Introduction to Biomechanics

EID 424
Bioengineering Applications in Sports Medicine
Nov 15, 2021
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Outline

+ Introduction and history
+ Measurements
  + Motion
  + Force
+ Calculations
  + 2-D
  + 3-D
+ Applications
+ Complications

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Introduction

+ Broad field
  + Analysis of human motion
  + Forces in car crash impacts
  + Motion of insects
    + Large role in robotics
  + Strength of reconstructions/implants
  + Flow in blood vessels
  + Mechanical properties of plants

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Introduction

- Last time I was at ASB meeting:
  - Recovering from tripping
  - Mechanisms of ACL injury
  - Evaluation of riot helmets
    - Beat helmets with baseball bat
  - Instrumented cockroach!

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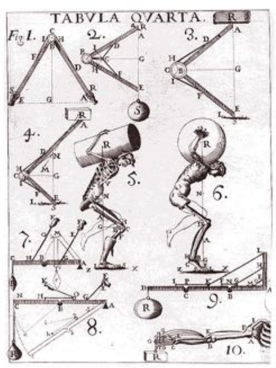
History

- Borelli
  - Considered father of biomechanics
  - *De Motu Animalium* (1680-1681)



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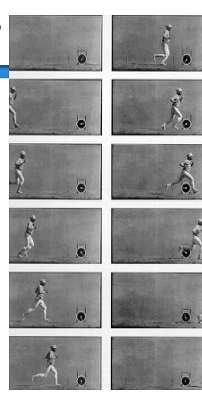
History: Lots of Pictures

- Marey (1838-1904)
  - Pioneer in use of many technologies
    - Photography
    - Measurement of forces



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History

+ Muybridge (1830-1904)
  + Sequential pictures of many activities
    + Walking
    + Running
    + Jumping
    + Marching
    + Wrestling (eww)
    + Many others

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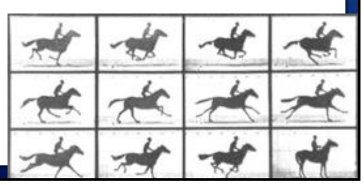
History Tidbits

+ Marey tested idea that "cats always land on their feet"
  + Filmed cats after having been dropped upside-down
+ Muybridge settled famous bet [1876]
  + Do horses fly?



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Currently

+ Motion capture techniques no longer limited to biomechanics
+ Entertainment industry now largest customer
  + Film
  + Video games

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How Big is Entertainment?

- Several biomechanists won a technical achievement Oscar in 2005
  - Work with techniques for producing smooth animation of motion capture data
- Pictured:
  - Ton van den Bogert
    - Cleveland Clinic
    - Mr. Simulation
    - Moderates biomch-l
  - Dan India
    - VP Sales, Qualisys
    - A decent human despite being a salesman
    - Buys beer every year for the Biomechanics Interest Group at the American College of Sports Medicine Conference
  - Oscar statue
    - Developed new finite-element model of human body
    - Got into biomechanics to support crystal meth addiction
    - Writing self-help book in rehab

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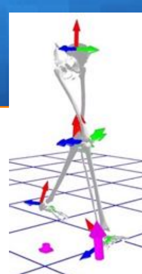
Kinematics

Motions of the Body



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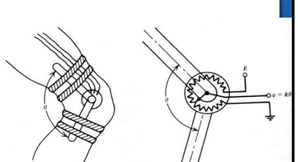
Simple: The Basic Electrogoniometer

- Goniometer
  - Device that measures angle
  - Electrify it!
- Not the most accurate
- Careful placement import
  - Align with center of rotatio joint
  - Center of rotation usually not fixed



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Basic Technique

- Attach markers to subject
  - Brighter than anything in background
  - Attach to useful points (landmarks)
  - Passive (reflective) vs active
- Record motions with > 1 cameras
  - Allows reconstruction of 3-dimensional data from camera images
- Analyze
  - Joint angles
  - Velocities/accelerations
  - Forces!

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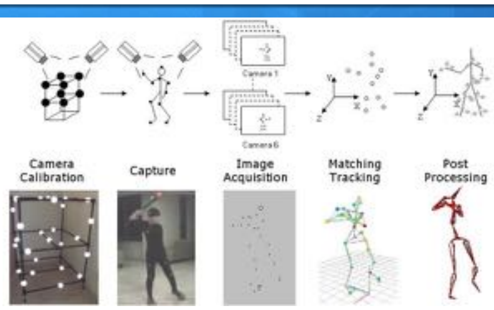
Basic Technique



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Technologies

- Camera-based
  - Usually infrared
  - Markers reflect light
    - Or emit light
  - Markers on subject show up brightly against background
- Electromagnetic
  - Transmitter emits magnetic field
  - Markers contain three orthogonal coils
  - Field couples into coils
    - Distance, orientation relative to transmitter determine received signal

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Historically

- Multiple video cameras
  - Each records to VCR
  - All synchronized
- Manually digitize points of interest in *each* frame on *every* tape
- Painful
  - Grad students

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Camera-Based Motion Analysis

- Very accurate
  - Often 1mm or better resolution
- Relatively easily-understood technology
- Well-accepted
  - Gold standard
- Expensive!
  - System with fast cameras can be $250-$500K
- Often requires intervention in post-processing
- Requires line of sight

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Electromagnetic Motion Analysis

- Can be much cheaper than cameras
  - $20K and up, if memory serves
- No line of sight
- No post-processing
- Distorted by nearby metal
  - Room can be calibrated
    - Don't move transmitter
  - In reality, some big distortions cannot be (metal force plates)
- EMG?

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Marker Pros and Cons

- Active
  - Sampled sequentially
  - No post-processing
  - Need wires for power, control
    - Subject tethered?
    - Wires interfere with motion
- Passive
  - All markers sampled in every frame
  - Inexpensive
    - Reflective balls
  - Often time-consuming post-processing
    - Fix swapping markers, etc.
  - Least hindering to subject

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Current Research Area

- Lots of effort going into research for markerless motion capture
  - Automagically track points in video from one frame to the next
  - Microsoft Kinect does this reasonably enough for video games, but not for research/clinical measurements

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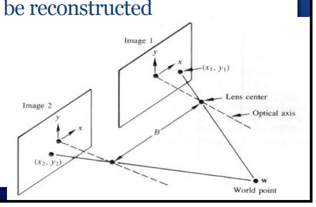
Cameras are 2-D How Do I Get 3-D?

- Multiple cameras
- If…
  - The same scene is viewed by more than one camera
  - The positions and orientations of the cameras relative to each other are known
  - 3-D image of scene can be reconstructed
  - Stereo imaging



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Stereo Imaging

- Reconstruct 3-D data based on 2-D camera images
- Direct linear transform (DLT) [Abdel-Aziz, Kahara, 1971]
  - Use a structure with markers at known points to calibrate system
    - At least 6 points
  - Like most things in this field, becomes an optimization problem
    - Minimize residuals

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Camera Calibration

- Traditionally, used calibration structure
  - Precisely measured
  - Typically, large and heavy
  - Should approximate size of measurement volume
- Modern systems use wand calibration
  - Four markers on ground at right angle to determine coordinate system
  - Two markers on ends of wand waved through volume to be calibrated
    - Calibration dance

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People Do Use 2-D

- One camera
- No or easy calibration
  - Measure distance to plane in which motion is taking place
- Measure joint angles in one plane
  - Typically, sagittal (i.e., view from the side)
- Careful!
  - Are you sure you're getting the plane you want?

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Motion System Vendors

- Motion Analysis Corp
- Vicon
- Qualisys
- BTS Bioengineering
- Innovative Sports Training (The Motion Monitor)
- Charnwood Dynamics (Coda)
- Northern Digital (Optotrak)
- Peak Performance
- Simi Reality Motion Systems

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Enough Technology, What Are We Measuring?

- Measure and *quantify* motions of the body
  - Specifically, motions of the *skeleton*, since that is the structure that is bearing weight
- Joint angles/rotations
  - Interested in joint *centers*

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Enough Technology, What Are We Measuring?

- A body in space has 6 degrees of freedom
  - 3 translations (x-, y-, z-)
  - 3 rotations (yaw, pitch, roll)
  - Segments of human body may be more constrained than having full freedom
- Sometimes 2-D analysis is enough

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2-D Techniques

- Place markers on joints
  - Use bony landmarks for repeatability
- Compute joint angles from lines drawn through markers
- Cannot get rotations this way
- Are we really getting the plane we're looking for?

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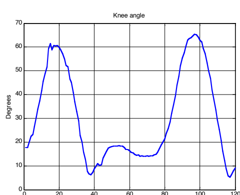
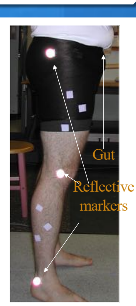
2-D Example: Gait

- Markers on greater trochanter, femoral condyle, lateral malleolus give knee angle
- Knee angle dominated by sagittal plane motion





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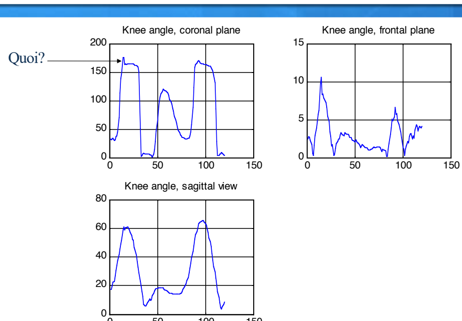
2-D Example: Gait



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3-D Techniques

- Place markers on body segments
  - *At least* 3 markers per segment
  - Can define coordinate system for each segment
- Calculate rotations of one segment relative to another
  - Transformation matrices
  - Beware!
  - Order of rotations can matter!
  - Gimbal lock
    - Second rotation is 90°

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3-D Techniques

- How to place consistently?
- Be sure to collect neutral trial
  - Estimate location of joint centers

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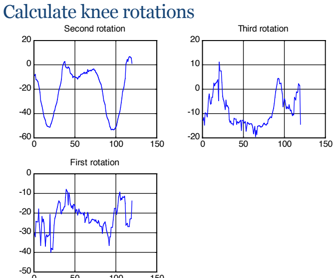
3-D Example: Gait

- Marker triads on thigh, leg
- Calculate knee rotations



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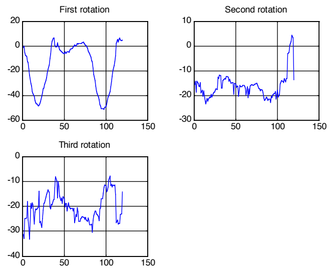
3-D Example: Gait

- Changed rotation order



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Why None of This Really Works

- Want to measure movements of *skeleton*
- Markers on surface of *skin*
  - Motion of markers relative to bone
    - Skin artifact
    - Mount markers on bone pins, insert surgically
      - Yeah, maybe in Sweden
  - Inconsistent placement
    - Use bony landmarks for reference
  - Determination of joint centers?
    - Calibrate with static trials, regression, tables of "normal" values
    - Papers written on this

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Motion is Only Half the Story

- Motion of skeleton is of little consequence without knowing forces to which it is subjected
- Can be measured with a force plate

Kinetics

Forces on and of the Body

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Force Plate

- Big hunk-o-metal with sensors embedded
  - Big and heavy
    - ???
  - Strain gauge or piezoelectric sensors
- *Very* sensitive
  - Can see heartbeat on best, well-installed ones
- Best bang for the buck in your motion lab
  - ~$20K
- Must be well-isolated from surrounding vibration

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Got Room in the Basement?

- Upper floors not recommended
  - Buildings sway, vibrate
- Dig a pit
- Fill with sand
- Block of concrete floating in sand
- Bolt force plate to concrete

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Portable Force Plates

- Feet somewhat isolated from floor with rubber
  - Think record player
- Not as sensitive, precise as regular plate
- Not good for high-impact activities

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Force Plate Outputs

- Forces in three directions
- Moments about three axes
- Point of application of force (center of pressure)
- Crazy accurate when installed correctly

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Force Data Normalizations

- As usual, difficult to compare data between subjects directly
- Forces typically normalized to body weight
- Moments normalized to:
  - Body weight
  - Body weight * height

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Force Plate Limitations

- Plates relatively small
  - Capture only one stride/jump/etc
  - Subjects sometimes have difficulty hitting plate
  - Is this representative?
  - Usually perform multiple trials, average them
    - Must normalize time at this point, e.g., % of gait cycle
  - Targeting issues
    - Want subject performing motion normally
    - Often cover plate to resemble floor

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Force Plate Manufacturers

- AMTI
  - http://www.amtiweb.com/
- Bertec
  - http://www.bertec.com/
  - Non-conductive plate for electromagnetic systems
- Kistler
  - http://www.kistler.com/
- BTS
  - http://www.btsbioengineering.com/

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Combining Motion and Force

- Combine motion and force plate measurements to estimate forces acting at joints of body
- Combine with Newton's laws of motion
- Assume body is a connected set of rigid links
- *Inverse dynamics*

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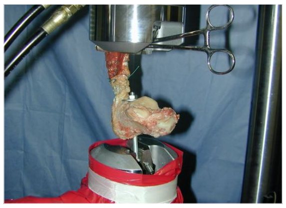
Completely neglected…

+ The entire field of crushing things or pulling them apart



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Completely neglected…

+ The wonderful world of modeling and simulation
  + Can be as simple as a mass on a spring
    + See work of Claire Farley
  + Can be *very* complicated and involve lots of partial differential equations
  + Read *anything* by Ton van den Bogert

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