Biomechanical Simulation and Control of the Face, Neck and Body

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Overview

The Face
- Biomechanical facial modeling
  - Capturing facial models from data
- Efficient facial tissue simulation

The Neck
- Biomechanical modeling of the neck-head complex
- Neuromuscular control

The Body
- Modeling body musculature
- Biomechanical simulation of the upper body
Realistic Facial Modeling

Square Pictures USA (2001)
Facial Motion Capture

Virtual Celebrity Productions, LLC

Biomechanical Facial Modeling
Real-Time Biomechanical Facial Simulation

Functional Facial Models
Scanned Data ➔ Synthetic Faces

Cyberware Scanner

Range Image
Texture Image
Cyberware Data
Synthesized Expressions
Raw Input Dataset ("Heidi")

*From CyberWare 3D Color Digitizer*

Range Image  RGB Texture Image

Generic Facial Mesh
Fitting the Generic Mesh

Feature-based image matching algorithm

localizes facial features in:

Processed range image
RGB texture image

Sampling Facial Shape

Fitted mesh nodes sample range data
Textured 3D Geometric Model

**Texture map coordinates**
- Positions of fitted mesh nodes in RGB texture image

Auxiliary Geometric Models

Eyelid Texture Interpolation
Complete Geometric Model

Neutral expression is estimated

The face: a complex biomechanical structure

Facial Anatomy

The face: a complex biomechanical structure
Facial Histology

*A complex, multilayer structure*

Biomechanical Skin Model

*Deformable tissue element*
Biomechanical Skin Model

Viscoelastic uniaxial primitive

Element dynamics

\[ r_{ij} = x_j - x_i \]

\[ e_{ij} = \left\| r_{ij} \right\| - l_{ij} \]

\[ f_{ij}^v = (c_{ij} e_{ij} + \gamma_{ij} e_{ij}^2) \frac{r_{ij}}{\left\| r_{ij} \right\|} \]

Span

Deformation

Viscoelastic Force

Stress

Biphasic Elasticity

Strain
Empirical vs Idealized Stress-Strain Curve

Non-isotropic stress-strain characteristics

Langer's Lines
Biomechanical Skin Model

Element dynamics

**Span**

\[ r_{ij} = x_j - x_i \]

**Deformation**

\[ e_{ij} = \| r_{ij} \| - l_{ij} \]

**Viscoelastic Force**

\[ f^e_{ij} = \left(c_{ij} e_{ij} + \gamma_{ij} \dot{e}_{ij}\right) \frac{r_{ij}}{\| r_{ij} \|} \]

**Differential Equations of Motion**

\[ m_i \frac{d^2 x_i}{dt^2} + \sum_{j \in N_i} f^e_{ij} = f^m_i \]

Muscle Forces

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Volume Preservation Constraint

Non-Interpenetration Constraint
Biomechanical Skin Model

Deformable tissue element and patch

Explicit Euler Method

Efficient near-stability limit for moderately deformable biomechanical skin model

\[
\begin{align*}
\mathbf{a}_i^t &= \frac{1}{m_i} \left( \sum_{j \in N_i} \mathbf{f}_{ij}^e + \mathbf{f}_{ij}^m + \mathbf{f}_{ij}^v + \mathbf{f}_{ij}^c \right) \\
\dot{\mathbf{x}}_i^{t+dt} &= \dot{\mathbf{x}}_i^t + dt \quad \mathbf{a}_i^t \\
\mathbf{x}_i^{t+dt} &= \mathbf{x}_i^t + dt \quad \dot{\mathbf{x}}_i^{t+dt}
\end{align*}
\]
Facial Subdivision Surface

Subdivision Surface with Tissue Model
Retriangulation Around Incision

Facial Musculature
Muscles & Insertions

35 Muscles
- Levator Oculi
- Corrugators
- Naso-Labial
- Zygomatics
- Obicularis Oris

plus
- Articulate Jaw
- Eyes/Eyelids

Facial Muscle Model Structure
Expression Analysis and Resynthesis

Capture expression in video

Transfer it to a synthetic facial model

NN Estimation of Muscle Actions

Trained neural network muscle control

Image Feature Input  Trained Neural Network Transducer  Muscle Action Output
Expression Analysis and Resynthesis

Facial Image Reconstruction from 2D Frontal Image
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Hierarchical Facial Model Structure
From expression control to images

Expression
Control
Actuators
Biomechanics
Geometry -> Images
Functional Model of “George”

The Neck
Anatomical Structure of the Neck

- 7 cervical vertebrae and a skull coupled by 3-DOF joints
- Ligaments/disks → passive joint springs
- Equations of motion

\[
M(q)\ddot{q} + b(q, \dot{q}) = \theta(q) f_c(q, \dot{q}, a)
\]

Skeleton Model
Biomechanical Neck Model

Total of 72 anatomically-based Hill-type muscle actuators in 3 layers

48 *deep muscles*  
(16 longus colli, 16 erector, 16 rotator)  
6 *muscles in each joint increase controllability*

12 *intermediate muscles*  
(scalerius: 4 anterior, 4 posterior, 4 capitis)

12 *superficial muscles*  
(2 sternomastoid, 2 cleidooccipital, 8 trapezius)

Challenge is actuation and control

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Biomechanical Neck Modeling

skeleton
What Would Leonardo da Vinci Think of This?

Biomechanical Simulation of the Neck-Head-Face Complex

*Neuromusculoskeletal model*

- voluntary controller
- reflex controller
- muscles
- skeletal system
- environment

- feedfwd signal
- setpoint signal
- muscle feedback (pose, velocity of head)
- muscle feedback (strain/strain rate)
- muscle activation levels
- muscle contraction forces
- gravity, applied force
- head pose
- proprioceptive feedback

Trained Neural Networks
Tension Control

Tension Control
Neck-Head-Face-Eye Behavior

Autonomous Multi-Head Interaction
Artificial Life

Comprehensive computational model of humans

The ALife Modeling Pyramid

Cognition
Learning
Behavior
Perception
Biomechanics

George in “Bureaucrat Too”
Muscles in the Spine

Posterior Muscles in the Deep Layers

Modeling all the major muscles participating in spinal posture
Skinned Model

A preliminary simulation demo

• flexing_solid.avi
• flexing_transparent.avi
Acknowledgements

Collaborators:

• Sung-Hee Lee  UCLA (neck model)
• Eftychios Sifakis  UCLA (body tissue simulation)
• Yuencheng Lee UofT (face model)
• Keith Waters Orange Labs, Boston
• Shigeo Morishima Waseda University, Tokyo

Additional info:
deformable.com

Thank You!