Title	A Study On Construction And Control Of A Three-Dimensional Physiological Articulatory Model For Speech Production
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Citation	
Issue Date	2009-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/7996
Rights	
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Abstract

In the literature, a number of speech scientists tried to reveal the mechanism of speech production based on observed acoustic signals and/or articulatory movements, and proposed a number of theories on the mechanism of speech production. However, most of the speech production theories ignore the motor commands that drive articulators to produce articulatory movements and speech and the activities of the central neural system that generate the motor commands in light of the linguistic representation. This causes a gap between the linguistic representation and physical realization of speech in those theories. If we can uncover motor commands and activities of central neural systems in speech production, we may bridge the gap between the linguistic representation and physical realization. Here, we follow a bottom-up framework to uncover the motor commands and activities of central neural system in speech production. First of all, we need to uncover the motor commands from observed articulation; then, we need to uncover the activities of central neural system in speech production based on the uncovered motor commands and the linguistic representation of speech. In this thesis, we focus on recovering the motor commands involved in speech production, especially in vowel production. Because observed articulations are generated by manipulating speech organs with motor commands, it is almost impossible to know the underlying motor commands if there is no good understanding of the biomechanical properties of speech organs. In this thesis, we uncover the motor commands of vowel production based on a 3D physiological articulatory model that inherently models the biomechanical properties of speech organs.

For this purpose, firstly, we constructed 3D jaw and vocal tract wall and combined them with a 3D tongue model to form a three-dimensional (3D) physiological articulatory model, which replicates morphological structure, musculature of the supra-glottal system. To make the proposed model more realistic, the orientation of muscles SG and IL in the 3D tongue are refined according to their anatomical descriptions. In addition, a module named contact handling is incorporated into the physiological articulatory model to deal with the contact between tongue and jaw, and tongue and vocal tract wall. Preliminary evaluation showed that the model behaves properly when the associated muscles are activated. Since the tongue and jaw in the model are driven by associated muscles, it is necessary to understand the detail function of tongue muscles. Here we quantitative analyze the function of tongue muscles by using the proposed 3D physiological articulatory model to shed light on the general function of individual tongue muscles and the agonist-antagonist properties of tongue muscle pair. The results show that (1) the function of muscle GGa, GGm, GGp, SG, and MH for the movement of both tongue tip and dorsum are consistent with the speculation based on the anatomical orientations; (2) the muscles (T, V, and SL) located in the superficial layer of the tongue contribute most to deformation of the tongue surface; (3) muscle pairs GGm-SL, GGm-HG, GGA-HG act as antagonist muscle pairs for tongue tip, while as agonist of tongue dorsum; (4) muscle pairs GGp-HG, GGp-SL, GGm-SG act as the antagonist muscle pairs for tongue dorsum while act as agonist pairs for tongue tip. For the purpose of uncovering the motor commands in vowel production by using the proposed model, it is necessary to evaluate the ability of the model in realizing specific articulation of vowel production and corresponding muscle activations. This is done by driving the articulatory model to approximate the observed vowel articulation via an optimization procedure which aims to minimize the 3D difference between simulation results and observations. It shows that the model can generate the specific articulations of observed vowel production, and the estimated muscle activations are consistent with those observed from EMG experiments. After constructing and evaluating the model, we elaborated a feed forward control strategy, which maps articulatory posture to muscle activations via intrinsic representation of articulatory posture by using General Regression Neural Network, to efficiently uncover the motor commands in isolated vowel production. The results show that this method can control the proposed 3D physiological articulatory model with high accuracy.

After constructing the 3D physiological articulatory model, the biomechanical properties of tongue and jaw and the interaction between the tongue and surround structure in speech production are properly modeled. In addition, it is easily to uncover the underlying motor commands from observed vowel articulation by using the elaborated feed forward control strategy for the proposed 3D physiological articulatory model for vowel production.