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3D Dynamic Visualization of Swallowing from Multi-Slice Computed Tomography

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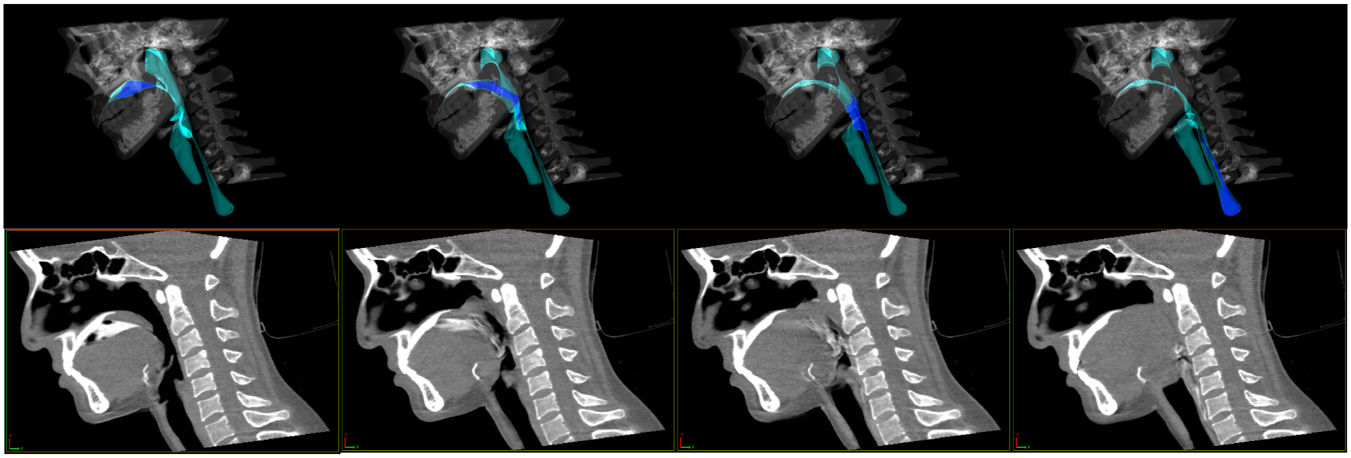

Figure 1: *The top row of images shows a sequence of the visualization at different times of the swallow. A left-side view is shown, with bones and airway slightly transparent. The boundary motion was derived from 3D + time images of a single subject swallow. The bottom row shows a sequence of mid-sagittal slices of the CT images at times corresponding to the visualization above it.*

1 Introduction

Human swallowing and its disorders (dysphagia) are still poorly understood, and yet many speech-language pathologists (SLPs) need to be trained to recognize correct, incorrect, and potentially dangerous swallows. The anatomy of the head and neck region is notoriously complex and difficult to visualize and study. Currently, training programs that teach SLPs to recognize swallowing disorders use artistically derived animations of swallowing, rendered at fixed viewpoints, to help students visualize the anatomy of the head and neck region.

This work improves on these animations by using state-of-the-art medical images to create a dynamic, interactive, 3D simulation of human swallowing. Images of a male subject during swallow were captured in a single shot using a 320-slice CT scanner [Inamoto et al. 2011]. The images have very high spatial resolution ($0.5 \times 0.5 \times 0.5$ mm^3), but low temporal resolution (10 Hz). The low temporal resolution resulted in blurring of the fluid being swallowed, making automatic segmentation and visualizations of the fluid difficult to generate.

2 Approach

A moving airway boundary was segmented from the medical images, and this in turn was used as the input to a Smoothed Particle Hydrodynamics simulation (SPH). The low temporal resolution of the images meant that interpolation between time frames was required.

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In order to generate the moving airway, an initial surface mesh representation was created from the first 3D volume of the sequence using the commercial software package *Amira*. This initial mesh was deformably registered to subsequent volumes in the time sequence using *Blender* modelling software. By using the "Sculpting" features of *Blender*, the mesh topology remains constant between time frames. This allows us to interpolate the airway positions in between time frames by simply performing interpolation over the vertex positions in time. In this work, cubic interpolation was used.

The liquid being swallowed was simulated using SPH. A standard, viscous, weakly-compressible SPH formulation was used. There is good agreement between the predicted fluid position and the positions shown in the images.

3 Conclusions and Future Work

Using the ArtiSynth simulation platform, one is now able to visualize the swallowing in any 3D orientation, make use of transparencies, scrub back and forth through time, and arbitrarily slice the geometry in order to isolate a particular view of the airway.

This work can be extended in order to allow SLPs-in-training to modify the airway boundary timings and to visualize the results. Provided the simulations are adequately valid, this will provide an excellent platform for asking "what-if" types of questions, and give a much deeper understanding of the importance of swallowing timings.

References

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