FINITE ELEMENT MODELING OF THE TONGUE

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1. INTRODUCTION

There is an increased need to study the human oropharyngeal anatomy for research in speech production, feeding motion, and breathing activities. Computational anatomic models are also useful to conduct virtual experiments without extensive use of human subjects, to plan and train surgeries. Recent improved methods for fast and high resolution imaging of internal organs, such as, Magnetic Resonance Imaging (MRI), three-dimensional Ultrasound, and Computer Tomography (CT) combined with automatic image extraction techniques, dynamic modeling techniques, and increased computation capacity, enhance possibilities to create realistic computational models.

One central organ of the vocal tract is the tongue, which has been modeled using statistical parametric models [2, 8], explicit shape descriptions [16, 12], physiological models [17], and dynamical models (both spring-mass [7], and finite element models [20, 15, 10]). A recent survey [11] describes existing methods in detail. For many surgical simulation applications, tongue models need to support the following:

- Two and three-dimensional coherent models;
- Separate tissue and muscle behavior;
- Dynamic interaction with other anatomical parts like jaw, palate;
- Large deformations;
- Non-linear tissue properties;
- Real-time simulation;
- Registration to different individuals.

For these requirements, finite elements provides a good solution and has a long tradition in Engineering [3, 21]. So far, only non real-time solutions have been developed for tongue models [20, 15, 6, 10]. Recent developments in the fields of physical-based animation [13, 18, 14, 19] and surgical simulations [4, 5] provide finite element algorithms which can run in real-time to provide plausible results even for large deformations. Compared to spring-mass models, they have better stability and accuracy.

In this work, we will create a real-time two and three dimensional finite element model of tongue tissues and demonstrate a complete work flow from image data extraction to model configuration to model validation in the framework of ArtiSynth [1].

2. FINITE ELEMENT MODELING OF TISSUE

We are working on the implementation of the finite element modeling method developed by Müller et al. [14] in both two and three dimensions, which provides a real-time and unconditional stable solution for a wide range of tissue models. The method offers real-time capabilities with less precision. In computer animation, linear elasticity models are popular for real-time simulations, but the drawback is that these models are not precise for large rotational deformations. Müller et al.'s algorithm is based on linear displacements tetrahedra (3D) or triangles (2D) to solve the underlying partial differential equations. To evaluate the stiffness matrix, they use a pseudo-linear model with a warped stiffness, in which the model elements are rotated back in their undeformed reference frame. This method separates the deformation in a rotational part and a linear part. The performance of the algorithm is similar to linear elasticity models with a smaller loss of precision.

3. DATA EXTRACTION

The tongue shapes are extracted from magnetic resonance image volumes in two sagittal planes using a semi-automatic live-wire algorithm [9]. Live-wire extraction requires manual selection of 3 to 5 seed points on the desired boundary from which the algorithm completes the contour based on an energy gradient model.

4. MODEL ACTIVATION

The integration of the model intro ArtiSynth enables to communicated by forces of muscles and the rigid jaw at the mesh node vertices. The intrinsic and extrinsic muscle configurations and tissue material properties of the tongue are inspired by Dang et al. [7]. In contrast to their work which is based on spring-mass models, our finite element model will be more stable over a large range of deformations.

5. VALIDATION

Using muscle activation of the stand-alone tongue model, we will explore motion range of synthesized tongue surfaces. We can validate the model to see how close it can fit MRI images sequences of articulation postures. The integration into ArtiSynth allows both the connection to the rigid jaw and to the air-tract, and augments the animation of a complete vocal tract model. The animated shapes will be able to produce sounds within ArtiSynth for acoustic validation.

6. SUMMARY

In this work we introduced a fast and stable finite element model and ways to derive the configuration of the tongue model. Using MRI images allows validation of the model in the geometric/image domain. By connecting the model to a complete vocal tract within ArtiSynth we can validate acoustically as well.

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