AME 21213: Measurements and Data Analysis Lab
Technical Memo

Date Submitted: Wednesday, February 15, 2017
Dates Performed: February 1, 2017 & February 8, 2017 (Wednesdays 4:30 - 5:20 PM)

To: Devon Mason
From: [redacted]

Subject: Lab E1 – Beerless Pong, Water Conservation, and PS3 Hot Shot

Summary:

In this lab, three distinct experiments were conducted. First, a system for scoring beerless pong was developed by measuring the number of of ping-pong balls in a cup and identifying the color of said balls ~~was tested~~. The system found the mass of a single ping-pong ball to be 2.723 g, .85% different from a standard value 2.700 g [1]. The system was also able to distinguish between red, white, and blue balls by comparing the amplified output voltages of a photocell mounted inside the pong cup (see Table 1). Both results demonstrated the system's effectiveness. The second experiment correlated the flow rate of a faucet to the angle to which the faucet lever was opened. From the results, it was extrapolated that the average person uses .66 gal of water washing their hands daily, and that this usage could be more than halved (to .25 gal/day) by limiting the faucet's degree of operation to 45°. The third experiment measured the internal temperature of a PS3 and the corresponding fan speed during operation. The results showed that the internal temperature and the fan speed of the PS3 are positively correlated. Additionally, the heat dissipated from the Central Processing Unit (CPU) was considered. This is a really nice summary! :)

Findings:

Experiment 1: A cantilevered beam with a cup mounted to the free end was configured in a full Wheatstone bridge configuration with two identical strain gauges mounted to the top and bottom faces of the beam. When a load was applied to the beam, say the mass of a ping-pong ball, the beam underwent strain which in turn extended the wire in the top strain gauges and compressed the wire in the bottom strain gauges. Strain gauges operate by linearly correlating an output voltage to the resistance of the gauge, which is given by Eqn. 1 below where ρ is the resistivity of the gauge material, A is the effective cross-sectional area of the wire, and L is the length of the wire. R = resistance.

$$R = \frac{\rho L}{A} \tag{1}$$

From Eqn. 1, it is apparent that resistance is linearly proportional to wire length. It is known from Hooke's Law and the definition of strain that the change in length of the wire ΔL is linearly proportional to the mass applied to the beam m. Therefore, the output voltage of the strain gauges in the Wheatstone configuration could be linearly related to the mass applied to the beam. Eqn. 2 below is a linear correlation model relating the output voltage of the Wheatstone bridge V to the mass applied to the beam m.

$$V = 0.042m + 0.039 \tag{2}$$

Using this equation, output voltages recorded for different numbers of ping-pong balls added to the mounted cup were converted to masses, and, again, a linear correlation model was found relating the number of ping-pong balls added to the recorded mass. Both the raw data and the linear correlation model are shown in Figure 1 below.

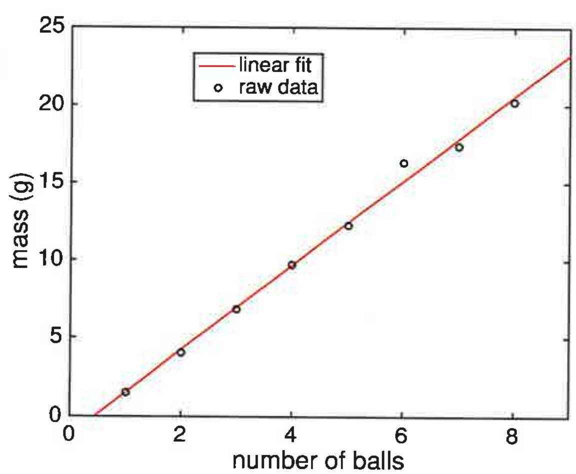

Figure 1: A plot of the number of ping-pong balls added vs. mass g and a linear fit of the data.

From the slope of the linear model, the mass of a ping pong ball was experimentally found to be 2.723 g with an error of .85% from the standard value 2.700 g [1]. That the error of the calculated mass for a single ball is so minute suggests that the the system is sufficiently sensitive to determine the number of balls in the cup. However, the amplification of the output signal is still necessary in that the amplified output voltage for a single ball is very small (0.1 V). If the signal was not amplified, the bridge would not be sensitive enough to detect a single ball. To determine the color of the ping-pong balls in the cup (and, consequentially, which beerless pong team scored), a photocell was mounted inside the cup and card board placed over the cup to shade it and simulate a real beerless pong environment. The photocell was connected to an amplifier with a gain of 10 to more clearly differentiate the response of the photocell to different light intensities, and then the amplified output voltages for a red, a white, and a blue ball (as well as no ball in the cup) were recorded as shown in Table 1 below.

Table 1: Photocell voltages for different colored ping-pong balls.

Color	no ball	red	white	blue
Voltage (V)	.30	.24	.31	.20
Amplified Voltage (V)	3.20	2.58	3.43	2.30

As seen in Table 1, the photocell can distinguish between the three different colored balls. The reason for this difference in the output voltages is the photocell's sensitivity to different light wavelengths: the sensitivity to blue wavelengths (450 nm) being about 15% and the sensitivity to red wavelengths (700 nm) being about 95% [2]. Because the photocell is more sensitive to red wavelengths of light, it will output a larger voltage for a red ball than for a blue ball for a given intensity of light. The difference in output voltage of the white ball is because the white ball reflects all wavelengths of light causing the photocell to feel a greater light intensity than the red and blue balls do. However, it is suggested that white balls not be used in the beerless pong system being that the interior of cups typically used for the game are white, which could result in false positives.

Experiment 2: In this experiment, the correlation between the flow rate of a faucet and the angle to which the faucet lever was opened was studied. To determine the angle of the faucet lever, a capacitative accelerometer was used. Before being used, however, the accelerometer was calibrated by recording the output voltage of the accelerometer at several known angles. Capacitative accelerometers operate on the principle that the force due to gravity on the parallel sides of a capacitor will change the distance between the two sides, hence changing the capacitance of the the capacitor, which the accelerometer linearly relates to an output voltage. Because the force due to gravity on the accelerometer can be modeled as the force of gravity on an object on an inclined plane (Eqn. 3), the output voltage of the accelerometer can be trigonometrically related to the angle of the accelerometer as shown in Eqn. 4.

$$F = \frac{m}{g} \sin\theta \tag{3}$$

$$V = A \sin\theta + B \tag{4}$$

From the calibration, the values of A and B are found to be 0.320 and 1.76 respectively. Actual output voltages of the accelerometer used for calibration and the theoretical trigonometric relationship (Eqn. 4) are shown in Figure 2 below.

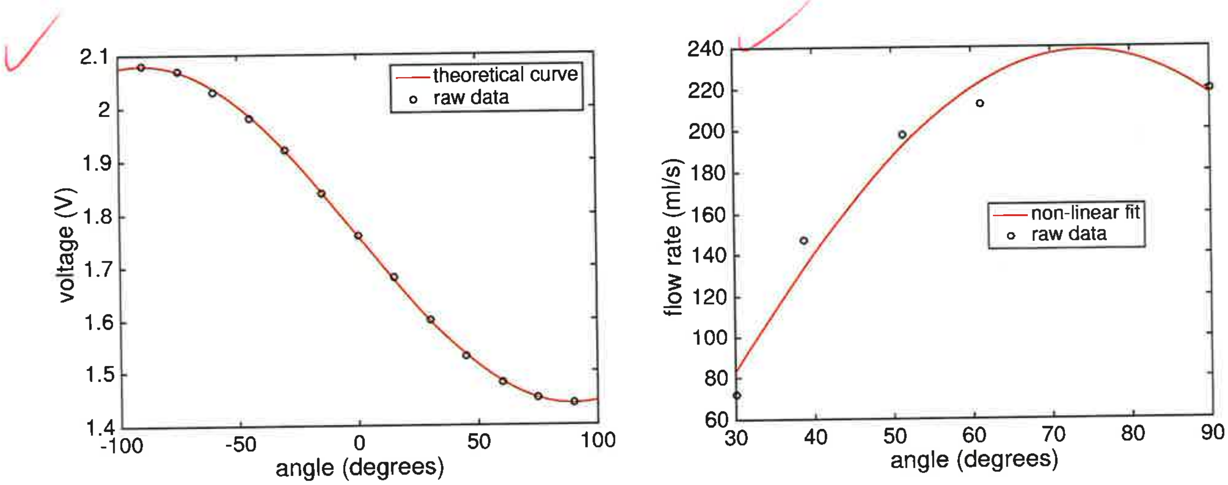

Figure 2: Plots of accelerometer voltages at known angles and a theoretical trigonometric curve (right), and the flow rate of the faucet vs. angle of the faucet lever and a trigonometric fit (left).

After calibrating the accelerometer, the accelerometer was attached to the faucet lever to measure the angle to which it was ajar, and the times which it took the faucet to fill up a 1000 ml beaker at different angles were recorded. A illustration of the experimental setup can be seen in Appendix A. The flow rates of the faucet were found by dividing the volume filled (1000 ml) by the time it took to fill. A plot of flow rate versus the angle of the faucet lever is shown above in Figure 2. Also shown in Figure 2b is theoretical trigonometric model of the flow rate described by the equation,

$$\dot{V} = 238.6 \sin(.02740\theta - .4664) \tag{5}$$

where $\dot{V}$ is flow rate and θ is the angle of the faucet lever. This model was derived by considering the mechanism of the faucet which is controlled by a ball valve. For a ball valve, the rate at which flow is allowed through the valve ($\dot{V}$) is linearly dependent on the effective area of the valve opening. This effective area changes sinusoidally with the angle to which the ball valve is opened, so the flow rate through the valve is also related sinusoidally to the angle. Using the model in Eqn. 5 and assuming that people on average wash there hands 5 minutes a day with faucets completely open ($\theta = 90$), it is estimated that the average person consumes 0.66 gal of water a day, a little more than the 0.5 gal necessary for a human to survive [3]. One way to conserve more of the water used for washing hands would be to limit the angle to which faucets can be opened. If faucets were prevented from opening more than 45°, the average person would reduce their daily water waste from washing their hands to 0.25 gal. Assuming the undergraduate population of Notre Dame to be roughly 12000, about 4900 gal of water would be saved on campus daily by restricting faucets.

Experiment 3: In the third experiment, the internal temperature of a PS3 and the corresponding fan speed were measured and compared. To measure the internal temperature, a RTD was mounted between the PS3's power supply unit and blue ray player and the output voltage of the RTD was related to air temperature (see [4]). To measure the fan speed, a laser and a photocell were mounted on either side of the fan. When the fan blades came between the laser and the photocell, the output voltage of the photocell would dramatically change; the voltage signal was then processed using a Fast Fourier Transform (FFT) to find the fundamental frequency of the signal, which was subsequently divided by the number of fan blades (15) to yield the fan speed for a give time interval. Additionally, the temperature of the CPU heat sink was monitored with a thermistor to prevent the PS3 from reaching critical temperatures (170 F°). A plot of the internal temperature, CPU temperature, and fan speed versus time is given in Figure 3 below.

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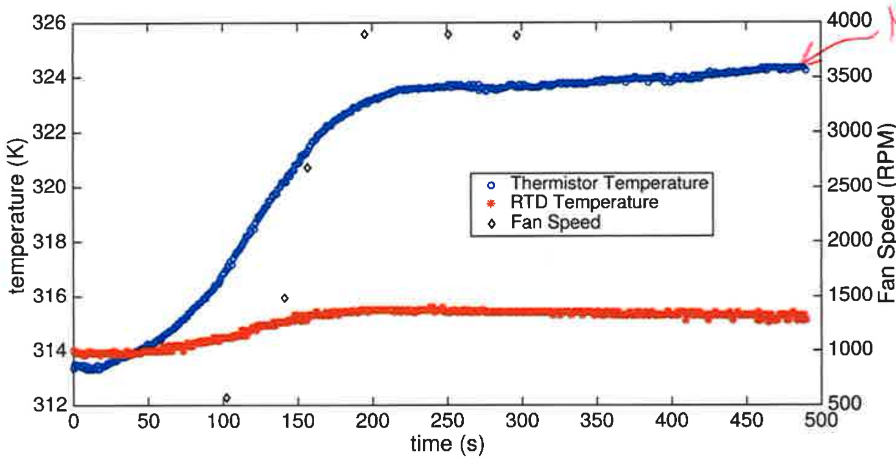

Figure 3: A plot of the internal temperature, CPU temperature, and fan speed vs. time of a PS3 during operation.

As seen in Figure 3, fan speed is positively correlated with the CPU and internal temperatures which is what one would expect. The hotter the PS3 got the faster the fan spun to more effectively convect away heat. The reason that the fan is designed to operate at variable speeds (instead of always operating at the maximum speed) is to conserve power and the durability of the fan. When the fan is running at its maximum speed, it requires more power than it would at lower speed and is, consequentially, less economical. Additionally, operating at its maximum capacity all the time means the fan undergoes more wear and is prone to break sooner. To have a comparable lifetime to a variable speed fan, Sony would have to use more durable and expensive fans if the fans were to operate at their maximum speed. However, manufacturers must also balance efficacy with economy. From PS3 technical specifications [5], the average power consumption of a third generation PS3 CPU is around 200 W and its dimensions are 65 nm by 65 nm. From the first law of thermodynamics, the time rate of change of temperature of an object is directly proportional to the power exerted on it and inversely proportional to its volume; so, because the volume of the

CPU is very small, the change in temperature of the CPU, without a heat removal mechanism, is very rapid. For this reason, the PS3 fan must be efficient to prevent the CPU from overheating.

Conclusions:

In experiment 1, a beerless pong system was implemented using a full Wheatstone bridge and a photocell to determine the number of balls in a cup and to which team the balls belonged. The bridge very reliably (with a relative error of .85%) measured the mass of different numbers of balls in a cup and the photocell distinguished between red and blue balls (about a .3 V difference). It is suggested that white balls not be used with the system to avoid false positives being that the typical beerless pong cup has a white interior. In experiment 2, the flow rate of water out of a faucet was compared to the angle at which the faucet was opened. From the experimental results, it was calculated that the average person uses .66 gal of water washing their hands daily, and that this usage could be more than halved (to .25 gal/day0 by limiting the faucet's degree of operation to 45°. In experiment 3, the CPU and internal temperatures and the corresponding fan speed of a PS3 were measured during operation, and the temperatures and fans speed were found to be positively correlated. Additionally, the power and size of the PS3 CPU were considered to explain the need for an powerful and effective fan.

References:

[1] Allain, R., 2012, October 20, "Super Fast Ping-Pong Ball Gun", Wired Science.
[2] AME21213, Spring 2017, "CdS Photoconductive Cells Data Sheet", http://www3.nd.edu/ jott/Measurements/Sensors/photocell.pdf.
[3] AME21213, Spring 2017,"Sensors/Measurement Systems/Calibration", Lab E1a, University of Notre Dame, Notre Dame, IN.
[4] AME21213, Spring 2017, "RTD/Thermistor Calibration", http://www.3.nd.edu/ jott/Measurements/Sensors/E1-thermal-revised.pdf.
[5] "PlayStation 3 technical specifications," Wikipedia, 13-Feb-2017. [Online]. https://en.wikipedia.org/wiki/PlayStation-3-technical-specifications.

Appendix A:

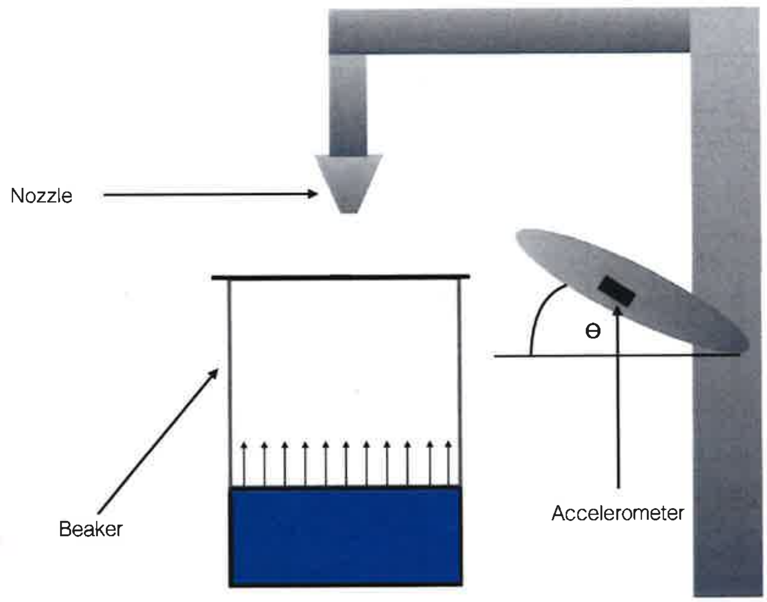

Figure 4: A schematic of experimental setup of experiment 2.

AME 20213: Measurements and Data Analysis
Technical Memo

Date Submitted: 02/15/2017
Dates Performed: 02/01/2017 and 02/08/2017 at 3:30 PM

To: Prof. Ott
From: [redacted]
Subject: Lab Exercise 1 - Measurement Systems/Calibration

great report

Summary:

Three different studies were performed during this exercise. The first study used a system of strain gauges and a cantilevered beam to measure the mass of Ping-Pong balls and a photocell to capture color sensitivity in order to assess the possibility of automated scoring in a game of beerless pong. ~~However, r~~ R esults were mildly inaccurate, with an overall relative error of 49.6% between the experimental mass and the known mass of a ping-pong ball. The second study calculated the flow rate of water as a function of the faucet angle using a three-axis accelerometer. This experiment showed that flow rate increases as the faucet angle increases. ~~In addition, i~~ It was estimated that two

active voice

→ 2 ~~the most~~ humans ~~that~~ could survive ~~every~~ on water typically used to wash one's hands ~~...~~

humans could survive a day with the average amount of water it takes to wash one's hands. Finally, estimated to be ...

the third experiment used a thermistor and a resistive temperature detector (RTD) to measure the temperature of a PlayStation3 (PS3) game console. A laser and photocell system were used to calculate the fan speed inside the console. The relationship between the temperature and the fan speed was then analyzed, which showed how the fan reacted to the internal temperature of the PS3. However, the RTD returned incorrect data, which did not contribute to the study of the PS3.

Tell the result don't just say you looked at it

Findings:

Study 1: A cantilever mass measurement system, sketched below in Figure 1, used strain gauges and a Wheatstone bridge configuration to measure mass by recording the output voltage when small masses and later ping-pong balls were placed inside the cup on the edge of the beam.

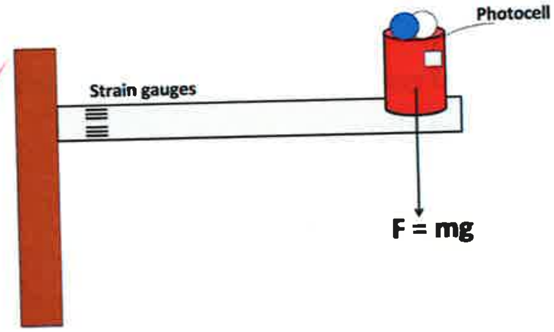

Figure 1: Schematic diagram of the cantilever beam set-up used in Part 1 of the lab to measure mass and color sensitivity of Ping-Pong balls.

Equation 1 below represents the best fit for the linear calibration of mass vs voltage on the cantilever beam, and was found by fitting a line through the calibration data points.

$$m_e = (2.75 \pm 2.26)V_{out} + (2.01 \pm 1.41), \tag{1}$$

Here, m_e is the experimental data and V_{out} is the output voltage measured by the strain gauges. Using this calibration equation, mass vs number of ping-pong balls was plotted in Figure 2.

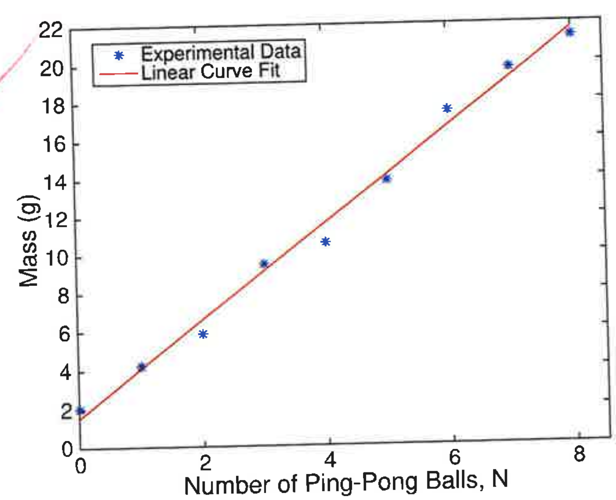

Figure 2: Data points represent the measured mass of the ping-pong balls. The line represents the linear curve fit applied to the data points.

The linear curve that best fits the data is given by Equation 2 below, where m_t is the theoretical mass of the ping-pong ball and N is the number of ping pong balls.

$$m_t = (2.51 \pm 0.20)N + (1.53 \pm 0.96), \tag{2}$$

According to Equation 2, the mass of a single ping-pong ball should be about 4.04 grams, which is way above the published value of 2.7 grams. This deviation from the known mass was caused by a hysteresis of -0.4 volts during the calibration of the Wheatstone bridge. The plotted values in Figure 2 were modified to correct for this effect, which lead to an inaccurate theoretical linear fit. The relative error of measurement in the mass vs number of ping-pong balls is about 49.6%, which suggests low sensitivity. Although, for the game's purpose, it would only need to identify between ball and no ball, and the system could benefit from amplification and more accurate calibration. Because ping-pong balls are extremely light, a more accurate calibration should be done using smaller masses in a closer range to 3 grams.

After testing for weight sensitivity, a photocell was used to test for color recognition. Table 1 outlines the values of the photocell reading for different colored balls and the empty cup.

Table 1: Photocell Readings for Different Colored Balls

Color	Raw Voltage (V)	Amplified Voltage (V)
White	0.11	1.09
Red	0.90	1.00
Blue	0.05	0.57
No Ball	0.12	1.39

There is a notable difference in the amplified voltages between the colors and when the cup is empty. The visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye ranging in wavelengths from about 390 and 700 mm. Colors within the visible spectrum will exhibit different wavelengths. Looking at the graph of spectral response for the photocell [3], sensitivity changes with wavelength, which explains why different colored balls will yield different output voltages. An amplified photocell reading could be effective in distinguishing two colors if they are far enough away from each other in the spectrum, as shown by the difference between Blue and Red in Table 1.

Study 2: The second part of the lab used a 3-axis accelerometer to relate voltage, angle, and water flow rate. Equation 3 was derived using a force balance diagram to calculate voltage as a function of the angle, where V_{out} is the output voltage, V_{90} and V_0 are the voltages recorded when the accelerometer is at 90° and 0° respectively, and θ is the angle from the horizontal.

$$V_{out} = (V_{90} - V_0)\sin\theta + V_0, \tag{3}$$

Using an angle calibration fixture, voltage was recorded as a function of angle. Figure 3 below illustrates the registered data and the theoretical line from Equation 3.

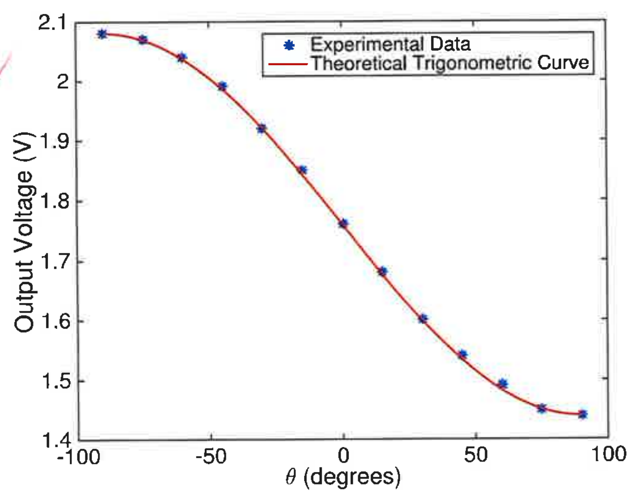

Figure 3: Data points represent the measured voltage in 15° intervals. Line represents theoretical voltage as calculated in Equation 3.

Then, flow rate was recorded for different accelerometer voltages. Equation 3 was used to convert the voltages to faucet angles, and flow rate was plotted as a function of θ (Figure 4). A trigonometric curve fit was applied to the measured data and is expressed below in Equation 4, where f_{rate}

is flow rate and θ is the faucet angle.

$$f_{rate} = (250.1 \pm 172.7)\sin\theta - (1.75 \pm 112.2), \tag{4}$$

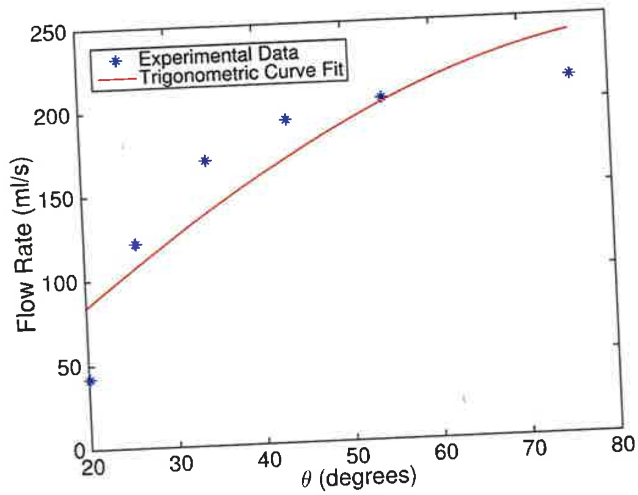

Figure 4: Data points represent the measured flow rate at six different angles. The line is a trigonometric curve fit represented by Equation 4.

It makes intuitive sense that as the faucet angle increases, the water flow rate increases, and this behavior is reflected in the plotted data. However, the variation from linearity can be attributed to several limitations in this experiment. Measuring the exact flow rate was difficult due to the meniscus in the water level, which lead to timing inaccuracies as it is hard to be precise in measuring exactly 1000 ml with running water. In addition, this effect was worsened at higher flow rates due to water turbulence. This experiment also assumed constant water flow, and perhaps air in the water lines lead to variations in pressures in the pipe which could have resulted in a varying flow. The analysis was mostly dependent on communication between members and reflexes, which limited the degree of precision of most of the measurements.

Study 3: In the final experiment, the core temperatures of a PS3 were studied to understand how game console designers must modify their design to account for heat generation. Both the temperatures of the central processing unit (CPU) and the power supply were measured using a thermistor and an RTD, respectively. The fan speed was calculated using a photocell and laser system. In order to transform this output voltage to frequency, a Fourier transformation was performed at each time stamp when the fan changed speed. Once the blade frequency was determined, this value was converted to revolutions per minute (RPM) noting that each fan had 15 blades. The relationship between the temperatures and the fan speed is plotted below (Figure 5).

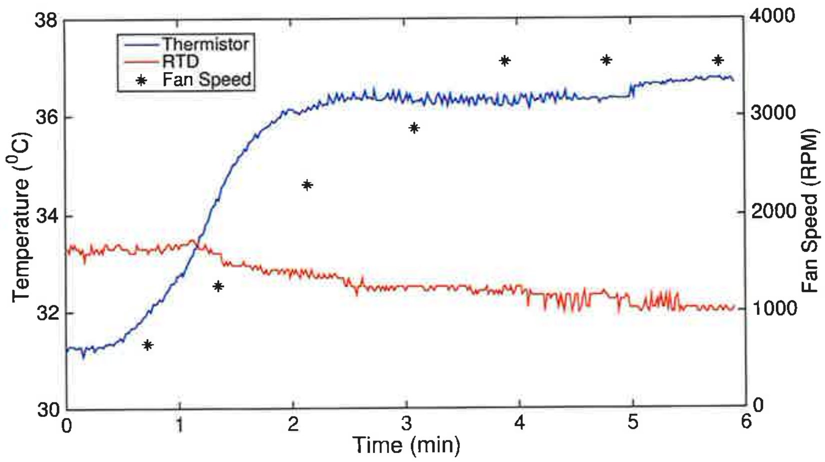

Figure 5: On the left hand axis, the voltage output measured by the thermistor and RTD is calibrated and plotted as temperature. On the right hand axis, the measured output voltage of the photocell is calibrated and plotted as fan speed. Both temperature and fan speed are functions of time.

The temperature of the power supply measured by the RTD appears to decrease with time. It is very likely that the RTD gathered erroneous data, because by experience, the temperature of the console usually increases with time as the game is being played. This erroneous data was most likely caused by an installation error. Perhaps the RTD sensor was not placed properly inside the console, or perhaps the wiring was not properly connected which could have led to inaccurate signal readings. Nonetheless, from the data gathered by the thermistor, it is reasonable to assume that the temperature of the power supply actually increases with time, and the fan speed likewise increases with time in order to counteract this heat generation.

Conclusions:

A cantilever mass measurement system with strain gauges in a Wheatstone bridge configuration and a photocell were used to assess sensitivity to mass and color. While sensitivity to mass could have been improved by more precise calibration, color recognition is benefited from the amplification of the signal. Overall, it appears that a sensor system similar to the one tested could be successful in automating the scoring in a game of beerless pong. The water conservation experiment illustrated a correlation between flow rate and faucet angle; the larger the angle, the greater the water flow rate. The average amount of water consumed when washing one's hands is 1 gallon [4]. The average human requires 0.5 gallons of water a day to survive. According to this estimate, two people could survive for one day with the amount of water used in washing one's hands. A greater flow rate might decrease the amount of time the faucet is open, but a smaller flow rate could reduce water waste. Further experimentation would need to be considered to decide which option would actually increase water conservation.

In the third part of the lab, a direct correlation between fan speed, temperature, and time is established, which proves why game console designers create fans with variable speeds. The original PS3 produces about 400 Watts of power during normal use [5]. To keep the console from overheating, fan speed needs to increase as temperature increases. The plotted data for temperature and fan sped begins to level out near the six minute mark, which could indicate that the console had reached its maximum temperature.

References:

[1] AME20213, Spring 2017, "Measurement Systems/Calibration", Lab Exercise #1, University of Notre Dame, Notre Dame, IN.

[2] Dunn, P. F., 2009, Measurement and Data Analysis, University of Notre Dame, Notre Dame, IN, Chap. 6.9.

[3] AME21213, Spring 2017, "CdS Photoconductive Cells", Sensor Information, University of Notre Dame, Notre Dame, IN.

[4] Perlman, H., December 2016, "Typical water use at home", https://water.usgs.gov/edu/qa-home-percapita.html.

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AME 20213: Measurements and Data Analysis
Technical Memo

Date Submitted: 02/13/2017
Dates Performed: 01/31/2107, 02/06/2017 *Monday/ 4:30pm*

To: Dr. Ott
From: [redacted]

Subject: Lab Exercise 1 - Sensors/Measurement Systems/Calibration

Summary:

In this experiment, three types of studies were conducted. The first was the calibration and testing of a cantilevered beam with strain gages to model an automated scoring system for a game of beerless pong, the second used a 3-axis accelerometer to study water conservation, and the third used a PlayStation 3 with various sensors placed inside to analyze the machine temperature throughout processing. For the beerless pong study, a relationship was developed to relate the number of balls in the cup and measured mass by using the voltage measured by the strain gage. From this relationship, the mass of a single ping pong ball was found to be approximately 2.16 g compared to the published value of 2.7 g, showing a 20% error. The second portion of the beerless pong study utilized a photocell sensor to detect the wavelength of light in the cup, which was found to be dependent on the color of ball in the cup, and convert the reading to voltage in order to distinguish different ball colors. The measured differences in voltage were noticeable but not significant, making this model difficult to effectively implement. The second study, water conservation, determined a relationship between the angle of the faucet handle and the corresponding flow rate of water. A power curve was found to be the best fit equation for this data, but the resulting confidence interval was large, making it difficult to know the accuracy of the fit curve. The final experiment, PS3 Hot Shot, used a Resistance Temperature Device (RTD) and a thermistor to measure the internal temperature of a PlayStation 3 (PS3). The speed of the PS3's cooling fan was measured by a laser and photocell sensor. The relationship between the recorded temperature datasets and the fan speed were then analyzed to show how the fan speed increased with the internal temperature to avoid

overheating of the unit.

Findings:

In this experiment, three studies were conducted: 1) Beerless Pong - a cantilever mass measurement system based on strain gages and a Wheatstone bridge, and the signal amplification as measured by a photocell sensor, 2) Water Conservation - using an accelerometer to design and calibrate a flow rate measurement system, and 3) PS3 Hot Hot - a temperature and fan speed measurement system using photocell, thermistor and RTD sensors.

Study 1 - Beerless Pong: The objective of this experiment was to develop an automatic scoring system for a game of Beerless Pong. This was to be done by detecting a made shot as a change in mass in the cup, as measured by the strain gages on a cantilever beam apparatus. The cantilever apparatus for this experiment was composed of a cantilever beam affixed with strain gages, an amplifier, and an integrated voltmeter for outputting voltage from the Wheatstone bridge. The force balance was calibrated by adding small known weights in increments of $5g$ to the cup attached to the end of the cantilever beam, and recording the output voltage on the voltmeter. A linear calibration curve was fit to the resulting data and is shown below in Equation 1, where m is the measured mass in grams, and v is the output voltage in volts.

$$m = 25.8v + 0.0481 \tag{1}$$

Next, ping pong balls were added to the cup in increments of one, and the output voltage on the voltmeter was once again recorded. A plot of the measured mass as a function of the discrete number of ping pong balls in the cup with a linear curve fit is shown in Figure 1, with the equation for the fit line included in Equation 2.

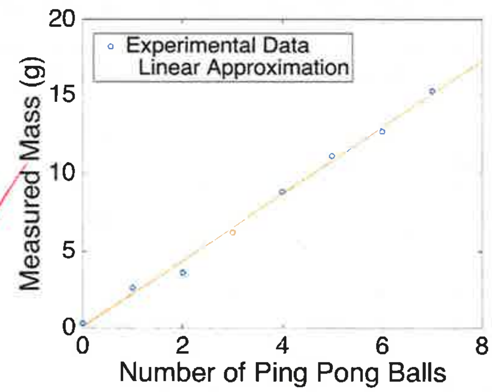

Figure 1: Plot of measured mass in g as a function of the number of ping pong balls in the cup with a linear curve fit. The equation for the best fit line is shown in Equation 2.

The equation of best fit is as follows, where m is mass in grams and n is the number of balls:

$$m = 2.16n + 0.019 \tag{2}$$

The linear fit acquired from the experimental data can be used to estimate the mass of a single ping pong ball. Based on the data and linear approximation, the mass of a ping pong ball used in this experiment is 2.16 g. From [1], the weight of a ping pong ball is 2.70 g, meaning the experimental data has an error of 20%. The error in the determination of this value could be due to a nonzero output voltage reading when no mass was placed in the cup, offsetting the data collection.

The next portion of this study utilized a photocell sensor to detect the number of ping pong balls in the cup. Dark and light calibration voltages were measured using the photocell sensor to obtain baseline data for the sensor. Then voltages for an empty cup and different colored balls in the cup were recorded and are shown below in Table 1.

As stated in [2], photocells use semi-conductors whose resistance changes upon exposure to light. As detailed in [3], a CdS photocell is more sensitive for certain wavelengths than others. This sensitivity should allow the photocell to detect the difference between different colored balls placed in the cup, therefore serving as way to keep score between teams using two different ball colors in a game of beerless pong. The different colored balls correspond to different levels of resistance

Table 1: Photocell voltages for different colored balls and empty cup.

Ball	Raw Voltage (V)	Amplified Voltage (V)
No ball	0.15	1.66
Red	0.13	1.50
Blue	0.11	1.25
White	0.16	1.79

in the photocell, resulting in different output voltages. As shown, the photocell sensor is able to distinguish between the different colored balls, but the voltage differences are minimal, making this an impractical way of tracking score in a game of beerless pong.

Study 2 - Water Conservation: For the second study, a flow rate measurement system using an accelerometer was used to determine the average amount of water consumed to wash one's hands. The accelerometer was connected to a Sensor Interface Box, and was calibrated by recording several data points of the output voltage as a function of pitch angle θ. Figure 2 depicts the accelerometer voltage in volts as a function of the angle θ in degrees with a theoretical trigonometric curve generated from the calibration data, which is detailed in Equation 3.

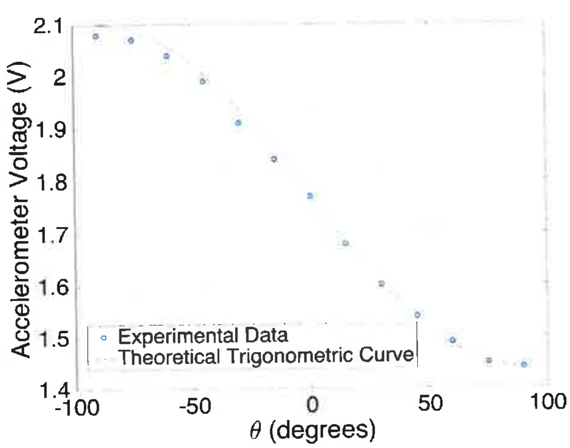

Figure 2: Plot of accelerometer voltage (V) as a function of angle θ (degrees) with the theoretical curve described in Equation 3.

The equation of the theoretical trigonometric curve is as follows, where y is voltage (V) and x is the angle θ (degrees):

$$y = -0.33sin(x) + 1.77 \tag{3}$$

The accelerometer, affixed to the faucet handle, was then used to determine flow rate by recording the time a 1 L beaker required to fill with water for the specific angle of the faucet handle. The flow rate (mL/s) is plotted as a function of the angle of the faucet handle (θ) below in Figure 3.

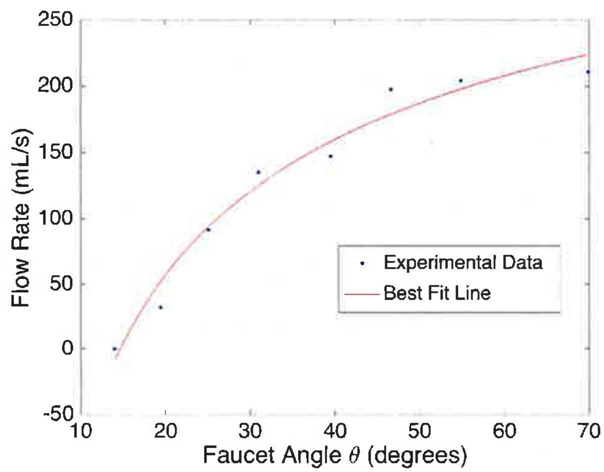

Figure 3: Plot of flow rate (mL/s) as a function of the faucet angle θ (degrees) with the non-linear curve fit described in Equation 4.

The equation of the best fit curve is a second-degree power fit, and is as follows, where y is flow rate in mL/s and x is the faucet handle angle θ in degrees:

$$y = -1450x^{-0.426} + 461 \tag{4}$$

Error in the data collection could have occurred from difficulty determining when the volume reached 1 L as a result of turbulence at higher water pressure, an uneven sink, and the water meniscus. These error factors could contribute to the level of accuracy of the theoretical fit curve that was determined to be best for this dataset. Based on the Center for Disease Control [4], the average amount of time it takes to wash one's hands is 20 seconds. Assuming that the faucet is at

an angle of 45° or halfway open, the flow rate would be 174.52 m
mL or 0.92 gal of water are used to wash one's hands and could
water for nearly two people, based on [2].

Study 3 - PS3 Hot Shot: For the third study, the heat generatio
PlayStation 3 (PS3) was analyzed. Both the central processing
temperature were measured, along with the frequency of the coolin
were detected by an RTD and thermistor sensor, while the fan bla
a laser and photocell sensor combination. The experimental data
was transformed using the calibration curves in [5] to obtain tem
frequency was divided by the number of blades on the fan to dete
minute. The resulting temperature data is plotted versus time in Fi
speed as measured at seven different data points when the PS3 fan
A schematic of the PS3 system and the sensors used for this study

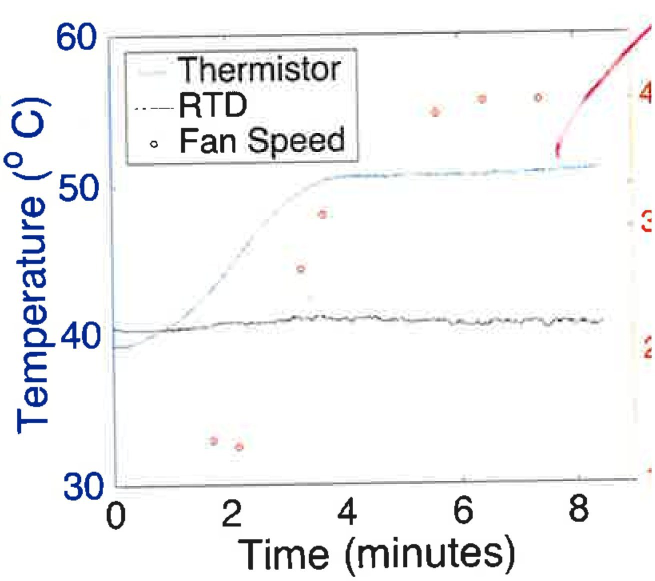

Figure 4: Plot of temperature (°C) as a function of time (minutes

by the graph is the difference between the RTD and thermistor temperature readings. Because the temperature is being recorded at two different locations - the CPU and inside the console - the readings vary increasingly as the run progresses and the temperature inside rises faster than the fan can cool it compared to the CPU which remains at a lower temperature. This is likely an intentional design feature, as the CPU is a valuable portion of the hardware and should be protected from overheating.

Conclusions:

In the three studies performed in this lab experiment, various sensors were calibrated and used to measure properties such as mass, flow rate, and temperature. In the first study, the output voltage measured by strain gages was transformed to determine a relationship between the measured mass and the number of ping pong balls in a cup. A photocell sensor was also used to model an automatic scoring system by detecting the change in wavelength that is a result of different colored balls being placed in the cup. In the second study, an accelerometer was used to relate the angle of a faucet handle to the flow rate of water. This relationship was found to be parabolic with multiple sources of possible error. The final study measured the temperature and cooling fan speed of a PS3 to demonstrate how the game console uses varying fan speeds to prevent overheating of the hardware.

References:

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[3] AME20213, Spring 2017, "Sensors", Senba GL5528, University of Notre Dame, Notre Dame, IN.

[4] Center for Disease Control and Prevention, 2016, "Healthy Living", Wash Your Hands, https://www.cdc.gov/features/handwashing/.

[5] AME20213, Spring 2014, "Calibration Curve for the Thermistor", Lab Exercise #1, University of Notre Dame, Notre Dame, IN, http://www3.nd.edu/ jott/Measurements/Sensors/E1thermalrevised.pdf/.

Appendix

A

Schematic of PS3: Top View and Side View