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Virtual Speech

Researchers use virtual tools to model and simulate the human vocal tract and upper airway.

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Computer-generated models consistently help research groups to understand, diagnose and treat disorders of human oral and airway anatomy — such as swallowing disorders due to stroke, chewing disorders after cancer surgery, obstructive sleep apnea (OSA), and various speech pathologies.

The dynamic models of these anatomical components for biomedical applications are valuable research tools, but they are often difficult to construct. They require unusually high fidelity and stable simulations of complex, hybrid models. The complex physics includes coupled rigid bodies, finite element method (FEM) and fluid simulations, all in a fast, interactive simulation environment. In addition, the models must be made available in modules that allow groups of researchers to collaborate on complex projects.

France's Grenoble Images Parole Signal Automatique lab (GIPSA-lab) and Techniques de l'Ingénierie Médicale et de la Complexité (TIMC-IMAG) laboratory have used ANSYS simulation software successfully for almost 10 years to study speech production mechanisms and computer-aided surgery. These labs jointly developed finite element models of the human tongue, jaw and face. Their models are used to study speech gesture controls and the consequences of maxillofacial surgeries on facial mimics and speech production. More recently, the University of British Columbia (UBC) in Canada extended and implemented the models into its own biomechanical simulation tool, ArtiSynth, which was developed at UBC's Human Communication Technologies (HCT) lab for human anatomy studies.

UBC has been using a combination of ANSYS Academic Research simulation software and ArtiSynth to push the limits of knowledge about human oral and airway anatomy dynamics (the oral, pharyngeal and laryngeal [OPAL] complex) in biomedical and speech applications. One project models the OPAL complex for speech and computer-aided surgery and can provide a "gold-standard" result to compare with ArtiSynth, the human biomechanics simulation engine; a second simulates airflow through the OPAL cavity — specifically, aero-acoustic simulation of burst ("pa") and fricative ("sh") sounds.

Structural Dynamics

To accomplish the objective, the GIPSA and TIMC-IMAG labs generated a 3-D biomechanical model of the tongue and oral cavity controlled by a functional model generating muscle forces coupled with an acoustic model. For example, the diagram in Figure 1 shows how the tongue muscles work when uttering French vowels. Researchers modeled the tongue using ANSYS SOLID185 hexahedral elements with the hyperelastic properties of the five-parameter Mooney–Rivlin model. The muscles, represented by specific subsets of elements, generate forces to deform and move the tongue and mandible.
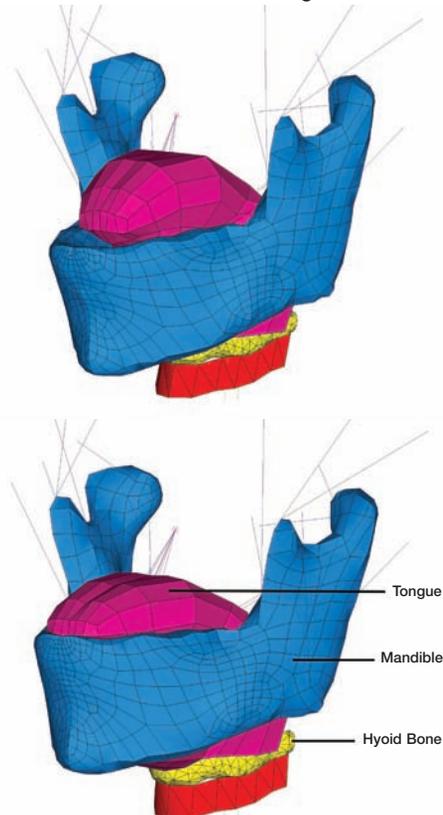

Figure 1. Combined functional model and acoustical model control a 3-D biomechanical model of tongue and oral cavity (top); element subsets generate forces to move the tongue and mandible (bottom).
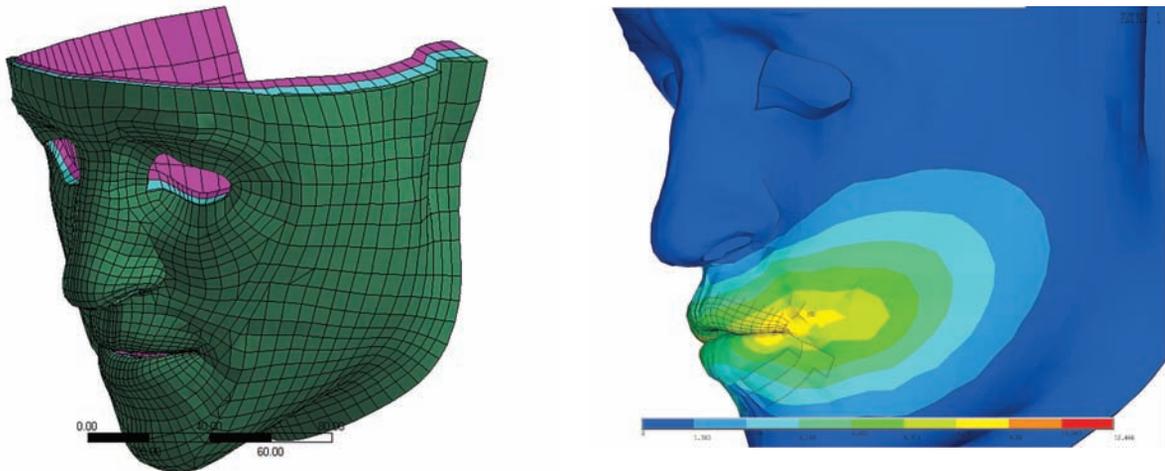
Figure 2. Manually designed 3-D finite element mesh consists of three layers of full and degenerated ANSYS SOLID185 hexahedral elements (left); round-shaped lips with a protrusion make the sound "ou" (right).

The GIPSA and TIMC-IMAG labs developed a 3-D biomechanical model of the human face and focused on lip deformations, since this articulator has a major influence on the acoustic signal generated by airflow coming from the lungs. Using computed tomography (CT) data, the team manually constructed a 3-D finite element mesh, consisting of three layers of full and degenerated ANSYS SOLID185 hexahedral elements. A hyperelastic Mooney–Rivlin constitutive law accounts for the nonlinear behavior of facial tissue, and muscles fibers are represented by piece-wise uniaxial tensile elements.

The project simulated a large number of facial movements and facial mimics that develop during speech, such as lips that form a round shape with a protrusion, which is required to make the sound "ou" (Figure 2).

The GIPSA and TIMC-IMAG labs coordinated their efforts with the modeling work performed at UBC's HCT lab. The lab combined the face, jaw, hyoid and tongue into a rigid-body/FEM framework that provided features for these structures. The features included collision detection and handling, a tightly coupled FEM/rigid body solver, various FEM types, muscle models, rich graphical user interfaces and interactive simulation rates for testing what-if scenarios.

Team members worked closely with the results from ANSYS software and were able to confirm that the interactive simulations using ArtiSynth are consistent with the gold standard that ANSYS simulation software provides. Effectively, stress and strain computed by ArtiSynth compared favorably with those from the gold standard provided by ANSYS. The lab now has a tool that can be trusted for clinical researchers to investigate the dynamics of the OPAL complex — including chewing, swallowing and speech production.

Fluid Dynamics

UBC scientists also studied the fluid dynamics of the airflow, which is crucial for speech and plays a role in OSA. In studying speech production, the objective is to understand the complex motor actions that produce speech. Speech movements and acoustic signals are influenced by communicative linguistic goals, perceptual constraints and physical properties of the speech-producing apparatus. To learn how these different factors combine and interact with each other, researchers need an efficient approach that generates realistic physical models of the speech-producing system. In preliminary research, UBC used ANSYS FLUENT software to simulate the air flow of two speech utterances.

The first utterance was a fricative consonant, a sound that is produced by turbulence typically due to a channeled flow of air striking the teeth ("sh" in show). A compressible flow was simulated so the acoustic (pressure) waves could be directly measured, and large eddy simulation (LES) was used to model the turbulence. A buffer zone around the outlet prevented the waves from reflecting back into the domain. Although the spectra calculated from the simulation results did not agree with experiments on a number of spectral features, they are promising because the amplitudes and trends of the spectra do agree. For example, observe the acoustic waves escaping from the airway's mid-sagittal section (Figure 4). The most useful measurement was a direct resolution of the acoustic waves by measuring pressure.
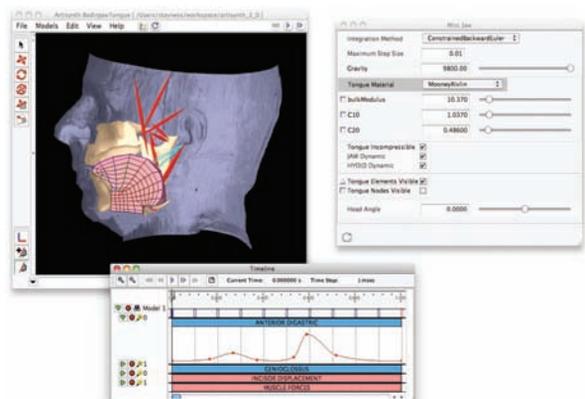

Figure 3. Models of the face, jaw, hyoid and tongue are combined in anatomical modeling framework.
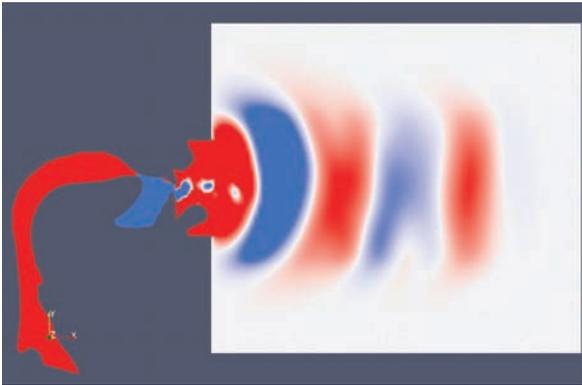
Figure 4. Acoustic waves escape from the mid-sagittal section of airway.
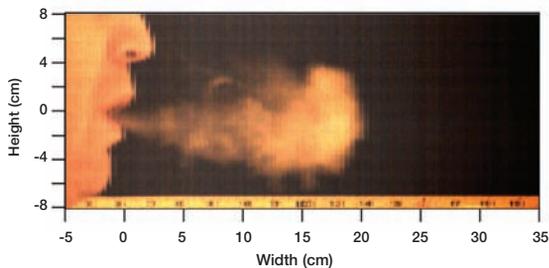

Figure 5. Simulations show good correlation with microphone experiments and high-speed videos from actual speech.

Researchers also simulated a bilabial plosive ("pa" in paper), which develops when the lips rapidly open to release a pressure pulse from the mouth. The ensuing burst of turbulent air is of interest because it produces a negative microphone pop, and it has a positive influence on speech perception. The team modeled the mouth as a wide oval, using LES to simulate the utterance as a burst of pressure from the mouth.

The simulations agreed well with experiments (Figure 5), demonstrating that a fluid–structure interaction simulation involving lip motion would be needed to capture further complexities of the air flow. Evidence of this close correlation is shown (Figure 6) between the
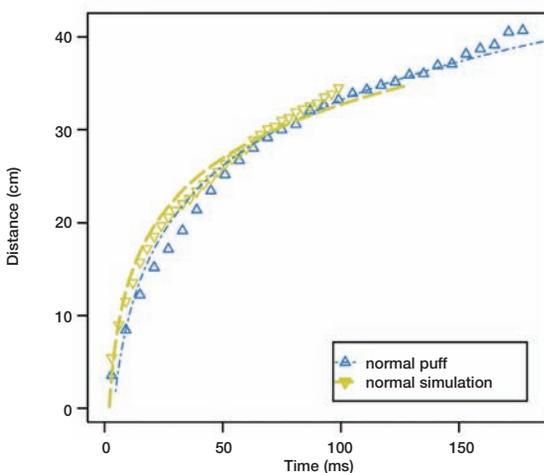
high-speed video and particle front simulation, and between microphone experiments and pressure front simulation (Figure 7).

ANSYS technologies have been a valuable tool in UBC's investigations of oral, pharyngeal and laryngeal anatomy. UBC continues to use these tools to better understand the regions of interest and to help create a tailored clinical research tool to let non-experts more easily access modeling results.

For more information
University of British Columbia: http://www.ece.ubc.ca/~hct/research
GISPA-lab: http://www.gipsa-lab.inpg.fr
TIMC-IMAG: http://www-timc.imag.fr
ArtiSynth: http://www.artisynth.org

References
Stavness, I.; Lloyd, J.; Payan, Y.; Fels, S. Coupled Hard–Soft Tissue Simulation with Contact and Constraints Applied to Jaw–Tongue–Hyoid Dynamics. *International Journal of Numerical Methods in Biomedical Engineering*, **2011**, vol. 27, pp. 367–390.

Derrick, D.; Anderson, P.; Gick, B.; Green, S. Characteristics of Air Puffs Produced in English "Pa:" Experiments and Simulations. *Journal of the Acoustical Society of America*, **2009**, vol. 125, pp. 2272–2281.

Buchaillard S.; Perrier P.; Payan Y. A Biomechanical Model of Cardinal Vowel Production: Muscle Activations and the Impact of Gravity on Tongue Positioning. *Journal of Acoustical Society of America*, **2009**, vol. 126(4), pp. 2033–2051.

Nazari, M.A.; Perrier, P.; Chabanas, M.; Payan, Y. Simulation of Dynamic Orofacial Movements Using a Constitutive Law Varying with Muscle Activation. *Computer Methods in Biomechanics and Biomedical Engineering*, **2010**, vol.13(4), pp. 469-482.

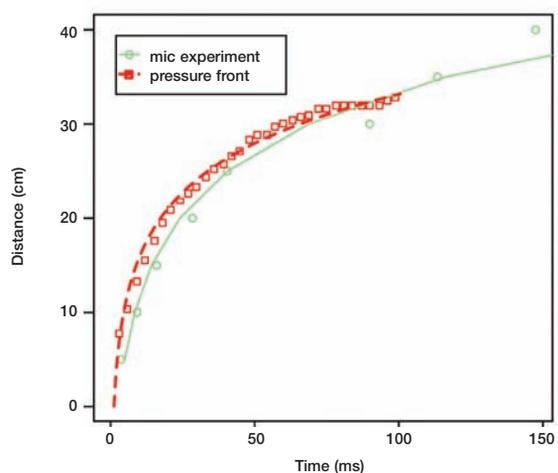Figure 6. Comparison between high-speed video and particle front simulation

Figure 7. Microphone experiments correlate well with pressure front simulations.