Lecture 17: Transformation of formants for voice conversion using artificial neural networks

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ECE 537, Fall 2022
1 Voice Conversion

2 Formant Synthesis: Spectral Envelope

3 Formant Synthesis: the Voice Source

4 Formant Analysis

5 Summary
Outline

1. Voice Conversion
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3. Formant Synthesis: the Voice Source
4. Formant Analysis
5. Summary
Voice conversion generates a target speech that has the same text content as the source speech, but sounds as though produced by a particular target speaker.
Usually, voice conversion is performed separately for **excitation parameters** and **spectral envelope parameters**.

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<th>Method</th>
<th>Excitation Parameters</th>
<th>Envelope Parameters</th>
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<td>Formant Synthesis</td>
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<td>$F_1, F_2, F_3, F_4$, $B_1, B_2, B_3, B_4$</td>
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<td>LPC</td>
<td>$e[n], F_0, \vec{\beta}, \text{Gain}$</td>
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Formant Synthesis: Overview

Klatt, 1980. (c) Acoustical Society of America
Formant synthesis computes speech by filtering an excitation, $e[n]$, through a transfer function, $h[n]$:

$$s[n] = h[n] \ast e[n]$$

The **transfer function**, $h[n]$, may include:

- Regular formants (**cascade synthesis**): appropriate for vowels, glides, and nasal consonants
  - + **Nasal Pole, Nasal Zero**: appropriate for nasal consonants
- Selected formants (**parallel synthesis**): appropriate for fricatives and plosives
The Formant Resonator

A formant resonator is:

\[ R_k(z) = \frac{a_k}{1 - b_k z^{-1} - c_k z^{-2}} , \]

which is implemented as:

\[ y[n] = a_k x[n] + b_k y[n - 1] + c_k y[n - 2] \]
The filter parameters are related to the formant frequency, $F_k$, formant bandwidth, $B_k$, and sampling frequency $1/T$ by

\[
c_k = -e^{-2\pi B_k T} \\
b_k = 2e^{-\pi B_k T} \cos(2\pi F_k T) \\
a_k = 1 - b_k - c_k
\]
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Klatt, 1980. (c) Acoustical Society of America
Formant Synthesis: Excitation

\[ s[n] = h[n] * e[n] \]

The excitation signal, \( e[n] \), may include:

- **Regular voicing**: a parametric model of the air pressure immediately above the glottis (proportional to \( u'_g(t) \), the derivative of the volume velocity through the glottis)

- **Sinusoidal/breathy voicing**: a parametric model of \( u'_g(t) \) when the glottis doesn’t close completely

- **Aspiration**: turbulent noise at the glottis, filtered by the whole vocal tract.

- **Frication**: turbulent noise at a supraglottal constriction, filtered by only part of the vocal tract
Regular Voicing: The LF Model

The LF (Liljencrants-Fant) model is a parametric model of $e(t) = u'_g(t)$, the derivative of volume velocity through the glottis. From time 0 to time $t_e$, $u'_g(t)$ is an unstable oscillation. At time $t_e$, the vocal folds start to collide, and start to slow down.

$$u'_g(t) = \begin{cases} E_0 e^{\alpha t} \cos(\omega_g t) & t < t_e \\ \frac{E_0}{\epsilon t_a} (1 - e^{\epsilon (t_c - t)}) & t > t_e \end{cases}$$

(c) Fant, Liljencrants & Lin, 1985.

http://www.speech.kth.se/qpsr
Shape of the LF model is determined by $T_0$ (the pitch period) plus four other parameters:
- $E_e$, amplitude of excitation
- $t_e$, time of the excitation
- time from upward-going zero-crossing, $t_c$, to downward-going zero-crossing, $t_p$
- slope of the return part, $\frac{E_e}{t_a}$

(c) http://www.speech.kth.se/gpsr
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How do we find formant frequencies and bandwidths?

Basically, the formant frequencies and bandwidths are the roots of the LPC polynomial:

\[ H(z) = \frac{G}{1 - \sum_{k=1}^{p} a_k z^{-k}} = \frac{G}{\prod_{i=1}^{p} (1 - p_k z^{-1})} \]

\[ F_k = \frac{1}{2\pi T} \angle p_k \]
\[ B_k = -\frac{1}{\pi T} \ln |p_k| \]
Utterance: “Why were you away a year ago?” Notice that formant tracking fails during the /g/.

A few complications (but not many)

- Formant tracks are unreliable during consonants, creaky voice, & breathy voice.
- Use dynamic programming to find the most likely formant tracks during consonants, creaky voice, & breathy voice.
Formant frequencies determine the vowel. Inside each ellipse, people with longer jaws (e.g., men) typically have lower formants, and vice versa.

Peterson and Barney, 1952.

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Voice conversion usually separates excitation and envelope.
- Envelope can be modeled using a formant synthesizer.
- Excitation can be modeled using the LF model.
- Formant analysis finds the roots of LPC.