Laboratory 1: Rigid Body Kinematics
September 12/13, 2006
BIOEN 5201 – Introduction to Biomechanics
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Lab Quiz:
A 10 point lab quiz will be given before class, accounting for 10% of the lab report grade. You should be able to describe what this lab is about, what you will be testing and what data you will leave with.

Background:
Kinematics is the branch of physics which involves the description of motion, without examining the forces which produce the motion (dynamics or kinetics, on the other hand, involves an examination of both a description of motion and the forces which produce it). A subset of kinematics is that of rigid body kinematics, which as the name suggests, concerns the motions of one or more rigid bodies.

In bioengineering, body segments are typically considered to be rigid bodies. These body segments are tracked using a number of techniques such as goniometry, accelerometry, magnetic tracking, fluoroscopy, video systems and stereophotogrammetry. The technique used in this lab is a video based stereophotogrammetry system, commonly called photogrammetry. In this system a number of markers are tracked using two or more calibrated video cameras. By placing markers on each body segment, the position and relative angles of each joint can be found.

These techniques are most renowned for their use in computer animation, where markers are placed on actors who are then video taped by multiple cameras during a scene. The video data is then used to re-create the actor’s motions in computer animated characters. Photogrammetry is also used in clinical applications for gait analysis. For example, cerebral palsy patients are often analyzed using motion tracking systems in order to determine the abnormalities in their gait. So called “gait reports” are then given to doctors who are often able to use this information to perform corrective surgeries. Finally, motion tracking of this type is used in numerous research applications, such as tracking the motion of cadaver knees or generating data for input into a finite element model.

Objective:
The objective of this laboratory is to use a 3D motion analysis system and 3D electromagnetic digitizer to measure the kinematics of a bovine knee joint under passive flexion. The student will learn how these measurement techniques work and how they can be combined with the equations of 3D rigid body kinematics to track the relative motion between two rigid bodies. If done properly, the data gathered in lab can be used to generate data sets of the angles and translations that the test knee undergoes during passive flexion.

NOTE – there is only one set of digital cameras and framegrabbers. Thus, this experiment will be performed by one group at a time.
**Equipment required:**
2 Pulnix TM 1040 digital cameras, tripods and incandescent lights, lenses and extension tubes
Dual Athlon PC with 2 Bitflow Roadrunner Framegrabbers and DMAS motion analysis software
Polhemus electromagnetic digitizer
2 kinematic marker clusters and associated screws for attachment to femur and tibia
3D calibration frame
Extremity holder clamping system
Bovine knee
Drill press or cordless drill for mounting of kinematic marker clusters to femur/tibia
Philips screwdriver to attach kinematic marker clusters
CD-R for data backup
Freezer for specimen storage
Digital calipers
Plastic metric ruler

**Supplies required:**
Chux, gloves (non-sterile), dissection tools, 0.9% normal saline, cleanup supplies

**Experimental procedure:**

NOTE – DO NOT MOVE THE CAMERAS DURING TESTING! THEY ARE CALIBRATED BASED ON THEIR CURRENT LOCATIONS!

1. Attach kinematic markers to femur/tibia *(TA before class)*
2. Calibrate volume around knee with DLT (Direct Linear Transform) using DMAS software *(TA before class)*
3. Mount knee in extremity holder at close to 0 degrees flexion (see Figure 1 on the next page).
4. Establish a neutral position for the knee at approximately 0 degrees flexion.
5. Record approximate distance between markers in femoral cluster, between markers in tibial cluster, and between the two clusters for later verification of results from the motion analysis system. (Use a ruler and/or digital calipers)
6. Using the Polhemus digitizer, digitize the coordinates of the markers on the femoral cluster. This will be necessary for establishing a coordinate system for the femoral markers. Repeat for the tibia. Now record the point of the marker located in the corner of the pan—this will be the origin for the global coordinate system. In this lab the marker coordinate system is set up so that it coincides with the embedded (or anatomic) coordinate system, thus no transformation between the marker coordinate system and embedded system will be necessary. The TA will guide you through the digitization process.
7. Flex/extend knee between 90 and 0 degrees flexion and then back to 90 while recording both cameras at 5 Hz (1 cycle, approx 30 sec/cycle)
8. Determine the 3D coordinates of all markers on the femoral and tibial marker clusters using the DLT calibration in the DMAS software package. Your TA will show you how to do this.
9. Back up all data onto a CD-R or USB drive before leaving the laboratory. You should have:

Data from the electromagnetic digitizer (anatomical coordinates used to define embedded coordinate systems in femur and tibia), the coordinates used to define the reference system and the coordinates of the tibial and femoral markers that were obtained during the passive flexion.

**Data analysis:**

The objective of the data analysis is to determine the Grood-Suntay joint angles and translations during knee flexion/extension based on the transformation matrix between the femoral embedded coordinate system and the tibial embedded coordinate system. You will be provided with a MATLAB program to perform the data analysis. Please see the instructions for the lab report for details on the procedure for analyzing the data and preparing your report.

The overall picture of the analysis (which is done for you in the MATLAB program) is as follows:

1) Determine the 4x4 transformation matrix between the embedded coordinate system in the femur (fe) and the marker coordinate system in the femur (fm), $T_{fe\rightarrow fm}$. Note that this transformation NEVER CHANGES during the test, as both coordinate systems are affixed to the same rigid body. This matrix is calculated from the digitized data.

2) Determine the 4x4 transformation matrix between the embedded coordinate system in the tibia (te) and the marker coordinate system in the tibia (tm), $T_{tm\rightarrow te}$. Note that this transformation NEVER CHANGES during the test, as both coordinate systems are affixed to the same rigid body. This matrix is calculated from the digitized data.

3) Determine the 4x4 transformation matrix between the embedded femoral coordinate system and the embedded tibial coordinate system, $T_{fm\rightarrow tm}(t)$. This matrix is calculated from the recorded DMAS position data. This transformation is illustrated graphically in Figure 2. The overall transformation matrix between the embedded femoral and tibial coordinate systems is given by:

$$
[T_{fe\rightarrow te}(t)] = [T_{tm\rightarrow te}] [T_{fm\rightarrow tm}(t)] [T_{fe\rightarrow fm}]
$$

*Figure 1:* Experimental setup. Bovine knee is mounted in holder, with kinematic marker clusters attached to femur (top) and tibia (bottom).
4) Calculate the three Grood-Suntay joint flexion angles (flexion/extension, abduction/adduction, tibial rotation) and three translations (medial/lateral tibial displacement, anterior/posterior tibial displacement, joint distraction) as a function of time based on the overall transformation matrix for each of the experiments (see equations 16-20 of the Grood-Suntay JBME manuscript).

**Tips:**
Use your ruler measurements between the approximate origins of the coordinate systems to verify the translations. The components of the rotation matrix can be verified by computing the appropriate dot products between the coordinate axes. This yields the cosine of the angle between the axis for a quick check that the angles are approximately right.

It will be easiest to verify the transformation matrices if you stick to the conventions described above and in the Grood-Suntay paper for orientation of your axes. For instance, the Grood-Suntay paper always defines the z-axis along the long direction of the bone, with positive in the proximal direction. The x-axis is always oriented medial-lateral, with the lateral direction as positive. The y-axis is always oriented anterior-posterior, with the anterior direction as positive.

When composing the transformation matrices, remember that you are looking for the transformation that rotates/translates one set of axes into another. Make sure that you define your displacement vectors appropriately (i.e., don’t get them backwards).