KIN 523 Winter 18
Homework Set 6 – Force Measurement Pavol

Due: 3/01/18

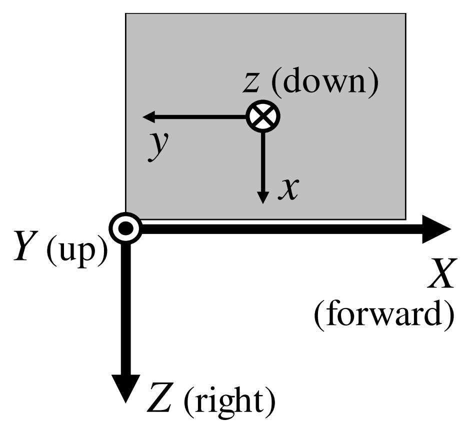
Answer the following problems.
You must show all work, including equations used, numbers substituted, and answers with units.
If Excel was used, e-mail a copy of the workbook to me.
If a computer program was used, either attach or e-mail me a copy of the program.
Your written portion must indicate what equations were used in Excel and/or your program.

Notes:

- If the equation to use is explicitly given to you in this assignment, you do not need to include the equation in the written portion of your submission.
- Due to the quantity of data involved (~2600 samples), DO NOT include any tables of the values for each sample in the written portion of your submission.

We used one of the Bertec force plates in the Biomechanics Lab to record the forces acting under an individual's left foot during a countermovement jump.

- The figure to the right shows the orientation of the *XYZ* axes of the motion capture system and the orientation of the *xyz* axes of the force plate.



- The origin of the force plate coordinate system (i.e. the center of the top surface of the force plate) is located at the point:

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = \begin{bmatrix} 0.300 \\ 0 \\ -0.205 \end{bmatrix} \text{ m}$$

within the *XYZ* coordinate system.

- The individual landed directly on the top surface of the force plate (i.e. no flooring material was placed on top of the force plate).
- The manufacturer-provided calibration matrix for the force plate is:

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} 612.8 & -2.9 & 0.1 & 1.4 & 0.1 & 0.7 \\ 5.5 & 616.3 & -3.3 & -1.8 & 0.2 & -7.5 \\ 30.6 & 2.7 & 945.1 & -2.7 & -10.4 & 3.5 \\ 0.4 & -29.0 & -0.7 & 351.3 & 1.5 & 0.6 \\ 25.6 & -0.2 & -0.7 & -0.7 & 246.9 & 0.3 \\ 0.8 & 0.6 & 0.6 & 0.5 & 0.6 & 143.8 \end{bmatrix} \begin{bmatrix} V_{FX}/G_1 \\ V_{FY}/G_2 \\ V_{FZ}/G_3 \\ V_{MX}/G_4 \\ V_{MY}/G_5 \\ V_{MZ}/G_6 \end{bmatrix}$$

where the *V* are in Volts, the forces are in N and the moments are in Nm.

- The manufacturer also states that the true origin of the force plate is located 0.044 m below the top surface of the plate.
- All of our force plate amplifier gains, G_i, were set equal to 2.

- We sampled the force signal at 1080 Hz.
- We used a 16-bit analog-to-digital (A/D) converter, with each of the 6 analog input channels configured as a bipolar signal with a range of ±10V.
- The sampled data were low-pass filtered with a fourth-order Butterworth no-lag filter with a cut-off frequency of 120 Hz.
- We will assume that, if the downward (+*z*) force acting on the force plate is less than 20 N, our participant's foot was not in contact with the force plate.

1. *(0.4 pts)* Assume that for one sample of one of its channels, the A/D converter output a digital value of 4673 counts. What was the corresponding voltage of the analog input signal to the A/D converter?

The comma-delimited file "Forces.csv", posted on Canvas, contains the data output by the force plate amplifier for one of our participant's jumping trials. The format of the file is as follows:

Column	Label	Description	Units
1	Sample	Sample number	
2	FX	Force in *x* direction of force plate	V
3	FY	Force in *y* direction of force plate	V
4	FZ	Force in *z* direction of force plate	V
5	MX	Moment about *x* axis of force plate	V
6	MY	Moment about *y* axis of force plate	V
7	MZ	Moment about *z* axis of force plate	V

For the data in "Forces.csv", do each of the following:

2. *(0.3 pts)* The Wheatstone bridge circuit in the force plate amplifier was not balanced perfectly; there is typically an error on the order of 0.2% FSO. We therefore first measured the voltages output by the amplifier when the force plate was unloaded. These baseline ("zero") voltages were:

   FX = 0.0595 V   FY = 0.0438 V   FZ = 0.0748 V

   MX = 0.0485 V   MY = 0.0519 V   MZ = 0.0497 V

   Correct the 6 voltage signals by subtracting the corresponding baseline voltage from the measured voltage:

   $V_{actual} = V_{measured} - V_{baseline}$

3. *(1 pt)* Using the calibration matrix and the amplifier gains provided, convert the 6 baseline-corrected voltage signals from problem 2 into the forces and moments acting on the force plate. These 6 forces and moments should be expressed within the *xyz* coordinate system of the force plate.

4. *(0.7 pts)* From the results of problem 3, compute the position of the center of pressure within the *xyz* coordinate system of the force plate as a function of time. Any time that the foot is not in contact with the force plate (see earlier definition), set the center of pressure position equal to the center of the top surface of the force plate.

5. *(0.4 pts)* From the results of problems 3 and 4, compute the "free moment", T_z, acting about the z axis of the force plate at the center of pressure.

6. *(1 pt)* From the results of the previous problems, convert the loads being applied to the force plate from the *xyz* coordinate system of the force plate into the *XYZ* coordinate system of the motion capture system. You must compute:
   a) The (X, Z) coordinates of the center of pressure;
   b) The force acting in each coordinate direction at the center of pressure (i.e. F_X, F_Y, F_Z);
   c) The "free moment" acting about the Y axis at the center of pressure (i.e. T_Y).

   Note: Because our motion capture system used the Y axis as upward and the Z axis as rightward, you will need to make the following adjustments to the equations given in the lecture notes:

   Y_{COP} in notes becomes $-Z_{COP}$ | Y_0 becomes $-Z_0$ | F_Y becomes $-F_Z$

   Z_{COP} in notes becomes Y_{COP} | Z_0 becomes Y_0 | F_Z becomes F_Y | T_Z becomes T_Y

   Everything else in the equations stays the same. It is suggested that you write out each adjusted equation and check it against the figure on the first page to see if it makes sense.

7. *(0.4 pts)* From the results of problem 6, determine the ground reaction force (GRF) and "free moment" acting on the participant's foot in the *XYZ* coordinate system of the motion capture system. You must compute:
   a) The force acting in each coordinate direction at the center of pressure (i.e. F_X, F_Y, F_Z)
   b) The "free moment" acting about the Y axis at the center of pressure (i.e. T_Y).

8. *(1.2 pts)* Graph the following over the duration of the trial:
   - F_Y acting on the foot vs. time
   - F_X and F_Z acting on the foot vs. time (both forces on the same graph)
   - T_Y acting on the foot vs. time
   - X and Z positions of the center of pressure vs. time (both positions on the same graph)

   You will need to compute the time from the sample number. For synchronization with the motion capture data, sample 0 must correspond to a time of 0 s.

9. *(0.4 pts)* From the results of problem 7, and using the aforementioned force threshold, find and report:
   a) The time of takeoff from the ground (i.e. foot no longer touching the ground);
   b) The time of touchdown with the ground (i.e. foot touching the ground again after takeoff).

   Times must be determined within 8.3 ms (i.e. within one motion capture frame at 120 Hz).

10. *(0.9 pts)* From the results of problems 7 and 9, compute and report the following:
    a) The participant began her upward motion leading to takeoff at about sample 927. What was the impulse generated by the vertical component of the GRF acting on the participant's foot between sample 927 and when takeoff from the ground occurred?
    b) What was the peak magnitude of the vertical component of the GRF acting on the foot after touchdown?
    c) Assuming that our participant had a mass of 56.3 kg, express the peak force from part (b) as a proportion of body weight (not body mass).

11. *(0.7 pts)* Determine the rate of change of the vertical component of the GRF acting on the participant's foot over the duration of the trial. In computing the rate of change, use a 5-point (i.e. 3.7 ms) moving window:

$$\frac{dF}{dt}(i) = \frac{F(i+2) - F(i-2)}{4\Delta t} = \frac{F(i+2) - F(i-2)}{t(i+2) - t(i-2)}$$

    where $F(i)$ and $t(i)$ are the respective force and time at sample i and Δt is the time between consecutive samples (= 1/[sampling frequency]).

    Express the rate of change in body weights per second and graph this rate of change of the vertical force vs. time for the trial.

    Note: You will not be able to compute a rate of change for the first 2 and last 2 samples using this method.

12. *(1.2 pts)* The peak shear force prior to takeoff occurs in sample 1101. For this one sample of baseline-corrected data from Problem 2, use only the 6 elements on the main diagonal of the calibration matrix to calculate, in the *xyz* coordinate system of the force plate:
    a) The forces acting on the force plate (i.e. F_x, F_y, F_z);
    b) The (x, y) location of the center of pressure.

    Based on the corresponding values you found for this same sample of data in problems 3 and 4, is using only the terms on the main diagonal of the calibration matrix a large source of error? Justify your answer.

    Note: You will need to take into account the location of the true origin of the force plate in your calculations.

13. *(1 pt)* During the countermovement jump, the participant faced in the $+X$ direction of the motion capture system. From the results of problems 8 and 9, describe:
    a) The patterns (i.e. relative magnitudes and directions over time) of the forces *acting on the participant's foot* in the sagittal (XY) plane over the course of the jump and landing.
    b) The corresponding anteroposterior (X) movement of the center of pressure relative to the foot.

14. *(0.4 pts)* Activities in which large GRF (approx. 3.5 – 5 body weights) are applied to the lower limb at high loading rates (approx. 500 body weights/s) have been promoted for improving or maintaining bone density. Would you expect countermovement jumps, as executed by our participant, to be effective in this? Justify your answer.