Experiment 1
Topic: Sensors/Measurement Systems/Calibration
Week A Procedure

Prior to performing the experiments, review relevant sensor data sheets and videos. Also, you or your partner should bring a flash drive to lab.

Overview:
In this laboratory exercise, the students will conduct a series of two experiments, Beerless Pong and Water Conservation, each involving the use and calibration of several sensors. These sensors include a photocell and 3-axis accelerometer. Data sheets for each of these sensors can be found on the course website. Additionally, the students will use strain gages to measure displacement and strain. Various signal processors for the sensors will be used, including a simple sensor interface box(SIB). The course website has links to videos demonstrating the sensor and SIB.

Part 1: Beerless Pong:
Single-handedly responsible for the loss of countless engineers to another “unnamed” college, beerless pong is one of the most widely played games among college students today. However, despite its mass appeal the game has not changed much over the past decade, until now. Using a cantilever mass measurement system based on strain gages and a Wheatstone bridge, you will perform a proof-of-concept experiment for a Beer Pong 2.0 system, specifically demonstrating a new key design feature, automatic scoring.

Setup and Data Acquisition
1. The cantilever apparatus is shown in Figure 1. It consists of a cantilever beam affixed with strain gages, an amplifier, and a integrated voltmeter that reads the output voltage from the bridge. The bridge has already been configured as a full bridge in deflection mode. To set the input voltage to the Wheatstone bridge, set the “Signal Select” button to “Bridge Excite”. The red LED display should indicate now the bridge excitation voltage. Set it to 5 V using the turning knob in the upper left corner. To read the bridge output voltage, set the “Signal Select” button to “Amplifier Out”. The LED display now shows the output bridge voltage, which has been amplified by an op-amp that is inside the voltmeter box.
2. Balance the Wheatstone bridge so that the output voltage is ~0 V. Make sure that there is no weight attached to the beam. The range of measured masses should be up to 50 g. Take your calibration weights and place 50 g in the Red Dixie Cup. Then change the amplification factor so that the output voltage is ~2 V.

3. Remove the weights and balance the Wheatstone bridge again. At this point, the settings on the voltmeter should not be modified (the amplification, the bridge balance resistance, or the input voltage) because the calibration will only be valid for these settings.

4. Calibrate the force balance by sequentially adding known weights and recording the resultant voltage. Because ping-pong balls are light, it is suggested to start at no weight and increase in small increments (5-10 g). At least 5 data points are required to generate the calibration curve.

5. Sequentially add ping-pong balls to the cup while recording the resultant voltage after adding each ball. Using this data and the actual weight (published value) of one ping-pong ball, one can estimate the accuracy of the measurement system.

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**Part 2: Signal Amplification Study – Beerless Pong 3.0:**

Recall that a measurement device that measures mass served as inspiration for our Beer Pong 2.0 system. However, while this approach would be sufficient for automatic scoring, it does not provide a mechanism for team recognition. So for Beer Pong 3.0, we will take an optical approach. Rather than attempting to measure the mass, we will measure whether the balls actually make it into the cup using the photocell sensor. Further, we will try to distinguish between teams using red balls and those using blue balls.
Background
Photocells use semi-conductors whose resistance changes upon exposure to light. Importantly, though, they respond differently to different parts of the electromagnetic spectrum – the photocells used in this lab are more sensitive in the visible spectrum as opposed to the infrared and ultraviolet spectrums. Referring to the photocell data sheet, it is clear that a CdS photocell is more sensitive for certain wavelengths than others. Since red and blue are at different wavelengths, a CdS photocell should be able to distinguish between them when they are in the cup.

Setup and Data Acquisition
1. Connect the photocell to the Sensor Interface Box. Recall from the YouTube tutorials that all the sensors in this lab require three things: power, signal and ground. The photocell sensor uses the red wire for power(5V), blue wire for signal and black for ground.
2. Take and record a dark and light reading by covering the sensor with your finger and holding the sensor to the overhead light, respectively. This is essentially a two point calibration.
3. Tape the photocell inside the cup (about midway) facing the bottom of the cup and record a baseline reading.
4. Insert the red ball and record a baseline reading. Repeat for the blue ball. Note that these measurements are not too different and that our signal needs to be conditioned to make these two readings more distinguishable.
5. Set one channel of the red dual op amp box(DOB) gain to switch setting 2. This will set the gain to 10.

For the next three instructions, refer to Figure 6 in Appendix A.
6. Connect the black wire on the DOB(channel A) to GND on the sensor interface box.
7. Connect the red wire on the DOB(channel A) to +5V on the sensor interface box.
8. Connect the output of the sensor interface box to the input of channel A(the remaining solid color wire).
9. Connect the output of the DOB(stripe color wire) to the input of the second channel of the sensor interface box.
10. Record the base photocell readings and amplified readings for the following cases: no ball in cup, red ball in cup, white ball in cup and blue ball in cup.

(Note: Experience has taught us that a gain on the order of 10 is necessary to see a difference in the red and blue signals.)
Part 3: Water Conservation:
Water is scarce in many places, especially in parts of Asia and Africa, and only becoming scarcer. One possible solution: Use less water. The average human requires 0.5 gal of water a day to survive. How many people could survive on the amount of water it takes to wash your hands? Using the accelerometer, design and calibrate a flow rate measurement system to determine the average amount of water consumed to wash one’s hands.

Setup and Data Acquisition
1. Connect the accelerometer to the Sensor Interface Box as shown in Fig. 2. Recall from the YouTube tutorials that all of the sensors in this lab require 3 things: power, ground, and signal. In this station, the red wire red is power, black is ground and white is the y-axis signal.

Caution: Do NOT connect the red wire to the 5 V supply. It requires the 3.3 V. Failure to follow this step will result in destroying the sensor.
2. Using the angle calibration fixture, record the output voltage as a function of pitch angle $\theta$. The accelerometer should be oriented such that the wires are hanging down when it is in the vertical position. When the $y$-axis sensor is vertical, it corresponds to 9.81 m/s$^2$ or 1 g. Conversely when the $y$-axis sensor is horizontal, it corresponds to 0 g. Be sure to include the horizontal and vertical positions in your data.

3. The output voltage is a linear function of acceleration (i.e. $V_{out} = A\alpha_y + B$). Draw the free body diagram for the accelerometer pitched at an angle $\theta$, and determine the theoretical formula for output voltage vs. pitch angle $\theta$. Define your coordinates such that horizontal corresponds to $\theta = 0^\circ$.

4. As shown in Fig. 3, wrap the sensor in plastic; fix it to the shaft so that the $y$-axis points down and is parallel to the shaft; clamp to the cold water faucet handle.

5. Calibrate the accelerometer measurement system by relating the angle of the faucet handle to flow rate where flow rate is calculated by dividing the volume of water collected in the beaker by the filling time. Record the flow rate and accelerometer voltage reading for at least 5 different angles. (In your analysis, you will use your formula from step 3 to convert the measured voltages to angles.)
Figure 3. Procedure to (a) place sensor in plastic, (b) affix to extension arm, and (c) clamp to cold water knob.
Week A Deliverables – You are required to include the following items in your lab report. (See the E1 score sheet for points.)

1. The equation of best fit for the linear calibration of mass vs. voltage for the Wheatstone bridge on the cantilever beam. A plot of the calibration data for the cantilever beam is not necessary.

2. Make a plot of measured mass vs. the discrete number of ping pong balls (discrete) with the theoretical, continuous line plotted on top. (Use your calibration equation from deliverable #1 to convert the voltages to mass.) Apply a linear curve fit to the data and use the slope to estimate the mass of a single ping pong ball. Plot the curve fit on top of the data as a continuous line.

3. A table containing the recorded photocell voltages and amplified voltages for the different colored balls and the empty cup.

4. A plot of accelerometer voltage vs. pitch angle $\theta$ with a derived theoretical trigonometric curve that you came up with.

5. A plot of flow rate vs. the angle of the faucet handle $\theta$. Use the theoretical equation from deliverable 4 to calculate the faucet angle $\theta$ from the measured accelerometer voltage. Include a non-linear curve fit that captures the behavior of the system. You may use any type of function you like for the curve fit, except for a polynomial. (Do not use a polynomial!)

Suggested Talking Points

- Estimate the relative error of your measurement in the mass vs. number of ping pong balls. What does this suggest if this configuration were used in the automatic scoring feature on the beer pong 2.0 system? (Would this feature work? Does this signal need amplification? Is the system sufficiently sensitive? Is the calibration sufficient?)

- Download the data sheet for the photocell on Prof. Ott’s website. Use it to explain why the different colored balls produce yield different output voltages.

- Estimate the average amount of water consumed to wash your hands. The average human requires 0.5 gal of water a day to survive. How many people could survive on the amount of water it takes to wash your hands?
Appendix A

Equipment

- Cantilever Apparatus: (includes mounted strain gages with wire leads, an amplifier, and an integrated voltmeter, configured to read output voltage from full Wheatstone Bridge in deflection mode)
- Ping Pong Balls: (50 – both white and colored)
- 1 g – 50g slotted weight set
- 3 – axis Accelerometer with wire leads(female connectors)
- Accelerometer extension cord: (3 wire - 18” in length; male to female connectors)
- Digital Protractor
- Sensor Interface Box (SIB) w/ 9V battery and 9V power supply
- Water, Sink, and Faucet
- Faucet Handle Clamp w/12” extension rod
- Small Plastic Bag
- Medium Alligator Clamp
- Stop watch
- 2 L beaker
- Red Op Amp Box
- Set of 3 - Leads (12”- red, yellow , black)(3 – prong plastic-snap connector to 3-wire leads(female end connector – for Red Op Amp Box)
- Set of 3 - Leads (12”- red and white striped, yellow and white striped , black and white striped )(3 – prong plastic-snap connector to 3-wire leads(female end connector– for Red Op Amp Box )