Mechanical Engineering Seminar (U-Grad)
Special Topics in Mechano-Informatics II (Grad)
“Biomechanics of Human Movement”
Academic Year 2014
Dr. Emel Demircan
Course Information

Instructor:
- Dr. Emel Demircan
  Contact: emel@ynl.t.u-tokyo.ac.jp
  Office Hours and Location: Friday 16:30-17:30, Engineering Building 2, Room 82D1

Assistants:
- Tianwei Zhang
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  Office Hours and Location: Tuesday 14:00-15:00, Engineering Building 2, Room 82C1
- Kazunari Takeichi
  Contact: takeichi@ynl.t.u-tokyo.ac.jp
  Office Hours and Location: Friday 16:30-17:30, Engineering Building 2, Room 82C1
Course Information

Course Grading:
Attendance: 40%
Homeworks: 30%
Final Project Presentation: 30%

Homeworks:
Please submit each homework electronically to emel@ynl.t.u-tokyo.ac.jp by its deadline.

4/25: HW1 out
   5/2: HW1 due, 5pm
5/9: HW2 out
5/23: HW2 due, 5pm
   6/6: HW 3 out
6/27: HW 3 due, 5pm
Course Information

Final Project:
Students form teams and each team selects one topic from the list below:

- Exoskeleton Robots & Rehabilitation Robotics
- Human Performance Augmentation
- Animation and Simulation
- Human & Humanoid in Aging Society
- Human & Humanoid Skills/Cognition
- Human Motion Tracking
- Gait Analysis & Rehabilitation
- Human Musculoskeletal Modeling
- Socially Assistive Robots
- Natural Motion Generation in Humanoid Robotics
- Motion Analysis for Workspace Ergonomics
- Children Gait and Posture Rehabilitation
- Real-time Feedback Modalities for Motion Training
Schedule

4/18: Introduction
4/25: Spatial Descriptions, Kinematics, Introduction to Biomechanical Simulation
5/2: Skeletal Muscle Structure, Force Generation, Musculoskeletal Geometry
5/9: Production of Movement
5/23: Motion Tracking Techniques
6/6: Inverse Dynamics, Control, Operational Space Formulation
6/27: Human Articulated Body Model, Dynamics, and Motion Control
7/4: Advanced Topics in Human Motion Analysis, Student Presentations
Today

• Why to Study Human Motion?
• How to Study Human Motion? - Multi-Disciplinary Research
• Components and Functions of the Musculoskeletal System
• Examples of Applications
Understanding and Applying Human Motion to Robots

- To observe and understand how humans move. To apply similar strategies to robots.
Today

- Why to Study Human Motion?
- How to Study Human Motion? - Multi-Disciplinary Research
- Components and Functions of the Musculoskeletal System
- Examples of Applications
Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries
Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries
- for ergonomic analysis and design
Why to Study Human Motion?

Synthetic Motions through Simulations

- to design new rehabilitation techniques
- to evaluate injuries
- for ergonomic analysis and design
- to synthesize realistic interactions in computer-simulated environment
Today

• Why to Study Human Motion?
• **How to Study Human Motion? - Multi-Disciplinary Research**
• Components and Functions of the Musculoskeletal System
• Examples of Applications
Biomechanical Tools

Human Musculoskeletal Models

- Multi-body, rigid, tree-like branching structure
- Upper and lower body models


Biomechanical Tools
Human Musculoskeletal Models

- Multi-body, rigid, tree-like branching structure
- Upper and lower body models
- Different levels of complexity

<table>
<thead>
<tr>
<th>Joint</th>
<th>Degree of freedom</th>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>3</td>
<td>Ball and socket</td>
<td>Adduction/abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexion/extension</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Rotation</td>
</tr>
<tr>
<td>Knee</td>
<td>1</td>
<td>Revolute</td>
<td>Flexion/extension</td>
</tr>
<tr>
<td>Ankle</td>
<td>1</td>
<td>Revolute</td>
<td>Dorsiflexion/plantar flexion</td>
</tr>
<tr>
<td>Subtalar</td>
<td>1</td>
<td>Revolute</td>
<td>Eversion/inversion</td>
</tr>
<tr>
<td>Tarsal</td>
<td>1</td>
<td>Revolute</td>
<td>Flexion/extension</td>
</tr>
<tr>
<td>Lumbar</td>
<td>3</td>
<td>Ball and socket</td>
<td>Ext./bend./rot.</td>
</tr>
<tr>
<td>Shoulder</td>
<td>3</td>
<td>Ball and socket</td>
<td>Adduction/abduction</td>
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<td></td>
<td>Flexion/extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rotation</td>
</tr>
<tr>
<td>Elbow</td>
<td>1</td>
<td>Revolute</td>
<td>Flexion/extension</td>
</tr>
<tr>
<td>Wrist</td>
<td>3</td>
<td>Revolute</td>
<td>Flexion/extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ulnar/radial deviations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pronation/supination</td>
</tr>
</tbody>
</table>

Lenarcic et al.'00
DeSapio et al.'06
Seth et al.'10
DeSapio et al.'06
Experimental Tools
Sensing Human Motion

- Accurate 3D position data – Motion Capture (mocap)
- Easy to use, continuous whole-body sensing
- Synchronize with contact force, muscle activity data
History of Human Movement Science

1543: Andreas Vesalius publishes the first illustrated systematic anatomical atlas of the human body.

1872: Leland Stanford, former Governor of California, had taken a position on a popularly-debated question of the day: whether all four of a horse’s hooves left the ground at the same time during a gallop.

1877: Eadweard Muybridge settles the bet with a single photographic plate showing Occident, Stanford's own racehorse, with all feet in the air. By 1878, Muybridge had successfully photographed a horse in fast motion using a series of twenty-four cameras.

1894: Etienne Jules Marey invents the first slow motion camera.

1887: Etienne Jules Marey invents the "chronophotograph".

“No natural phenomenon can be understood without carefully considering how it emerged”
Robotic Dynamics and Control

Balance

Internal Constraints
Self Collision
Local Obstacles

Contact

Task

Posture
Robotics
Dynamics and Control

Balance

Internal Constraints
Self Collision
Local Obstacles

Contact

Task

Posture
Robotics provide methods to assess the dynamic performance of multi-degrees of freedom manipulators (Khatib and Burdick, 1987).

Dynamics can be reflected at the wrist of robotics systems using the feasible set of operational space accelerations.

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Muscle-induced joint torque limits

Bounds on maximum accelerations
Neuromuscular Library
Multidisciplinary Research
Physiology | Model | Dynamics | Control | Analysis
Today

• Why to Study Human Motion?
• How to Study Human Motion? - Multi-Disciplinary Research
• **Components & Functions of the Musculoskeletal System**
• Examples of Applications
Components of the Musculoskeletal System

- **Skeleton**
  - Appendicular & Axial
  - Mineral Storage
  - Protection of Vital Organs

- **Joints**
  - Linkage

- **Muscles**
  - Force Production
  - Support
Components of the Musculoskeletal System

- **Skeleton**
  - Appendicular & Axial
  - Mineral Storage
  - Protection of Vital Organs
Components of the Musculoskeletal System

• Joints
  – Provide linkage
  – Human Motion involves rotation of body segments about their joint axes
  – The force produced by a muscle is coupled with its moment arm to generate torque about the joint that it crosses
  – Torques are always determined with respect to a specific axis of rotation
Components of the Musculoskeletal System

- **Muscles**
  - Force Production
  - Support
Components of the Musculoskeletal System

- Muscle Types

- Pectoralis major
- Orbicularis oris
- Deltoid
- Sartorius
- Biceps brachii
- Extensor digitorum longus
- Rectus femoris
- Unipennate
- Bipennate
Today

- Why to Study Human Motion?
- How to Study Human Motion? - Multi-Disciplinary Research
- Components & Functions of the Musculoskeletal System
- Examples of Applications
Biomechanics of Human Movement Applications

- Computer Animation
- Ergonomics and Occupational Health
- Athletics and Sports Medicine
- Reeducation of Neuro-Musculoskeletal Disorders
Human Motion Characterization
Whole-Body Muscular Effort
Physio-Mechanical Advantage

\[ E = F^T \phi F \]

Muscular Effort Reduction = 146
Ergonomics and Occupational Health

*AnyBody*

Which handle bar height results in the minimal load on the body?
Experiment – Throwing

Professional Football Player

- Motion Capture
- Force Plate
3-D Dynamic Simulation
Professional Throwing
Dynamic Motion Analysis

Optimal Throwing?
Experiment – Golf Swing

College-level Elite Golf Player

- Motion Capture
- Force Plate
3-D Dynamic Simulation of Golf Swing
Subject-Specific Motion Analysis
Gait: Experiment and Simulation

Healthy Male
Free Speed (1.75m/s)

- Motion Capture
- Force Plate
- Electromyography

23DOF actuated by
92 muscle-tendon units
Gait: Experiment and Simulation
Gait: Experiment and Simulation
Experiment - Gait

- Contact forces were added in the dynamics
- Activation pattern scaled the muscle capacities
- Subject’s dynamics was reflected at the center of mass
Muscle Activations during Normal Gait (1.75m/s)
Subject-Specific Gait Analysis

\[ \ddot{x} = J(q)A(q)^{-1}(L^T m_{\text{max}} a - g(q) - J_{c1}^T F_{\text{ext1}} - J_{c2}^T F_{\text{ext2}}) \]

Results

<table>
<thead>
<tr>
<th>Results</th>
<th>Our findings</th>
<th>Liu et al. 2006</th>
<th>Neptune et al. 2004</th>
<th>Liu et al. 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus medius, vasti, hamstrings, gastrocnemius, soleus and dorsiflexors are important modulators of accelerations</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Subject-Specific Motion Analysis
Real-time Motion Dynamics, Task-based

- **Decoupled control** of human motion, postural behaviors, contact and additional constraints
- **Real-time** motion dynamics
- Subject’s dynamics at any **operational point**
- Real-time **feedback** (visual, haptic)
Musculoskeletal Disorders
Crouch vs. Normal Gait

Professor Scott Delp – Department of Bioengineering
Professor Jessica Rose - Stanford Children Gait Hospital
Department of Orthopaedic Surgery, School of Medicine
Reeducation of Musculoskeletal Disorders
Reeducation of Stroke Patients

Univrsite de Montpellier II
LIRMM, France

Post-Stroke subject

COP

Healthy subject

Frontal plane (m)

Sagittal plane (m)

Right
Left

Right
Left

0 0.1 0.2 0.3 0.4

0 0.1 0.2 0.3 0.4

0 0.1 0.2 0.3 0.4

0 0.1 0.2 0.3 0.4

Rehabilitation
Reaching & Grasping

Stanford Children Gait Hospital
Department of Orthopaedic Surgery, School of Medicine
Athletics and Sports Medicine
Injury Prevention in Sport

In a Collaboration with: Footwear Technological Institute, INESCOP, Mallorca
Understanding and Applying Human Motion to Robots

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• Examples of Applications
Next Week (4/25)

• Spatial Descriptions, Kinematics, Introduction to Biomechanical Simulation
  – Please bring your laptop (windows)
  – Please download “OpenSim 3.2” with GUI from simtk.org

• Project teams & topics selection due (instructor office hour)

• Feel free to contact the instructor and the assistants for your questions

• Have a Nice Weekend!
Symposium on Biomechanics of Human Movement
Graduate Program for Social ICT Global Creative Leaders
JSPS Invitation Fellowship Program for Research in Japan (Short S)

April 19th, Saturday 9.15am-17.30pm
Yayoi Auditorium

http://www.ynl.t.u-tokyo.ac.jp/~emel/symposium/home.html