On the Art of Speech (and) Modelling

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Vocal Tract
Anatomy
Vocal Tract

As a Filter

Vocal tract, [u]
Vocal Tract
As a Filter

Speech recording, vowel [u]

Glottal flow, simulated

Vocal tract, [u]
Introduction

Vowels

Finnish vowels
Magnetic Resonance Imaging

Data Acquisition

MRI machine

- Non-intrusive, safe 3D imaging.
- VT geometry automatically extracted from the sequence.

Head coil

Sagittal plane
Sound in MRI

Collecting speech and noise

Faraday cage
Sound in MRI(2)

Setup demonstration

Waveguides, speech and noise channels
Blue: MRI recordings, green: frequency sweep, red: anechoic recordings

- Peaks correspond to formants/resonances.
- Discrepancy between anechoic and MRI measurements.

Sweeping the frequency range
Webster’s Equation

- Used for speech synthesis research at the acoustics lab.
- Parametrise the centreline by $s \in [0, 1]$

$$
\frac{1}{c^2 \Sigma(s)^2} \frac{\partial^2 \phi}{\partial t^2} - \frac{1}{A(s)} \frac{\partial}{\partial s} \left( A(s) \frac{\partial \phi}{\partial s} \right) = 0,
$$

$\phi = $ Velocity potential,

$A(s) = $ Area of slice at $s$,

Rest = Don’t worry about it.
Resonances

• The resonant frequencies are related to the eigenvalue problem:
  Find \((\lambda, u) \in \mathbb{C} \times V\) such that
  \[c^2 \Delta u = \lambda^2 u,\]
  where \(V\) is the solution space (depends on the b.c’s).

• Model the head coil to account for mixed modes.

Pressure distribution for the vowel [ae]. Mixed resonance structure.
Geometries

- VT geometry and exterior acoustic space connected via a fixed interface (non-matching grids possible).
- Effect of exterior space can be pre-computed to some extent.
Interface

- The interface is automatically stitched to the VT geometry.
- Project the edge polygons (red) into two dimensions and triangulate.
- Solve a 2D Poisson’s equation to obtain smooth depth interpolation.
- Use Nitsche’s method to connect the exterior acoustic space.
4th mode for [a].
Some modes for [a], [i], [u]
Teeth Alignment

Markers visible in MRI data

Dental mould with markers, CT scanned
Sculptris + Blender
Exhibition

12 3D-printed models, different modifications
Exhibition (2)
Exhibition (3)

Modifications: normal, long, short, wide
Video installation
More Resonances

Testing the effects of VT length
The Future
...and Beyond

• More exhibitions, math and acoustics,
• Bigger papers and results,
• Better endings for presentations.
Thank you

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