ECE 4950 Research Project 2

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Executive Summary

The purpose of project two was to design and build a sensor and actuator system to further develop our understanding of how to use the Quanser Q4 board as a tool that can take inputs, make decisions with those inputs, and give an output. Also for this project we built a life-sized mockup of what our final design might look like physically, and demonstrated how we expect our design to work. For our sensor we chose a proximity sensor that gives an output voltage depending on distance between an object and the sensor's infrared eye. The actuator used was a 5V solenoid, and it was logically controlled to actuate by the Quanser board when the output from the proximity sensor reached a certain level. The mockup of our final design was made of cardboard and demonstrates our idea of using a two rail guiding system to move the arm vertically and horizontally.

Engineering Requirements for the Entire System

Customer Requirement	Engineering Requirement	Verification Tests
Quiet	Keep the entire system below 60 dB during operation.	Can be verified with a decibel meter that will measure the level output from the system.
Efficient	Does not need voltage over 12V to operate.	Keep all required power sources to 10V or less.
Fast	Move the bottle from one station to the next in under 10 seconds.	Record the times that the robot takes to move a bottle and random time and then take the average of them.
Safe	Ensure that the heaviest bottle will not be too much of a load on the motor. Make sure that the base is stable and the system has no sharp edges.	Go by the datasheet of selected motor on the Max load that the motor is capable of. Ensure that the base is secured with strong screws and glue. Finishing detail.
User-Friendly	Ease of use for all food-truck customers, including the interactive monitor.	Find random people of all ages to test the product and order food for themselves.
Smooth, Controlled Motion	Proper suspension and precise motor movement.	Find a motor that can move in small, concise angles without being too springy.
Robust	Designing the system with strong materials capable of withstanding abuse.	The use of strong materials, but lightweight materials such as wood, PVC, and thick plastic.
Cost Effective	Using the simplest design with the most affordable resources while still meeting requirements.	Perform a cost analysis with the team before purchasing required materials.

Table 1: System Engineering Requirements

Design Solutions

Concept 1: Central Rotational Robot Arm with Descending Linear Actuator

This is the first and most logical concept that our team came up with in our brainstorming session. This design is comprised of a robot arm placed in the middle of the condiment station and designed at a right angle so that the claw is positioned right above the bottles. Since the bottles are in a concentric circle, the robot arm will only ever have to rotate along a constant circle. For this reason, there is no need for it to move along more than one axis linearly. Once the arm is positioned over the proper bottle, a linear actuator will descend the claw and grab the bottle, which will be lifted over the over bottle as it is rotating to its next determined position. The image processing camera will be placed above the system in a rigid frame so that it can detect which bottle needs to be picked up and when. The frame will make the system more robust and easier to maneuver.

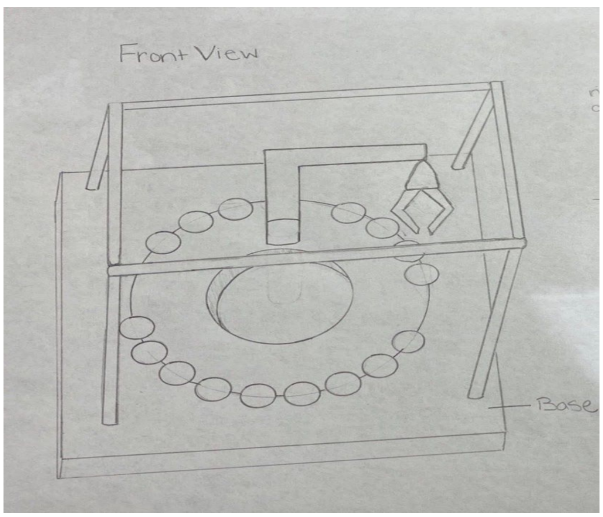

Figure 1a.

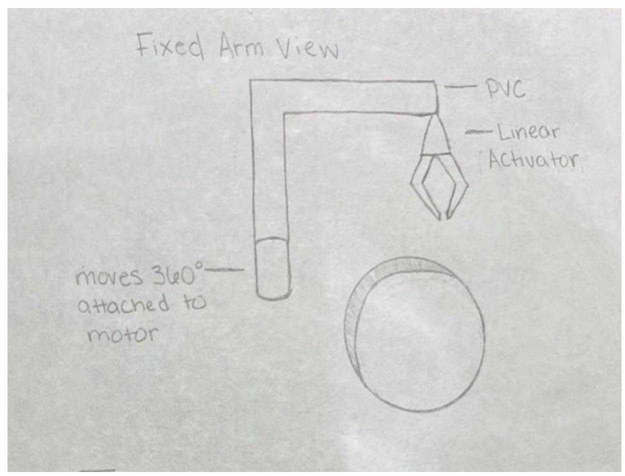

Figure 1b.

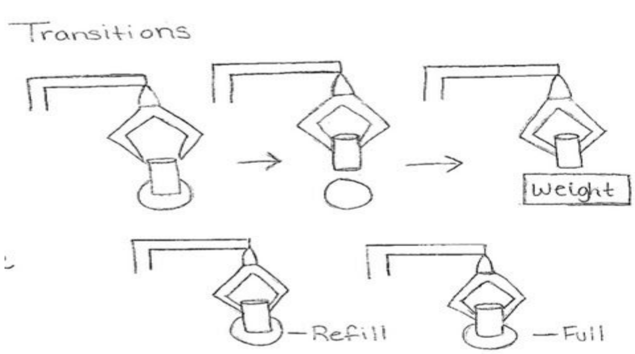

Figure 1c.

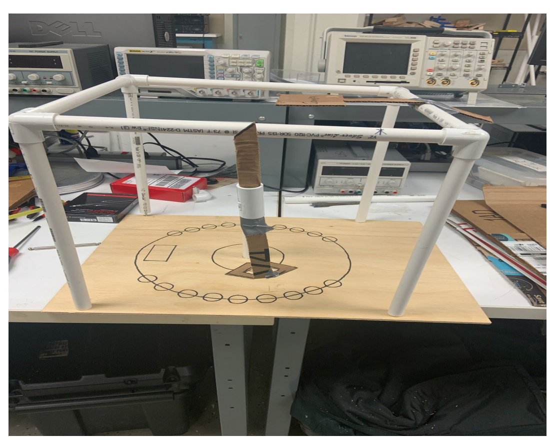

Figure 1d.

Concept 2: Box Structure Moving Linearly to Appear Rotational

This concept is based on the typical movement of the well known 3D printer. The way that this concept would operate is that it would move in the x-direction along one plane and then it will move through those planes, along the y-axis on another rail. This 2 rail system would be raised above the condiment station requiring a full four post frame. This will also have to be very robust since it will be housing two motors and a linear actuator. This will require a lot of material and time to build this design. While it is a tried and true concept that is used in other applications, it will also be very difficult to implement the movement in order for it to appear curvilinear. This will require a lot of software programming.

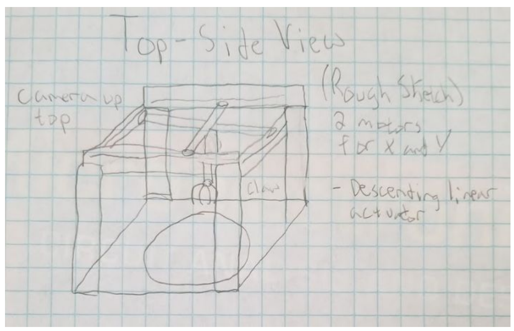

Figure 2: 3D printer like design

Concept 3: Central Rotational Robot Arm that Moves in all 3 Axis Directions

This concept was by far the most complex in terms of being able to complete the project in the allotted time. The premise behind the design is that it is comprised of a singular robot arm in the middle of the condiment station. There would be no need for a frame around everything because all of the movement would be occurring by the robot and the camera would be attached to the end of the arm as well. Imagine a human arm and the way it can move, this is what we were going for. It would be able to move on two different joints in order to pick up the bottle and then rotate around the center to place it correctly. The internal sensing camera will reset the initial zero point once the bottle is collected.

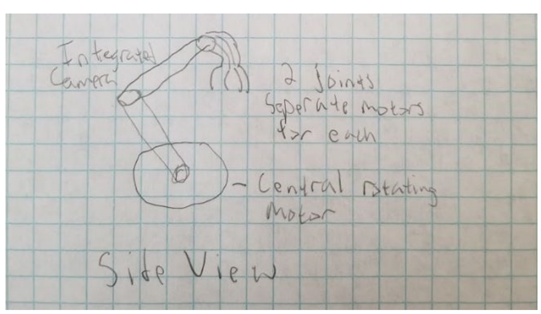

Figure 3: Fully Functioning Robotic Arm

Concept Evaluation

Feature and Description	Weight (1, 3, or 5)	Concept 1	Concept 2	Concept 3
Quiet	3	5	3	3
Efficient	1	5	5	1
Fast	3	3	3	3
Safe	5	3	5	5
User-Friendly	5	5	3	3
Smooth, Controlled Motion	3	3	3	5
Robust	3	5	5	3
Cost Effective	5	5	3	1
Total Score		**118**	**102**	**88**

Table 2: System Concept Evaluation

The concept that the team decided on, based on the decision matrix, is Concept 1. The reason that we chose this concept over the overs is that it will be the most affordable and simplest design to build. This will allow ample time for us to test and repair any bugs that might occur once we finish the robot.

Engineering Requirements for Key Actuator

Below shows the Customer and Engineering Requirements for the key actuator as specified by the consumer. As well as being quiet, fast, and safe, the actuator should be easy to replace since this system will be used by unpredictable people. There are many circumstances in which the motor can be over torqued by human interference.

Customer Requirement	Engineering Requirement	Verification Test
Quiet	Keep the entire system below 60 dB during operation.	Can be verified with a decibel meter that will measure the level output from the system.
Fast	Can complete a rotation under	Time rotation of the actuator

	load in less than 5 seconds.	under load.
Strong	Ensure that the heaviest bottle will not be too much of a load on the actuator.	Go by the datasheet of selected motor on the Max load that the actuator is capable of.
Safe	Have fine control over the speed and location of the actuator.	Measure accuracy of the actuator's movement.
Easy to replace	Low cost replacement Easy to wire	Shop around for the most affordable actuator cell. Datasheets are available online.

Table 3: Actuator Engineering Requirements

Design Solutions

To meet the customer and engineering requirements, the actuator should be able to move the condiment bottles with ease. The actuator should also be easy to replace because this is going to be used by people and people can be unpredictable. It should also be affordable for that same reason. There are many different types of actuators that have certain tradeoffs that will affect our whole system, so it is important that whatever actuator we choose best supports the engineering requirements.

Actuator 1: Brushed DC Motor (~$10)

Brushed DC motors are cheap and offer good torque, at the expense of less control, noise, and possible durability issues with the brushes.

Actuator 2: Brushless DC Motor (~$20)

Brushless DC motors are quieter, their speed can be precisely controlled, and provide adequate torque however are more expensive than their brushed counterparts.

Actuator 3: Stepper Motor (~$20)

Stepper motors offer the most precise control while meeting the torque requirements. They may be noisey and are much less efficient than their more standard DC counterparts.

Concept Evaluation

Feature and Description	Weight (1, 3, or 5)	Actuator 1: Brushed	Actuator 2: Brushless	Actuator 3: Stepper
Quiet	1	3	5	3
Fast	3	5	5	5

Strong	5	5	5	5
Safe	3	3	3	5
Easy to replace	3	3	3	3
Total Score		61	63	67

Table 4: Actuator Concept Evaluation Matrix

All motor types can meet the speed and strength requirements while having specific drawbacks regarding durability and replacement. Since stepper motors will give us the best control, they seem like the best option for our application.

Engineering Requirement for a Key Sensor

The table below shows a list of customer requirements and corresponding engineering requirements of the system. Apart from being able to be ready to use whenever a menu item is chosen, the other requirements we included were the ease of replacement and the responsiveness of the force-seeking load cell.

Customer Requirement	Engineering Requirement	Verification Test
System Ready to Use	System turns on when in use, and standby when not in use.	The scale is not operating until weight is applied to it.
Easy to Replace	Low cost replacement Easy to wire	Shop around for the most affordable load cell. Datasheets are available online.
Responsive	A very small amount of force difference represented as a change in voltage.	Using a load cell with very small voltage changes and then correct by amplifying it.

Table 5: Sensor Engineering Requirements

Design Solutions

To meet the customer and engineering requirements, the load cell should be able to place the bottle in the correct place given a weight limitation. The cell should also be easy to replace because this is going to be used by people and people can be unpredictable. It should also be affordable for that same reason. Load cells come in many shapes and sizes depending on the implementation. For this project, the load cell does not need to be too large since it will be measuring small force changes. For this reason, 300g load cell is recommended though other reasonable loads may be an option.

Load Cell 1: uxcell 300g ($9.37)

This is also a 300g load cell. It has an excitation voltage of 5V-10V which is higher than the other cells. The rated output of the cell is of .1mV per 1V. The wiring for this cell is easier to follow since it uses four different colors and there is an available data sheet. We had some issues with the very small gauge wire, but these cells are inexpensive to replace.

Load Cell 2: Brecknell Q45x10x6-500g ($39.50)

This is a 500g load cell. It has an excitation voltage of at most 6V and an output of .6mV+/- 20% per 1V input. This load cell weighs about 1 pound and is recommended for use in handable balances. The wiring is ambiguous and the data sheet doesn't seem to be much help. While the cell is moderately priced, it is still expensive for daily and unpredictable human interaction.

Load Cell 3: Brecknell FAB-47-300G ($74.00)

This is a 300g load cell. The excitation voltage for this load cell is up to 6V. It has an output of .9mV +/- 20% per 1V, weighs under 0.5 lb and is recommended for use in handable scales. The wiring is less than desirable as it is all different shades of gray and the cell is very expensive for this application.

Concept Evaluation

Feature and Description	**Weight (1,3, or 5)**	**Load Cell 1: Xcell**	**Load Cell 2: Brecknell 500g**	**Load Cell 3: Brecknell 300g**
Lock/Unlock System	3	5	5	5
Easy to Replace	5	5	1	1
Responsive	3	3	3	3
Cost	5	5	3	1
Total Score		**74**	**44**	**34**

Table 6: Sensor Complex Concept Evaluation Matrix

The best option for the project is the uxcell 300g load cell. Considering our limited income, it is by far the most economical. It is also easiest to wire and control. We will be purchasing a few of these cells during the building process to prepare for any issues that might arise with the fragile connections.

Sensor & Actuator Demonstration

For the sensor and actuator demonstration, we acquired a 100 gram mini load cell to measure a change in weight. The load cell has four wires. The red and black wires are for power and ground and the green and white wires carry an output signal that changes linearly with the amount of force on the load cell. The rated load cell output voltage of 0.6 ± 0.15 V when 100 - 200 grams is applied, 0.7 ± 0.15 V when 300 - 750 grams is applied, and 1.0 ± 0.15 V when 1000 - 1500 grams is applied. The voltage change in the output signal is small and will be difficult to detect on the quanser board, limiting the practical applications for a system. To counteract this, we built an amplifying circuit with a fixed gain. The amplifying circuit we used is the instrumentation amplifier utilizing three OP741 op-amps as demonstrated in **Figure 4a**.

If we let $R = R_1 + R_2 = R_3 = R_4 = R_5 = R_6$, then we can use the equation:
$V_o = (Sig+ - Sig-)\,(1 + \frac{2R}{R_G})$

We designed the circuit to have a gain around 10. From the equations above, we can set all resistors to the same value and change R_G to get the desired gain. We used 1 kΩ resistors for R1 - R6 and used a 265 Ω resistor for R_G. This will produce a gain of 8.5. This gain is big enough to observe the changes in the output signal of the amplifier. We assembled the circuit with the load cell connected on a breadboard shown in **Figure 6.** The left power rails are connected to -5 Volts, and the right power rails are connected to +5 Volts. We used a TENMA DC Power Supply to supply the power rails.

We created the LTSPICE simulation in **Figure 4b** and tested the output for the range of rated sensor outputs using LTSPICE. The resulting output is displayed in **Figure 5.** A 4.5 mV signal produces a 38.5 mV output and a 1.15 mV signal produces a 98.3 mV output. The gain is consistent for all the rated signals from the load cell.

The actuator we used in this circuit is the TR FCL DC motor. This motor is rated for 24 V. The output of the instrumentation amplifier will never come close to this but the quanser board cannot supply enough current to drive the motor. We connected the Simulink output voltage and the motor to an amplifier. The motor speed is proportional to the voltage supplied to it. This is intuitive from a energy conservation perspective as the input power should equal to voltage times current and the output power is equal to the torque on the motor times the angular velocity. Assuming the torque stays the same and the change in current is minimal, a change in voltage should change the angular velocity of the motor.
After connecting the sensor, instrumentation amplifier, and motor, we used the Simulink model in **Figure 7** to get the output signal response when applying force to the sensor shown in **Figure 8.** The output response is noisy and negative. A low-pass filter can be connected to the instrumentation amplifier to remove the noise. The direction of the change is due to the direction that the sensor wires are connected. Reversing the green and white wire will reverse the voltage polarity.

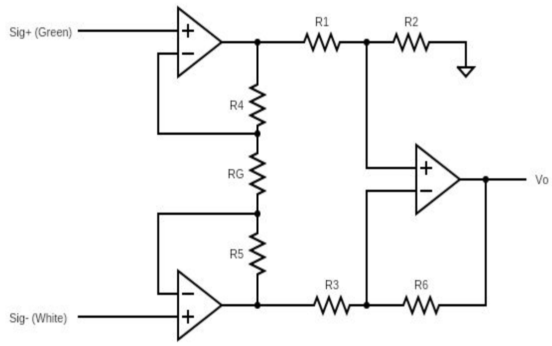

Figure 4a: Instrumentation Amplifier Circuit Diagram

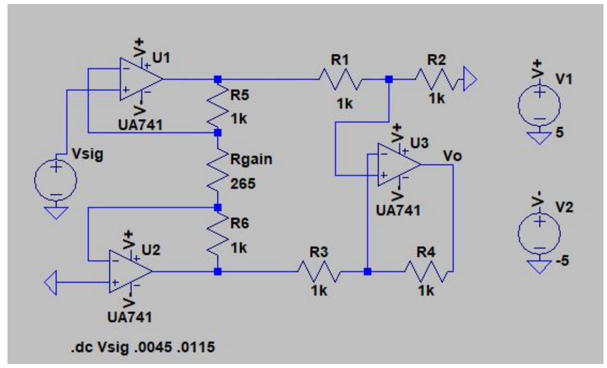

Figure 4b: Instrumentation Amplifier Simulation Circuit

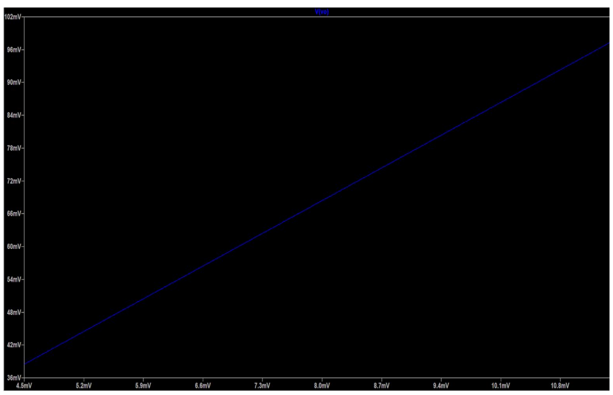

Figure 5: DC Sweep Simulation of Instrumentation Amplifier

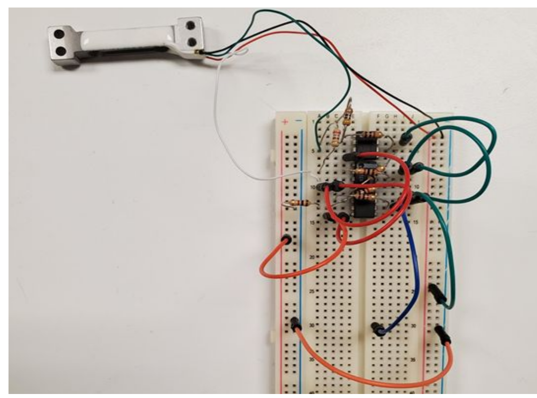

Figure 6: Instrumentation Amplifier Load Cell

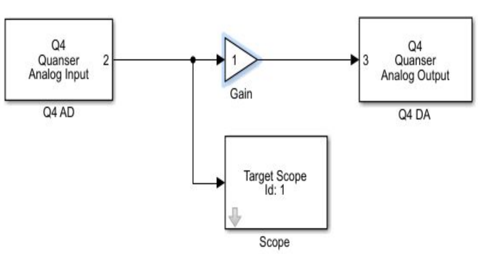

Figure 7: Simulink Model

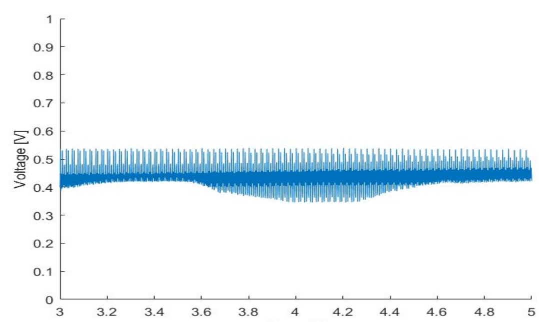

Figure 8: Signal Response from Load Cell Sensor

Financial Analysis

5 Guys- TEK Engineering
Estimated Financial Scenario

Start-up Costs

Personnel	5 Engineers @ $55K/yr + President @ $75K/yr + Admin. Asst. @ $25K/yr = $ 375,000
Fringe Benefit (FB)	A fringe benefit is a form of pay for the performance of services. For example, you provide an employee with a fringe benefit when you allow the employee to use a business vehicle to commute to and from work. Assume Fringe Benefit Package @ 36% (incl. employee's SS tax, vacation, holidays, medical, retirement (401K), dental, life insurance, relocation, unemployment insurances, etc): (5 x $55,000 + $75,000 + $25,000) x 0.36 = $ 135,000 *Note: Federal Insurance Contributions Act (FICA) tax (Social Security and Medicare) is imposed by the federal government on both employees and employers. The entire FICA percentage of 15.3%* ● *Employee's pay 6.2% for SS and 1.45% for the Medicare (this is not included in your cost)* ● *The employer is liable for 6.2% Social Security and 1.45% Medicare taxes=7.65%*
Building	Initially rent a suite of offices with 2 engineers/office (12' x 14'), an office/conference room for President (12' x 20'), and a reception/office area of 16' x 20'. (3 cubicles) x (12' x 14'/cubicle) + President office of (12'x 20') + Reception/office area of (16' x 20') = 1064 sq ft Use nominal figure for office space in industrial park sectors of Clemson area, $9.50/sq ft/mo. Then the lease rate for office space will be $0.79/sq ft/mo x 1064 sq ft = $841 /mo. = $10,087 /yr.
Furniture	Rental of a desk, chair, credenza set will run about $60/mo. Need 7 sets for a total monthly expenditure of $ 420/mo = $5040/yr The remaining equipment, furniture and software expenses are estimated to be about 7 computers @ $1500/computer — $10, 7 sets of general software @ $1000/set — $7,000 Specialized software — $18,000 Copier, printer — $4,000 Table and chairs for conference room — $3,888 7 telephones @ $35/ea — $245 Total — $48,673

Phone and Internet	According to Bell South, the cost of a combined voice/data line, is $70.00/mo for operation. For 7 telephones the total cost will be $5,880 /year. Assume that long distance calls add another 40% to this to get a total estimated annual phone cost of $8,232
Travel	Another cost item which will be important is travel. There will have to be continual contact with potential clients, attendance at selected technical conferences and workshops, and visits to plants or other locations where potential clients might be. Assume (modestly) that this will that the cost per local trip is $200 and the cost per out-of-state trip is $3000 there will be 2 of each trip each month $6,400/mo for the first year, or an annual total of $76,800.
Interest	Capital (i.e. money) is needed to fund these initial purchases as well as to underwrite operating expenses until a revenue stream is established by selling engineering services to customers. Assume that through personal contacts a credit line of $800,000 has been established. This is to be repaid over the period of a year with 11 equal payments starting 1 month after the loan date. The negotiated interest rate is 5% per year. The monthly payment M is calculated from = $74,726 Where P is the principal amount ($800,000), I is the interest rate (5%), and q is the number of payments to be made (11). From this, Debt Service = Total interest paid in year = 11 x M - P = $21,983.

Cost Estimate

Salaries		$375,000
FB @ 36%		$135,000
Building	$10,087	
Furniture		$48,673
Debt service		$21,883
Travel		$76,800
Internet and Phone Service	$8,232	
Total Costs		$ 675,000

Overhead Calculation

Now we will estimate the Overhead (Indirect Technical Expense) we must charge to recover our costs. This cannot be too large, or else we will price ourselves out of business. On the other hand, we must be realistic, or else we will go broke, and therefore out of business.

Assume that the first year, the 5 engineers will be at least 75% "sold", i.e., 75% of their total time can be charged to customers. Then we can bill

5 engineers @ 75% sold (salaries billable to clients)	$206,250
FB @ 36% (FB billable to clients)	$74,250
Total Billable to Clients	$280,250

The remaining salary dollars and FB's must be charged to overhead.

Total Expenses = Total Costs - Total Billable to Clients = \$280,500 (Overhead Number)
This implies an Overhead rate of

OH rate = (\$395,275/\$280,500) x 100% = 140.92%
= (Overhead Number / Total Billable to Clients) x 100%

This implies that every labor dollar (at the "loaded" rate, i.e. with FB's) must be increased by a factor of 1.4592 (1+ (OH rate/100%) + (5% profit/100%)) in order to recover the costs of doing business and make a profit (assuming a 5% profit). This is the figure that you will use when estimating the cost of a contract to a customer in a proposal. An overhead rate of 150% means that for each \$1.00 of direct labor budgeted for a project; \$1.50 needs to be budgeted for overhead costs.

Using the Overhead Number

You estimate that a project will take 1 week (40 hours) of your time, i.e. what does it cost for one week of an engineer's time. How much do you bill your client for this time?

Bill to Client

$$= \left[\frac{\text{1 week work}}{\text{52 weeks per year}} \bullet \left(\frac{\text{salary} = \$55\text{K}}{\text{year}} + \frac{\text{FB} = 0.36\Box\$55\text{K}}{\text{year}}\right) \bullet \left(1 + \frac{\text{overhead rate}}{100\%} + \frac{\text{profit} = 5\%}{100\%}\right)\right]$$

= \$47,304.24

ECE 4950 Project 2 – Sensor, Actuator, Financials, and Website Rubric

Use the guidelines below to complete your report and add at the end of your report.

Group Number and Name:____Group 3: Five Guys. Marini, Holmes, Thomas, Jonakin, Dunn______

Score	Pts		Performance Indicators
	5	**General Format - Professional Looking Document/Preparation (whole document)** a) Fonts, margins (11pt, times new roman, single spaced. 1" margins on all sides). b) Spelling and grammar are correct c) Layout of pictures – all figures need numbers and captions and must be referenced in the text d) Follows the page limitations below. e) References. Use IEEE reference format. f) This grading sheet is included as the final page.	g.1
	5	**Page 1: Title, Group Name, Group Members, and Date** **Executive Summary** (1 concise, well-written paragraph) Provide an overview of this project. Briefly describe what you did and what you learned.	g.1
	25	**Overall System Design** **Page 2: Engineering Requirements for the Entire System** (~1 page) Make a three-column table that lists a Customer Requirement in the first column and the resulting Engineering Requirement(s) in the second column. Note that a customer requirement may branch to multiple engineering requirements. The third column should contain the test that will be done on the prototype to verify that the design chosen meets each requirement. **Page 3-4: Design Solutions** (~2 pages) Use a brain-storming session to generate concepts. Document your top three most feasible ideas with sketches and brief descriptions while providing the main features of each concept. **Page 5: Concept Evaluation** (~1 page) Use a Complex (weighted) Concept Evaluation Matrix to show how the final design was chosen from the three best ideas described previously. Include a description of the weighting factors. Make sure to use at least six of your most important criteria in the matrix and be sure to provide and include the weighting factor (i.e. importance) for each criterion. Describe your final design choice, including how the final decision process, which may include more than just the Decision Matrix result (~1 paragraph). The robot mockup will be graded based on the following criteria: a) Does it demonstrate the proposed concept in sufficient detail? b) Is it well-thought out? c) Does it look like the final construction using this concept will be robust?	c.2 c.1 c.4
	20	**Actuator Subsystem** **Page 6: Engineering Requirements for Key Actuator** (~0.5 page) Make a three-column table that lists a Customer Requirement related to Actuation in the first column and the resulting Engineering Requirement(s) in the second column. Note that a customer requirement may branch to multiple engineering requirements. The third column should contain the test that will be done on the Actuator to verify that the device/product chosen meets the Customer Requirement(s).	c.2
	20	**Sensor Subsystem** **Page 10: Engineering Requirement for a Key Sensor** (~0.5 page) Make a three-column table that lists a Customer Requirement related to Sensing in the first column and the resulting Engineering Requirement(s) in the second column. Note that a customer requirement may branch to multiple engineering requirements. The third column should contain the test that will be done on the Sensor to verify that the device/product chosen meets the Customer Requirement(s).	c.2

	20	**<u>Page 14-15: Sensor & Actuator Demonstration</u>** Build a simple physical prototype that demonstrates the working of the sensor and actuator and meets the customer requirements. Note the that sensor should trigger the actuator when certain conditions are met (these conditions can be user-defined specifically for this demonstration). Provide detailed information regarding sensor readings and actuator responses. Demonstrate the range of the sensor and actuator (as needed) using graphs and explanations. Describe any electrical and/or mechanical design details (calculations, schematics, simulation results, mechanical sketches) needed to make the sensor and actuator work (individually and together). Include information on how this design will continue to be refined with an eye on the final project.	g.2 k.3 b.1 k.1
	5	**<u>Page 12-14: Financial Analysis</u>** Provide a financial analysis that examines turning your group into a start-up company. Use the spreadsheet provided to make calculations and report your results using the MS Word document template and include here.	c.3
		<u>Page 15: Grading Sheet</u>	g.1
	20	**<u>General Website Format</u>** – ***provide link here:*** Is the website: a) Aesthetically clean b) Complete. Does it include: 1. The Team Description? 2. Reports 1 and 2? 3. Outline of future sections? 4. Proper use of graphics? c) All links should be relative to the starting directory so that it can be viewed offline. d) Follow the website guidelines, including accessibility compliance at: http://akapadi.people.clemson.edu/ece4950_websiteDesign.html	g.1

Website Link: http://joelsod.github.io/4950-Site/