Synthesis of Trumpet Tones Using a Fixed Wavetable and a Centroid-Controlled Second Order Filter

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Abstract

The spectral response of an acoustic musical instrument varies dramatically depending on the performed pitch and dynamic of the instrument. This paper presents a method for automatically determining parameters for synthesis of a trumpet across its full pitch and dynamic ranges. The synthesis technique uses a pitch-dependent wavetable followed by a spectral-centroid-controlled time-variant second-order filter. The method assumes that the spectral response of the instrument changes as a function of its centroid, implying that if two different spectra produced by an instrument have similar centroid values, they also have similar shapes. Instruments with well-defined format characteristics such as the trumpet often exhibit this property.

1. The Analysis/Synthesis Procedures

The overview of our model is shown in Figure 1. As the first step, we compute a set of 10 spectral envelopes based on a training set of trumpet tones performed at various pitches and dynamics. Each spectral envelope corresponds to one of 10 centroid levels (see Figure 2) and is calculated by averaging the partials of centroid-assigned spectra in critical band-frequency bins.

![Figure 1. Overview of trumpet analysis/synthesis method.](image)

![Figure 2. Computed spectral envelopes for trumpet.](image)

After finding the underlying spectral envelopes for the training set, a source-filter model is matched to the spectral envelopes. The source signal is generated by a fixed wavetable constructed from the highest centroid spectral...
envelope. The tone we wish to model (not necessarily one from the original training set) determines the fundamental frequency, and we sample the highest centroid spectral envelope at the harmonic frequencies to define the wavetable.

Next, 10 fixed second order filters are matched to the 10 spectral envelopes and their respective centroid levels. The filter needed for the highest centroid spectral envelope is therefore flat, and the other filters approximate the corresponding spectral envelopes divided by the waveform spectrum. Enumerative search determines the analog filter coefficients that provide the best perceptual fit to the spectral envelopes when driven by the source wavetable at a low frequency. The standard bilinear transform then translates the analog filter (s-plane) parameters into digital filter (z-plane) coefficients.

Resynthesis uses the time-variant fundamental frequency, rms amplitude, and spectral centroid of the particular tone we are matching. Thus, once the source wavetable and the low-pass filter are determined, these three time-variant functions control the synthetic sound. The training set or other tones are resynthesized using the pitch-determined wavetable and direct interpolation between the centroid-indexed digital filter coefficients.

2. Results

We have tested the model on a set of trumpet tones representing the full pitch and dynamic ranges of the instrument with good results. Figure 3 shows the spectrum of a trumpet tone and its resynthesis. Low register resynthesized tones often sound "stronger" than the corresponding original tones because they don't have the spectral irregularities of the originals. On the other hand, the micro-details in the time-variant frequency, rms amplitude, and centroid envelopes provide cues that the synthetic sounds are "live", even if all details of the time-varying spectrum are not matched.

![Figure 3. Original (left) and resynthesized (right) time-varying trumpet spectra.](image)

3. Conclusion

Spectral envelopes provide a good representation of the dynamics of the trumpet. A model consisting of a centroid-controlled second order filter and fixed waveform source provides an efficient means of implementing this representation. The model produces high-quality synthetic trumpet tones while only using three time-varying control functions: spectral centroid, RMS amplitude, and fundamental frequency. Therefore, the model provides an excellent platform for computer music applications such as synthesis-by-rule and timbral interpolation. We expect that this model will capture the dynamic spectra of other acoustic instruments as well, especially the wind instruments.

References


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