THE SPEECH MOTOR CONTROL PROBLEM

Given a set of controllable parameters, determine corresponding set of control values that effects an observed sequence of coordinated articulatory movement.

IDEA: USE A SMALL NUMBER OF CONTROL SEQUENCES TO PRODUCE ALL MOVEMENTS!

Gestural hypothesis:
Act of speaking can be decomposed into atomic units of action, or gestures – dynamically-controlled constriction actions of distinct vocal tract organs. (e.g., lips, tongue tip, tongue body, velum, glottis).


SCHEMATIC IDEA OF THE PAPER

The Speech Motor Control Problem

Dataset

• Synthetic data generated using TaDA (Task Dynamics Application) and a Configurable Articulatory Synthesizer (CASy)
• 972 synthesized Vowel – Consonant – Vowel (VCV) sequences consisting of all permutations of 12 consonants and 9 vowels in English.
• Allows us to get a basic sampling of the whole range of vocal movements.

Step 1: Estimate Dynamics & Controls

Step 1a: Initialize Dynamical System Model

\[ \dot{x}(t) = f(x(t), u(t)) \]

where \( x \) is the state of the system and \( u \) is the input control signal.

Learn \( f \) using a nonlinear regression learning technique

\[ \dot{x}(t) = f(x(t), u(t)). \]

Use a simple 2nd order equation for the NLD system to “initialize” the functional map estimate \( f \).

\[ \hat{\phi} + M^{-1}B\hat{\phi} + M^{-1}K\tau = \tau \]

Estimation and Modeling (2013)

Step 1b: Learn (Nonlinear) Functional Map

Functional mapping can be estimated to a high degree of accuracy in data-driven fashion using Locally-Weighted Linear Regression (LWR) [3]

\[ x_i = \beta_i q_i \]

\[ \beta_i = (q_i^T W Q + \gamma_i^2 I)^{-1} q_i^T W X \]

Uses locally-defined, lower-order polynomials to approximate a global function

Closed-form solution with minimal parameter tuning

Step 1c: Find Controls that Produced Observed Movements

Goal: To find the optimal control signals \( u(t) \) that minimize cost \( J \)

\[ J(u(t)) = \sum f_i(x_i(t)) + \int_0^T l(x(t), u(t)) dt. \]

Usual control theory (1994), Neural Integration

Problem: Computationally intractable for nonlinear systems

One idea: Use approx. methods, find locally optimal solns:

Iterative Linear Quadratic Gaussian (ILQG) procedure

Lian Tenobor (2003), Iterative ILQG/ILQG methods

Step 2: Compute Control Primitives

Vectors of estimated control signals at t = 2

Formulation of this approach as a small number of control parameters

We get an average error of ~29% in recovering the control signals (a) and ~16% in recovering the original movement trajectories (b).

References