Experiment A9
Practical Implementation of Sensors
Procedure

Deliverables: Checked lab notebook, Brief Tech Memo

Overview

In this laboratory exercise, you will examine the practical use and calibration of several sensors in a couple of everyday devices such as a popular party game and a Play Station 3 game consol. These sensors include an RTD, thermistor, photodiode, and strain gauges. Data sheets for each of these sensors can be found on the course website. Various signal processors for the sensors will be used, including the sensor interface box (SIB), which has a power supply and digital voltmeter for the various transducers. The course website has links to videos demonstrating the sensor and SIB.

Part I: 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 two decades… until now. Using a cantilever mass measurement system based on strain gages in 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. Sketch a schematic of the cantilever beam setup in your lab notebook and write a brief description of the apparatus.

2. 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 operational amplifier that is inside the voltmeter box.

3. 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.
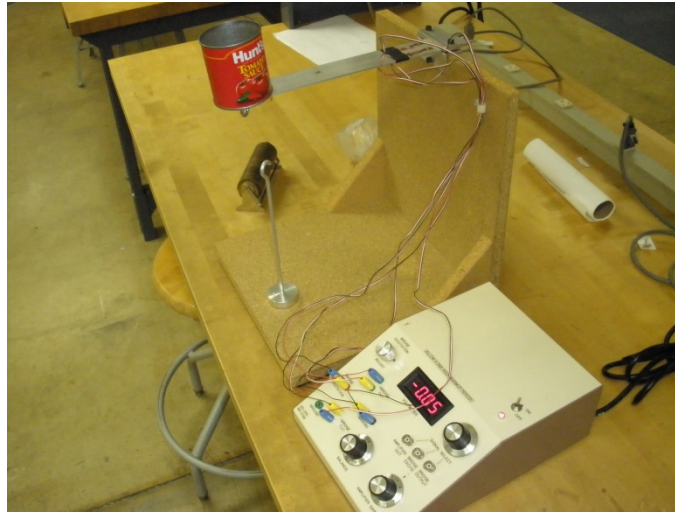
Figure 1 – The cantilever beam with strain gauges mounted in Wheatstone bridge circuit forms a "load cell" that can be used to detect when ping-pong balls

4. 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.

5. Calibrate the force balance by sequentially adding known weights and recording the resultant voltage in a table in your lab notebook. 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.

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

Part II: 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 photoconductive sensor. Further, we will try to distinguish between teams using red balls and those using blue balls.

The photoconductive sensor uses a semi-conductor 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.

NOTE: The Op-Amp box is powered by a $V_{cc} = 5$ V. The maximum amplifier output 4.9 V. Any theoretical output greater than 4.9 V will be clipped to 4.9 V. Notify the TA if the output voltage is clipped.

Setup and Data Acquisition

1. For the next four instructions, refer to Figure 2. Be sure to record BOTH sensor interface box channels when making measurements. Use a descriptive label for both channels (voltages) in your lab notebook.

2. 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

3. Connect the black wire on the red dual Op-Amp box (channel A) to GND on the sensor interface box.

4. Connect the red/white wire on the Op-Amp box (channel A) to +5V on the sensor interface box.

5. Connect the output of the sensor interface box to the input of channel A(the remaining solid color wire).

6. Connect the output of the Op-Amp box (stripe color wire) to the input of the second channel of the sensor interface box.

7. Make sure the dual Op-Amp box gain switch is set to #2, which gives a gain of $G = 10$.

8. Measure the dark and light voltage by covering the sensor with your finger and holding the sensor to the overhead light, respectively. Record these values in your lab notebook. This is essentially a two point calibration.

9. Tape the photocell inside the cup (about midway) facing the bottom of the cup and record a baseline reading. Be sure not to move the cup too much, as a subtle change in lighting will affect the data.

10. Insert the red ball and record a baseline voltage in your lab notebook. 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.

11. In your lab notebook, 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.)

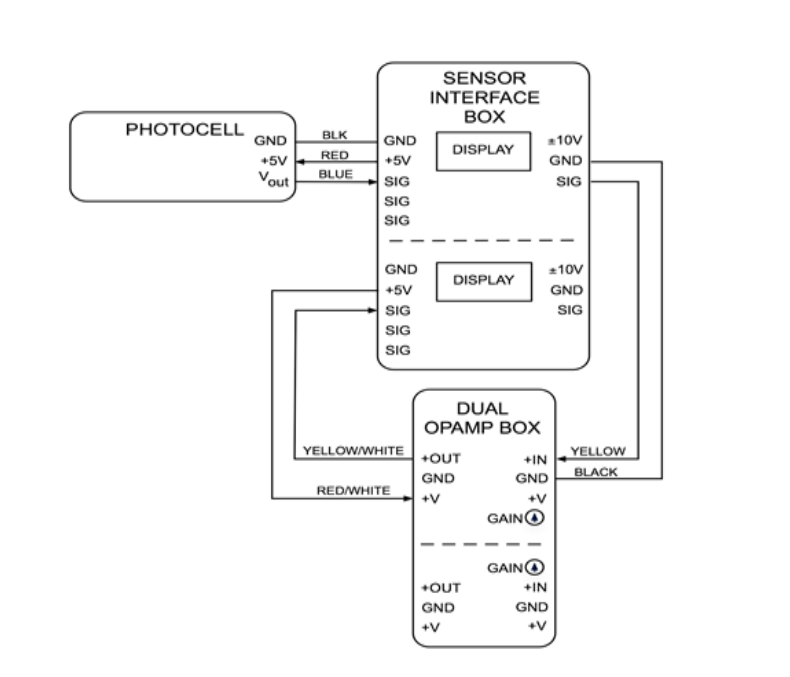| Switch Setting	Gain
0	100.
1	20
2	10
3	7
4	5
5	4.2
6	3.4
7	3
8	2.0
9	1.9

Figure 2 - Wiring Diagram of photocell and red dual operational amplifier box.

Part III: PS3 Hot Shot

Background

In the fast paced industry of console gaming, advanced graphics are pushing hardware to design limits. The result is increased heat production by the CPU, which can cause the gaming console to overheat and fail. In this lab exercise, you will examine how the game console heats up and utilizes its CPU fan to remove heat. Temperature will be measured using a thermistor, and the fan speed will be measured using a laser diode and photocell to form an *optical tachometer*.

Experimental Procedure

This lab exercise will be performed in groups of four, and you will need to divide the following tasks amongst yourselves:

- **Official Time-keeper** – Control the stopwatch and announce the start time and every single minute increment of the clock.

- **Thermistor Expert** – Connect the thermistor to the LabQuest, record the data at the proper sampling rate, transfer the data to the computer, and email the data to everyone in the group.

- **Fan-speed Guru** – Connect the photocell to the other LabQuest, align the "laser" with the photocell, record the data at the specified intervals, transfer the data files to the computer, and email the data to everyone in the group.

- **Elite Gamer** – Turn the PS3 on and off. Kill zombies.

After you have chosen a task, read the section corresponding to your task, and set up your equipment properly. (You only have one job, and everyone is counting on you!)

A. Time-keeper

When the game loads the level, you will start the stopwatch and tell everyone to go. You will then announce every single minute up to 10 minutes.

B. Thermistor

All of the sensors in this lab require 3 things: +5V Power (Red), Ground (Black), and Signal V_{out} (Blue). On the LabQuest Connector, orange is power (+5V), black is ground, and red is the signal.

1. Configure Channel 1 of the LabQuest for **Raw Voltage [0-5V]**:

   a. Tap the **Sensors** tab at the top of the screen.

   b. Then tap **Sensor Setup** then **Voltage** on the drop down menus, select **Raw Voltage [0-5V]**, and tap **OK.**

   c. Tap the **Rate** window on the right side of the screen to access the "Data Collection" window. This will allow you to set the sample rate and duration. Set the data acquisition rate to **60 samples/min for 10 min**.

2. Match the colors to connect the Thermistor (wires labeled "TH" coming from the PS3) to Channel 1 on the LabQuest.
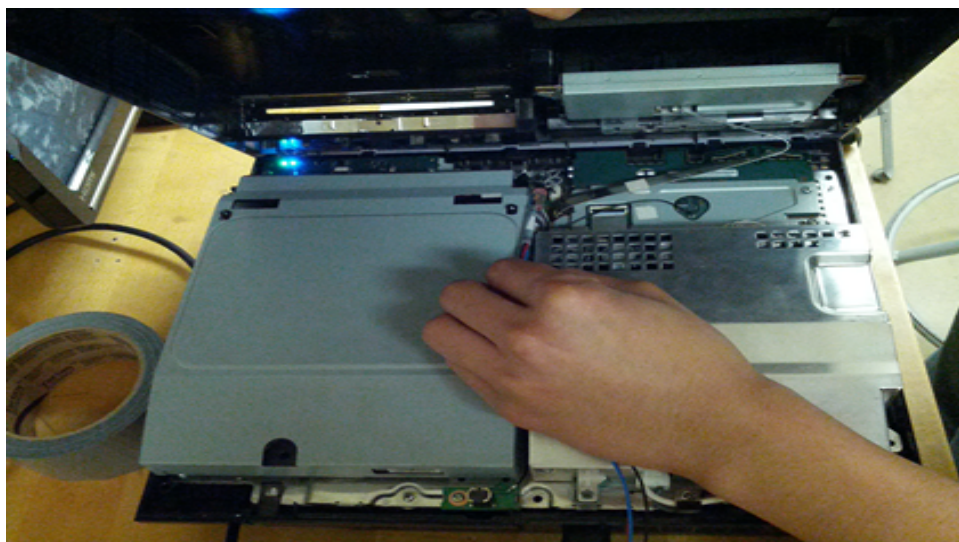
Figure 5 - Placement of the RTD in the PS3.

(a)   (b)
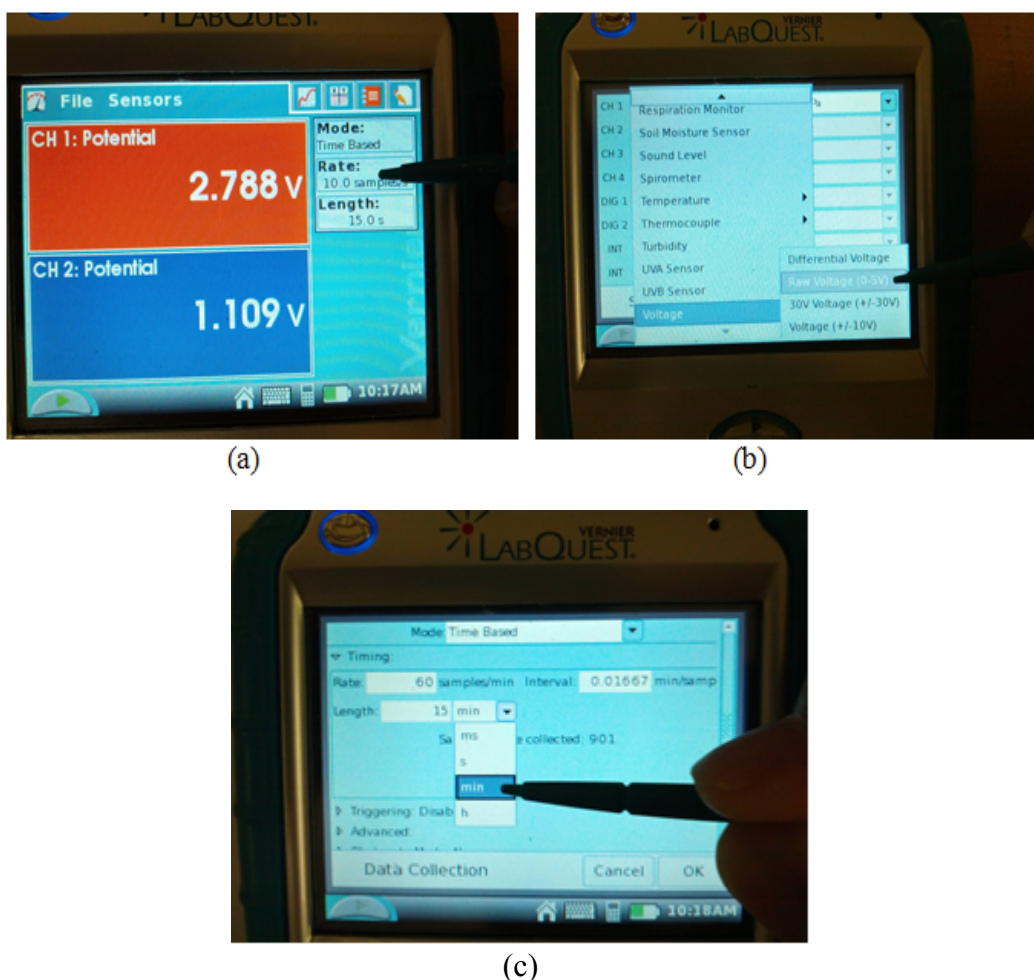

(c)

Figure 6 – (a) Set the sampling frequency in the LabQuest, (b) configure the channel, and (c) set the sampling duration.

B. Thermistor (Continued)

3. When the gameplay starts and the time-keeper says "go", press the green start button on the LabQuest screen to begin collecting data.

4. When the 10 minute run is up, press the file cabinet icon to store the data. Transfer the data to the computer using the USB cable and the Logger Pro software. Export the data as a .csv file and email it to everyone in your group.

Pro-Tip: Give your data intelligent, descriptive file names when you export it. Giving it a dumb name like "data.csv" will only create problems down the road for you and your group members.

5. Disconnect the LabQuest from the computer, return it to the PS3, and tap **File New** on the LabQuest to reset it for the next group.

6. Use the voltage divider equation and Steinhart equation to convert the sensor voltages to temperatures. Details can be found in the document on the A9 lab webpage.

C. Fan Speed

A photocell is mounted directly above the fan, pointing down in the PS3. A green laser diode passes betwixt the fan blades and strikes the photocell. As the blades spin, they eclipse the laser beam, causing the sensor voltage to periodically decrease. Thus, the voltage oscillates at the same frequency as the "blade passage rate". Dividing this rate by the number of blades ($N = 15$ blades) gives the fan speed in Hz.

1. Connect the Photocell to Channel 1 of the LabQuest. See the wiring diagram in Appendix B for details.

2. Configure Channel 1 of the LabQuest for **Raw Voltage [0-5V]**:

    a. Tap the **Sensors** tab at the top of the screen.

    b. Then tap **Sensor Setup** then **Voltage** on the drop down menus, select **Raw Voltage [0-5V],** and tap **OK.**

    c. Tap the **Rate** window on the right side of the screen to access the "Data Collection" window. This will allow you to set the sample rate and duration. Set the data acquisition rate to **20,000 samples/sec for 0.1 sec**.

3. Position the laser underneath the fan of the PS3. The final setup should look like Figure 7.

4. Connect Laser to bench power supply. Red to Red. Black to Black.

5. Turn on Power Supply. Set output Voltage to 6V.

6. Try to adjust the laser such that the photocell output is greater than 0.3V. If you are having trouble, ask the lab instructor for help.

7. When the gameplay starts and the time-keeper says "go", press the green start button on the LabQuest screen to begin collecting data.

8. The LabQuest will record data for only 0.1 seconds. When it is finished, press the file cabinet icon to store the data

9. When the time-keeper calls out each subsequent minute, press the green start button and file away the data.

10. When the 10 minute run is up, press the file cabinet icon to store the data. Transfer the data to the computer using the USB cable and the Logger Pro software. Export the data as a .csv file and email it to everyone in your group.

Pro-Tip: Give your data intelligent, descriptive file names when you export it. Giving it a dumb name like "data.csv" will only create problems down the road for you and your group members.

11. Inspect the data in the Logger Pro software. You should see a series of oscillations corresponding the fan blades blocking the laser beam.

12. Disconnect the LabQuest from the computer, return it to the PS3, and tap **File New** on the LabQuest to reset it for the next group.
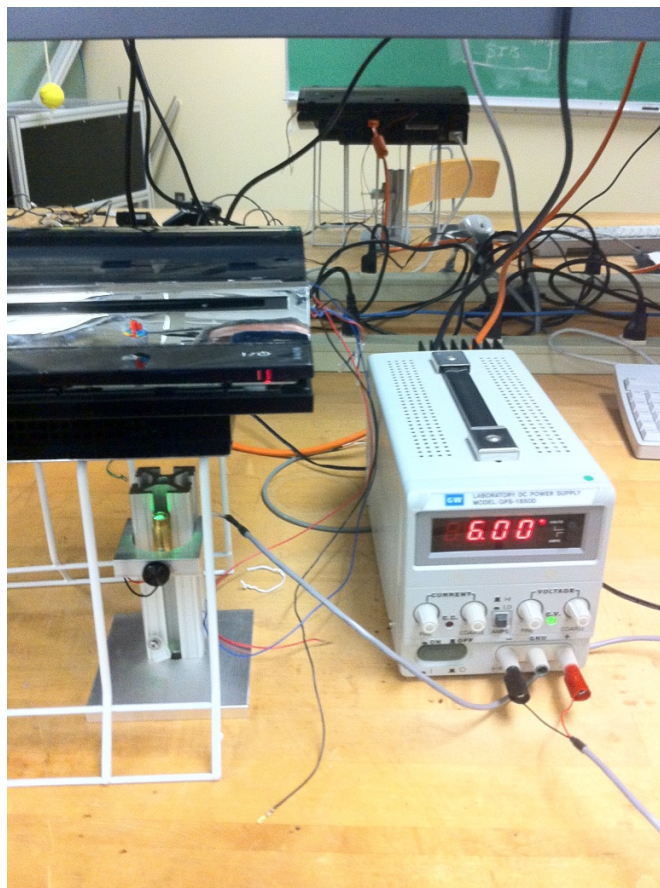

Figure 7 - Clamping and alignment of laser for photocell measurements of fan speed.

D. Gamer

Caution: You will be operating the PS3 at temperatures near the upper design limit, failure to follow these steps correctly will damage the console!

1. **DO NOT POWER ON THE PS3 UNTIL THE LAB INSTRUCTOR HAS CHECKED YOUR SET-UP.**

2. Power on the PS3, make sure the controller is correctly paired, and load the game.

3. Select Zombies and load the level. The time-keeper should tell everyone to start when the gameplay loads. The other group members should begin data acquisition simultaneously on both LabQuests at mission start. Once started, LabQuest 1 (heat sensors) will run unattended until the experiment is completed. LabQuest 2 (photocell) will sample data for 0.1 seconds then stop and repeat every minute.

4. When the 10 minute run is finished, quit the game and turn off the PS3.

5. Help your group members export the data from their LabQuests.

Data Analysis and Deliverables

Create plots and other deliverables listed below. Save the plots as PDFs, import them into either Microsoft Word or LaTeX, and add an intelligent, concise caption. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend. **Additionally, write 1 – 3 paragraphs describing the items below. Any theoretical formula you used in your analysis should be included as a numbered equation within these paragraphs.**

1. A plot of the calibration data (mass as a function of voltage) for the cantilever beam with the linear equation of best fit.

2. Make plot of measured mass vs. the discrete number of ping pong balls. (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 raw photocell voltages and amplified voltages for the different colored balls and the empty cup.

4. For one of the PS3 fan speed measurements, make a plot of the photocell output voltage vs. time for several periods of oscillation. Draw lines on the graph to indicate one full period of oscillation. In your paragraph, explain how this was used to determine the fan speed.

5. A single plot containing *both* the temperature vs. time for the thermistor (on the left scale) *and* the fan speed in RPMs vs. time (on the right scale). Use either the 'plotyy' or 'yyaxis' command in MATLAB to do this.

    NOTE: You must use the Thermistor calibration sheet from the lab webpage to convert your voltages to temperatures.

    NOTE: The fundamental frequency of the photocell output is essentially the "blade passage rate", and there are **15 blades** on the fan of the PS3.

Talking Points – Please address the following questions in your paragraphs.

* Estimate the relative error of your measurement in the mass of a ping-pong ball. 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? Is the system sufficiently sensitive to detect a single ping-pong ball?

* Qualitatively discuss the relationship between the temperature and fan speed. In particular, why did the engineers at Sony, design the PS3 with variable fan speeds?

* Look up the processor specifications for the PS3. How much heat (in watts) does the processor typically produce?

Appendix A

Equipment
Part I - Beerless Pong
- 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
- 10 - Ping Pong Balls: (both white, dark blue and colored)
- 1 g – 50g slotted weight set
- Pill bottle with 1 g and 2 g weights
- Sensor Interface Box (SIB) w/ 9V battery and 9V power supply
- 1 roll scotch tape on counter
- Red opamp box with 2 sets of leads
- photocell
- Gray extension cable for photocell

Part II - PS3 Hot Shots
- Play Station 3 (Thermistor w/ wire leads already mounted in unit heat sink; Photocell w/ wire leads already mounted directly above fan) (female end connectors)
- Orange HDMI Video cord, 6' length(from PS3 to monitor)
- Computer monitor with HDMI input connection
- PS3 controller w/ white extension cable, 6' length(from controller to PS3)
- White wire support Rack (supports PS3 over laser assembly)
- 2 LabQuests w/stylus
- LabQuest connector cable w/ 3-wire leads(female connector ends) (Qty. 2)
- 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)
- Laser pointer w/ 24" cable lead ending in 1 black and 1 red (m/f)banana fitting
- 80/20 - Laser Clamp Stand w/ aluminum slide bracket and plastic mounting screw
- GW Power Supply GPS – 1850D – used to supply power for laser
- USB to USB cord – 4' length (data from Labquest to computer)
- Stopwatch

Appendix B