Laboratory 2: 2D Strain Measurement – Instructions for Report
October 18/19 2006 Due: Thursday 2\textsuperscript{nd} November 2006
BIOEN 5201 – Introduction to Biomechanics
Instructor: Jeff Weiss
TA: Heath Henninger

Each student must turn in a separate laboratory report \textit{representing his or her own work}. The report should be prepared using MSWord or an equivalent word processor. The department has asked me to include grading of the grammar and style of your written report as part of the means of evaluation, so please proof your report, rewrite the initial draft as necessary and check for spelling and other grammatical errors before submission. The report should contain the following sections:

Title/Name:
Your report must include the following information in the upper-left corner of the first page:

\begin{verbatim}
BIOEN 5201 - Laboratory 2, Fall 2006: 2D Strain Measurement
<YOUR NAME HERE>
<DATE HERE>
\end{verbatim}

Objective: (1 paragraph)
State the purpose of the lab measurements and analysis. Motivate the need for the measurements. State your perception of the intended educational goals of the laboratory in terms of learning new measurement and analysis techniques. This section should be one paragraph.

Methods: (No longer than 2 pages)

a) Describe the methods and step-by step procedure to perform the measurements, i.e.
- Load Cell Calibration
- Test Sample Preparation
- Pre-test Measurements
- DMAS Calibration, importance of 2D calibration frame alignment
- Material Test Procedure (how you loaded/strained the sample)
- Use of DMAS system to track marker coordinates

b) Provide a high-level step-by-step overview of the program that you write (MATLAB suggested) to analyze the data. Please do your own work.
   Describe any subroutines and reference them by name
   Explicitly write (in direct notation) the overall equations that are used in your MATLAB program to obtain the strains and other results.

Sections a) and b) should be no longer than two pages, combined.

Note – \textbf{EVERY LINE OF YOUR EXECUTABLE CODE SHOULD HAVE A COMMENT.}
Please limit your comments to the first 72 columns so they don’t run off the edge of the page.
Results/Discussion (3 pages including 2 pages for plots):

Plot 1: Green-Lagrange Strains as function of time: Assuming that the test configuration corresponded to finite simple shear, plot the $E_{11}$ and $E_{12}$ components of the Green-Lagrange strain tensor based on the actuator displacement as a function of test time for the final cycle of testing. Include both curves on the same plot if you can.

Plot 2: Stress-strain curve: Plot the average 1st Piola-Kirchoff shear stress component $P_{12}$ (this is the current force over the reference cross-sectional area, the “engineering stress” in Pascals) as a function of Green-Lagrange shear strain $E_{12}$ determined based on actuator displacement for the final cycle of testing (from neutral to peak). Explain shape of response.

Strain tensor from marker coordinates: Determine the components of the Green-Lagrange strain tensor within the region defined by the markers, assuming that the strain is homogenous within that region, using the equation:

$$ds^2 - dS^2 = 2E_{MN} dX_M dX_N \iff ds^2 - dS^2 = 2dX \cdot E \cdot dX$$

Assume that the out-of-plane shear strains ($E_{13}, E_{23}$) are zero. You have four markers, so you can construct six different “$dX$” vectors. This will yield six equations for the three unknown strains ($E_{11}, E_{22}, E_{12}$). You can determine these unknowns for every time that you have marker data during the test by solving the normal equations. Alternatively, you could use singular value decomposition. Matlab can be used for this analysis – see “mls”, “lsqnonneg” and “pinv” functions.

Plots 3-5: Generate three additional plots using the data from the above analysis

- $E_{11}$ (marker) and $E_{11}$ (actuator) versus test time
- $E_{22}$ (marker) and $E_{22}$ (actuator) versus test time
- $E_{12}$ (marker) and $E_{12}$ (actuator) versus test time

Provide a detailed explanation for any differences between the strains determined from the marker coordinates versus those determined from the actuator displacement.

Plot 6: Assuming incompressibility, calculate and plot the out-of-plane normal strain $E_{33}$ based on the values for the in-plane strain components determined from the marker data as a function of test time.

Turn in the 6 plots described above (2 pages max)

Interpret your results. Are they what you expected? Why or why not?
The verbal description of your results and interpretation section should be \leq 1 page.

Also include in discussion:
- Limitations of the experiment
- If the DMAS 2D calibration frame was not lined up according to the markers during calibration, what could we do to fix this problem?
- How the experiment could be improved.
Here is a suggested outline for your program:

- Read in X-Y coordinates for your experiment as a function of time from DMAS text file and labview text file.
- Remove rows from the labview data that have zeros for positional information. Feel free to use the following code:

```matlab
%Remove zeros from the labview data
[maxrow,maxcol] = size(Data_in);
i=1;
j=1;
while maxrow >= i
    if Data_in(i,1)~=0
        Data_out(j,:)=Data_in(i,:);
j=j+1;
    end
    i=i+1;
end
```

- Create loop to solve for strains from actuator displacement data and stresses from load cell / dimension data.
- Establish $dX_1, dX_2, dX_3, dX_4, dX_5, dX_6$ vectors from coords at start of test (these never change)
- Calculate $dS_1, dS_2, dS_3, dS_4, dS_5, dS_6$ (these never change)
- Loop over data for each time point
  - Calculate $ds_1, ds_2, ds_3, ds_4, ds_5, ds_6$
  - Set up $A\cdot x=b$ equations
    - $A$ will have dimensions 6x3, $b$ will have dimensions 6x1
  - Solve equations for unknown vector $x$, containing $E_{11}, E_{22}$ and $E_{12}$
    - Option 1 – set up and solve the normal equations
    - Option 2 - use “lsqnonneg” function in Matlab
- End of Loop
- Make Plots

**NOTES:**
- Dmas frequency for $[w_1, w_3, h_1, h_3]$ is 30 hz. Dmas frequency for $[w_2, w_4, h_2, h_4]$ is 6 hz.

**Appendix:**

Include the source code for your analysis program as an appendix to the report.