Wave-shaping models of cyclic signals

Jean Schoentgen
Department "Signals and Waves", Faculty of Applied Sciences, Université Libre de Bruxelles, Brussels, Belgium, jschoent@ulb.ac.be

The presentation is devoted to the modelling of the glottal waveform, which is the acoustic signal that is generated by the vibrating vocal folds and pulsatile airflow. The formalism that is discussed is, however, generic and applicable to any band-limited cyclic signal the Fourier series of which exists.

A wave-shaping model is a non-linear memory-less representation of a cycle of a signal. Usually, the shaper is a pair of polynomials that transform a harmonic driving function into any desired cycle shape. The representation is exact when the desired waveform is band-limited and its Fourier coefficients are known.

Most often, the glottal airflow rate and its derivative are modelled by means of concatenated curves that mimic observed glottal cycle shapes. Although these models are very popular, their use may be problematic, especially when the model's parameters are manipulated so as to change cycle amplitudes, lengths or shapes rapidly in time. The reason is that the spectral bandwidths of arbitrary curve-based signal models are unknown a priori and the bandwidth may evolve in a non-obvious manner with the model parameters. This may be a problem in the framework of numerical syntheses of signals, when the bandwidth must be controlled to avoid spectral aliasing.

A possible solution consists in using curve-based models as templates of cycle shapes and approximating these by means of their Fourier series. The Fourier approximation enables controlling the bandwidth of the represented signals as long as these are periodic or pseudo-periodic. If, however, the fundamental frequency or amplitudes of the harmonics are strongly modulated to mimic signals the cycle lengths or shapes of which change rapidly, the modulation may broaden the bandwidth considerably in uncontrollable ways.

A formalism that enables an easier control of the bandwidth than the Fourier series is the wave-shaping representation. Its practical advantage stems from the predictable link between the bandwidth of the quasi-sinusoidal driving function and the total bandwidth. Checking the overall bandwidth of the output signal therefore amounts to restricting the bandwidth of a modulated sine, which is easier than controlling the full bandwidth of a time-evolving pulsatile signal.

In addition, wave shaping enables independently controlling the glottal cycle length, the spectral brilliance of the signal as well as the auditorily perceived speaker identity. This may be an advantage because letting evolve the parameters of curve-based models may re-touch all cycle properties at once.

The generic, mathematically based part of the presentation comprises the following items. First, a proof of the equivalence of the Fourier and wave shaper representations of harmonic signals; second, a formulation of the mathematical link between the bandwidth of the output signal and the bandwidth of the quasi-sinusoidal driving function; third, the generation of the derivative or integral of the represented signals by means of the shaper formalism of the original signal.

The relevance of the latter is that the glottal excitation signal is frequently modelled as the derivative with regard to time of the glottal airflow rate. The extension of the wave shaper formulation so as to automatically generate derivatives or integrals therefore enables simulating the glottal excitation and glottal airflow rate by means of the same core model.

The wave shaping-based model of the speech signal is illustrated in the framework of the simulation of disordered voices, which involves the rapid cycle-to-cycle evolution of properties such as the cycle length, amplitude and shape.