Digital Human Modeling with Applications

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Digital Human Modeling (DHM)

• What is DHM? Using computer technology to develop digital models to describe humans

• Why is DHM needed?
  – The human body is a complicated system
  – Humans differ from each other with vast variations
  – Humans need to understand themselves
  – Humans are at the center of various activities

• Application areas
  – Aerospace
  – Defense
  – Automotive
  – Sports
  – Heavy Duty Trucking
  – Farm Equipment
  – Service
  – Manufacturing
  – Human Factors
  – Ergonomics
  – Medical
  – Fashion
DHM Scope and Category

- Ergonomics
- Anthropometrics
- Biomechanics
- Gait and motion analysis

- Physiology
- Pathology
- Behavior
- Performance

✓ Multi-dimensional modeling for apparel fit and equipment interaction
✓ Biomechanical modeling for injury prevention and reduction
Ergonomics Modeling

• Ergonomics (or human factors): Application of scientific information concerning humans to the design of objects, systems and environment for human use

• Modeling
  – Posture
  – Movement
  – Physical capabilities
  – Cognitive capabilities

• Applications
  – Workload or task design
  – Human-machine interface
  – Workspace or work environment design
  – Accommodation
Anthropometrics Modeling

• Anthropometrics: concerned with the physical sizes and shapes of humans, including height, size, weight, and body segment proportion
• Variation with gender, age, and ethnicity
• Applications ranging from clothing, furniture, automobiles, buses, and subway cars to space shuttles and space stations

Gender

Age

Ethnicity
Human 3-D Shape — Data Collection

- 3-D whole body laser scanner
- High resolution, large volume of data
- CAESAR database
  - Civilian American and European Surface Anthropometry Resource
  - 2,400 U.S. & Canadian and 2,000 European civilians, men and women, aged from 18-65
  - Using 3D Laser scanner to collect body surface data
  - Each person in a standing pose, full-coverage pose, and relaxed seating pose
Human 3-D Shape Representation

- **Shape representation**
  - Traditional metrics
  - Landmarks

p1-p3 are principal axes 1, 2, and 3

(0,0,0) is the center of gravity (cg)
Human Shape Modeling and Morphing

• **Shape modeling**
  – Static modeling based on a shape descriptor
  – To reproduce a shape from scan data
  – To create a shape according to inputs of parameters

• **Shape Morphing**
  – From a base shape to produce variations
  – Anthropometric variations with respect to gender, age, and ethnicity
  – Within anthropometric variability limits
Human Gait Modeling

- Landmark trajectory, skeleton model, based on motion capture
- Kinematics of human motion
- Gait with respect to gender, age, or other anthropometrical factors
- Behavioral factors
Human Kinematic/Kinetic Modeling

• **Human motion modeling: kinetic modeling**
  – Musculoskeletal model with body shape
  – Bones, joints, muscles, and ligaments
  – Body motion governed by driving forces or based on optimization

• **Example models**
  – Santos, a virtual human model, VSR (Virtual Soldier Research), The University of Iowa, [http://www.digital-humans.org/santos/](http://www.digital-humans.org/santos/)
AnyBody

- Musculoskeletal model
- Joint function and muscle function
- Gait analysis
- Activity simulation
  - carrying a 20 kg rucksack
  - body posture accommodation to the changed weight distribution

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Santos

- Skeletal structure
- Kinematics system
- Optimization to determine the joint motion
- Gait analysis
- Activity simulation
Human Modeling in Human Motion Analysis

- Human motion analysis methods: model-based or non model-based
- Models used in motion analysis
  - Stick figure
  - 2D contour
  - 3D or volumetric models
Biomechanics Modeling

• Goals
  – To model the human response under dynamic loading
  – To understand injury mechanism
  – To improve crashworthiness of structures

• Applications
  – Auto safety
  – Injury prevention and reduction
  – Sports
  – Rehabilitation
Biomechanical Modeling Techniques

• **Rigid multi-body dynamics**
  - Entire body divided into a number of segments
  - Each segment treated as a rigid body, linking to another with joints
  - Describing kinematics

• **Model tools**
  - MADYMO (MAthematical DYnamic MOdeling)
  - ATB (Articulated Total Body)

• **Finite element method**
  - Using small elements (cubes) to describe the bones, soft tissues, and organs
  - Incorporating biological material models
  - Describing stress and strain

• **Modeling tools**
  - LSDYNA
  - PAM-CRASH/ PAM-SAVE
  - DYTRAN
  - MADYMO
Model Development Activities

- **Humos**: [http://humos2.inrets.fr/](http://humos2.inrets.fr/)
  - A Set of HUman MOdels for Safety
  - Funded by the European Commission

- **A research consortium of smart dummies**
  - Involving nine automakers and a pair of auto suppliers
  - Support from university biomechanical research groups
  - First set of adult models--three males and three females in small, medium and large sizes by March 2011
  - Models of children to follow
  - 1 million to 3 million elements for each model
Research Institutions

• Government agencies
  – NIH/NLM
  – NHTSA

• Universities
  – Bioengineering Center of Wayne State University
  – Center for Applied Biomechanics, Virginia University
  – Washington University
  – University of Michigan

• Industries
  – Automobile manufacturers’ R&D department
  – FE software vendors

• Associations
  – International Society of Biomechanics (ISB)
  – American Society of Biomechanics (ASB)
  – Society of Automobile Engineers (SAE)
Open Data Resources

• Bony structure
  ➢ VAKHUM: http://www.ulb.ac.be/project/vakhum/public_dataset/public-data.htm (University of Brussels)
  ➢ ISB: http://isbweb.org/o/content/view/66/73/ (International Society of Biomechanics)
  ➢ BEL: http://www.tecno.ior.it/VRLAB/researchers/repository/BEL_repository.html#ULB%20Virtual%20Human (Biomechanics European Laboratory)

• Soft tissues
  ➢ HUMOS2: http://humos2.inrets.fr/about.php (Project funded by the European Commission)

• Material models
  ➢ Soft tissue material models
    http://wwwiaim.ira.uka.de/web/SoftTissueDB/SoftTissueWiki/index.php/Material_Models (Institut für Technische Informatik)
Automobile Crashworthiness Modeling

- A finite element model of a four-door 1997 Honda Accord DX sedan
- Using a reverse engineering technique, with 220 parts and 117,353 elements
- Simulations of full and offset frontal, side, and car-to-car impact
Occupant-Airbag Interaction Modeling

- FE modeling of airbag using LSDYNA
- Rigid multi-body modeling of occupant using ATB
- Vehicle and interior structures modeled by respective planes using ATB
- Integration of FE airbag model with ATB occupant model
- Model used for
  - Safety performance assessment
  - Injury analysis and prediction
  - Airbag design and optimization
Head-Neck Injury Modeling

- Finite element modeling of the head-neck complex
  - Actual geometrical data of a 68-year old male cadaver specimen
  - Cervical spine C0~C7
  - Muscles and ligament
  - Rigid skull
  - Original model developed by DSO, Singapore

- Challenges to the model validation and modification
  - Accurate anatomical description
  - Material properties of bones, muscles, ligaments, and soft tissues
  - Function of muscles

- Simulation of head-neck response under dynamic tensile loading

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Seating Comfort Modeling

- Bony Structure model
- 3-D scan data and outer shape model
- Integrated Model
  - Multiple layers of solid elements for fat/muscles
  - A layer of shell elements for skin
- Simulation of pressure distribution between the seat cushion and buttock
Human Physiological Function Modeling

- Physiological function modeling
  - Cardiovascular function: blood circulation
  - Lung function: Inhalation/exhalation
  - Other Physiological Function Modeling

- Key Competencies
  - Fluid physics and fluid-structure interaction
  - Finite element analysis: organ level, tissue level, and cell level
  - Advanced analytical tissue models

- Applications
  - Human performance optimization
  - Status assessment: live or dead
  - Injury evaluation
  - Intention prediction
Sitting Arterial/Venous Circulatory Simulation

- Sitting posture arterial/venous circulation simulation with and without gravity
- Shown below: posture, arteries/veins, generated grid, and simulation pressure distribution at instant in time with and without gravity
- Shown at right: pressure traces in time of single heart beat at different points in body with and without gravity

An example, work done by CFDRC
DHM Recent Developments

- **Multi-Scale, Multi-Physics Modeling**
  - From organ level to tissue level and to cell level
  - From biomechanics to physiology, and pathology
  - From bones and soft tissues to vessels, nerves, and neurons

- **Blast induced injury modeling**
  - Blast: shock wave and wind force
  - High rate, short duration impact on human body
  - Modeling of lung, vascular, etc.
  - Modeling of traumatic brain injuries

- **Integration into virtual testing environment**
- **Model validation**
- **Distributed computation**
- **Web based applications**