Monte Carlo trials obtained from synthesized LDV signals.

1. Context

In this work, LDV is used for characterising acoustic velocities in weak flow (some mm/s) corresponding to the common laboratory conditions. Measurement have to be performed with mean acoustic levels (between 60 and 120 dB) corresponding to low velocity amplitudes (between 0.05 mm/s and 50 mm/s) and frequencies ranging from 50 Hz to 4000 Hz.

The estimation of acoustic and flow velocity parameters using many bursts needs to establish if a particle crosses the probe volume (detection / decision problem) on the one hand and to estimate the central time and the time of flight of each particle on the other hand (estimation problem). The aim of this work is to develop and validate a technique for detecting burst and for estimating the central time and the time of flight of each particle.

2. Doppler signal processing for acoustics

For a forced sinusoïdal acoustic excitation at frequency F_{ac}, the acoustic velocity of a particle q is

$$v_q(t) = V_{f,q} + V_{ac}\cos(2\pi F_{ac} t + \phi_{ac}),\quad ,$$

where $V_{f,q}$ is the flow velocity assumed to be constant over the burst duration., V_{ac} and ϕ_{ac} are respectively the amplitude and phase of the acoustic velocity. The Doppler signal is modulated in frequency and amplitude at the acoustic frequency.

The use of a frequency demodulation enables to estimate the instantaneous frequency $\widehat{IF}$ which is proportionnal to the Doppler signal phase and to deduce the acoustic velocity amplitude and phase from a parametric approach (Fourier series or least mean square method) applied to $\widehat{IF}$ from the beginning to the end of each burst q defined with the help of the central time $t_{c,q}$ and time of flight $T_{f,q}$.

3. Burst detection-estimation

The principle of the detection-estimation process consists in four steps. First step is the signal transform which leads to a representation in the time-scale domain, called scalogramm. The scalogramm is obtained thanks to a Wavelet Transform using the Morlet Wavelet. Second step is the detection process. The analysis of the scalogramm uses a threshold and enables to detect the events (burst) contained in the signal. Third step is the estimation process. For each detected burst, the central time $t_{c,q}$ and the time of flight of the burst $T_{f,q}$ are respectively estimated using an analysis over the time axis and over the scale axis. Finally, a validation procedure is used in order to apply the parametric estimation in good conditions (high SNR and low flow velocity).

4. Performances of the detection-estimation

Detector validation and estimations are realized on simulated data for 1000 Monte Carlo simulations (one event for one simulation) at various SNR. Each event contains at least one burst or no burst.

Results are obtained with a set of parameters corresponding to low acoustic displacement amplitude and high convection flow which corresponds to difficult conditions for the instantaneous frequency estimator. These conditions are defined by F_{ac}=4000 Hz, Vac = 0.04 mm/s (acoustic level of 58 dBSPL in free field) and $V_{f,q}$ =200 mm/s.

ROC curves obtained for for different SNR (0 dB, 3 dB, 5 dB, 10 dB) enable to choose an optimal value of the threshold.

The performances of the central time and time of flight estimation are established by comparing numerical simulations results with the calculated Cramer Rao Bounds (CRB). Results show that bias and variance are minimum when applying an optimal value of the threshold used in the detection. The experimental variance does not fit the CRB but results remain still acceptable (standard deviation on $T_{f,q}$ of 5 % for SNR = 0 dB).