ECE 4950 Project 2 (September 15, 2015):
Whack-A-Mole Design Concepts and Actuator Development

Team W8: Bode, Bode, Bode, Bode Plotting Everywhere

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I. Executive Summary

Project 2's focus was geared towards the design process of our overall system. In order to come up with a viable solution for this process, we evaluated the customer's need based off of the requirements presented to us from the customer and came up with our most reliable solution for the entire system as well as the actuator-sensor subsystem. In order to reach a solution, a complex decision matrix was made listing all the requirements for the entire system, and each of these requirements were then numerical graded (1-poor, 3-good, 5-oustanding) based on their importance. Using this complex decision matrix we were then able to grade our top 5 system ideas and come up with our most optimal system solution for our design. The same steps were utilized to find out which type of actuator would be used. From our decision matrices it was determined that the laser printer idea was the most viable, and a solenoid would be the best type of actuator to use for this system choice. With the laser printer solution, an actuator suspended above our game board in a cart via a rail way will be used to travel along the x-plane in order to push the corresponding button based off of what is being read by our RGB light sensor, which will also be suspended above the game board via fiber glass protruding from a side base arm of the entire system.

II. Engineering Requirements for Entire System

Customer Requirements	Engineering Requirements	Possible Tests
3 Month Timeframe	The robot needs to be completed during the duration of this class.	Construct and adhere to a work schedule.
Autonomous Design	The system should not require any user intervention to operate.	Check for automatic operation beyond interface start.
Fixed Game Board Dimensions	Dimensions must be 18"x2" with 8 2.25" sections	Ensure board meets dimension specifications.
$300 Budget	The cost for all required parts of the robot should not exceed $300.	Construct a budget and run financial analysis.
Use xPC and Quanser Q4 Board	Design must use xPC workstation to interface with Q4 board	Check design for inclusion of connections to Q4 board.
No Batteries	The robot needs to run off AC power. Use of an AC to DC converter or USB power is acceptable.	Do not include batteries in the design.
Software Interface Requirements	The interface should include a start/stop button and display the execution time.	Ensure interface includes the required buttons and displays the correct information.
Emergency Stop Button	Ensure a hardware stop button stops the robot at any point during execution.	Press the button during all phases of the game to ensure stop.
Low Noise	All noise produced by the robot must be less than 85 dB from 2 feet of the workstation.	Measure Noise with Skypaw Decibel 10^{th} software.
Design uses Electronic Components	Resistors, Capacitors, Inductors, Diodes, BJT/FET Transistors, etc.	Ensure the design includes useful electrical components.
Reliable	There should be no variation in the way the robot plays Whack-a-Mole.	Test robot for consistent gameplay behavior.
Durable	The robot should withstand wear over time.	Check the design operates after at least 50 test runs.
Safe	Use guards around hazardous areas of the design to protect users.	Inspect the robot for sharp edges during design process.
User Friendly	The design should only require basic instruction for operation.	Bring in a user outside of the group to test usability.
Lighting System	Design needs a digital logic based hardware circuit to light the game board.	Develop Logic System and test compatibility with Game Master equipment.

Figure 1. Final Design Requirements.

As seen in Figure 1, the requirements here are fixed and as given in the project rules and specifications. Among the most important requirements are that the robot must be completed in a three month time frame, be autonomous, and cost no more than three hundred dollars to construct. All of the given customer requirements are easily translated into verifiable and more specific engineering requirements. For example, a user friendly design can be more aptly described as one that does not require any more than basic instruction to become familiar with. This can be tested by introducing someone completely unfamiliar to our design and observing if they can start a Whack-a-Mole game with it.

III. Design Solutions

1. Traditional Single Arm "Whacker"

As shown in Figure 2, a traditional single arm whacker design would consist of a single arm that is mechanically capable of reaching each of the eight push-button switches. The arm will be located on a platform on the side of the board nearest the push buttons. In the software, we will have code that will tell the motor what to do to get the arm set up above the required button, depending on which light needs to be turned off. Once the arm is moved into position, an actuator would cause the arm to drop and hit the button, then retract to its original position. The camera will be located above the lights, and in such a position that the movement of the arm will never block the lights from the camera.

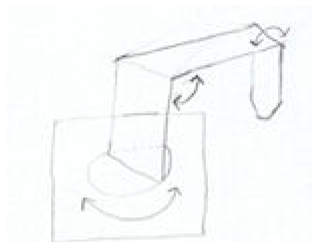

Figure 2. Traditional Whack-a-Mole Design.

2. Single Arm Laser Printer Style

A laser style whacker would consist of a single arm mounted to a rail and is below in Figure 3. The camera will be located above the lights, and in such a position that the movement of the arm will never block the lights from the camera. Once the camera locates a light that needs to be turned off, a signal will be sent to the motor that will move the actuator to the proper position on the rail, above the button that needs to be pressed. An actuator would then move the arm so that it would drop down and hit the proper button. The motor will be connected to a fish line type of wire, which will have reels on both sides of the rail. The unused wire will be wound around the reel like a garden hose, to avoid tangling.

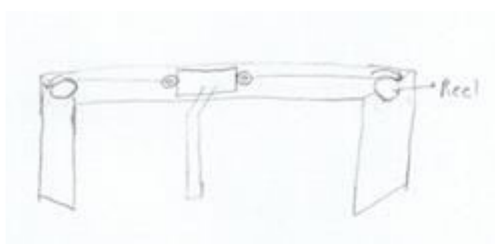

Figure 3. Laster Printer Whack-a-Mole Design.

3. Rotating Tank Tread with Whacker Attachment

As shown in Figure 4, a tank tread style design would involve a rotating tread with gears in between. The camera will be located above the lights, and in such a position that the movement of the arm will never block the lights from the camera. The actuator will be connected by the tread. The gears moving the tread will be controlled by the motor. Once a needed light is sensed, the software will tell the motor how much to rotate the tread, and therefore the actuator as well. Once the actuator is in position, it will drop down and hit the needed button. Then the actuator would be returned to its starting position

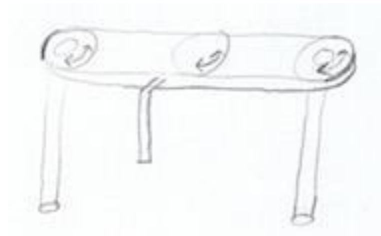

Figure 4. Tank Treads Whack-a-Mole Design.

4. "Octo-Arm": 8 Traditional Single Arm "Whackers"

This design involves eight single arms, which would be similar to the arm described in item one, but more simple. It is shown in Figure 5. Each arm would be mounted above one of the eight buttons. The camera will be located above the lights, and in such a position that the movement of the arm will never block the lights from the camera. Once a needed light is sensed, a signal will be sent to the needed arm from the software. The actuator on the needed arm would then hit the button immediately below it, then return to its starting position.

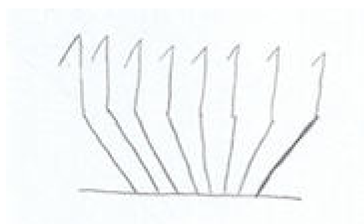

Figure 5. Octo-Arm Whack-a-Mole Design.

5. Single Arm with "Roller Ball"

The traditional arm with roller ball design would be similar to the traditional arm design in item one, but with a different kind of motor. In this design, the arm would be attached to a roller ball that would control its position. The camera will be located above the lights, and in such a position that the movement of the arm will never block the lights from the camera. Once the camera senses a needed light, a signal will be sent from the software to the motor. The motor will control the "ball" to move the base of the arm so that the actuator is above the proper button. The actuator would then hit the desired button, and the motor would move the arm back to its original position.

Figure 6. Roller Ball Whack-a-Mole Design.

IV. System Concept Evaluation

Overall "Whack-A-Mole" System Design Complex Decision Matrix						
	Weight	Traditional	Laser Printer	Tank Treads	Octo-Arm	Roller Ball
Timeframe Practicality	[5]	5	5	3	3	5
Cost < $300	[3]	3	3	1	1	3
Component Complexity	[3]	3	3	1	1	3
Reliablity / Durability	[5]	3	5	1	3	3
Gameplay Speed	[3]	3	3	1	5	3
Low Noise	[1]	5	5	3	5	5
Total Score	-	72	82	32	56	72

Scores	Meaning
[1]	Does not meet Criterion
[3]	Partially meets Criterion
[5]	Completely Satisfies Criterion

Figure 7. Final Design Complex Decision Matrix.

When using the complex decision matrix shown in Figure 7 to narrow down design options, the engineers decided the most important factors to weigh against were the timeframe practicality, the ability to fit the design budget, the complexity of the circuitry, the reliability and durability, the gameplay speed, and the noise level of each design. Because timeframe practicality, reliability, and durability all have significant impact into a successful working final design they were given the most weight. Cost, component complexity, and gameplay speed are all factors the team would like to optimize, so they were weighed with a three. Noise level was weighed with a one since it does not directly affect functionality.

During the brainstorming sessions, the team's initial thoughts leaned them toward the Laser Printer design. The traditional design seemed a little too dull, the tank treads design was the least practical, the Octo-Arm design would be difficult to manage given the amount of components necessary, and the roller ball design was too alike the traditional design. The complex decision matrix confirmed that the Laser Printer design is the best available option. In this design, the arm component moving on a single rail and being controlled by motor-powered reels on either side should provide an optimal balance between arm movement speed and design reliability. The team is excited to see how the design evolves throughout the semester.

V. Engineering Requirements for Key Actuator

Customer Requirements	Engineering Requirements	Possible Tests
Able to Move Arm	The actuator subsystem must be able to move the robot's arm to "whack moles" (strike buttons) in the final design.	Test actuator subsystem with game board before integrating it into the final design.
Low Power	The actuator should not require more than 5 volts to fire.	Test the voltage necessary for the actuator to fire.
Non Motor Actuator	The actuator cannot be a motor.	Ensure the actuator purchased is not a motor.
Quanser Q4 HIL Board Compatible	The actuator must interface with the Quanser Q4 board.	Check for connections to the Quanser Q4 board.
Durable	Actuator must be of quality design.	Check the actuator functions after at least 50 test runs.
Reliable	No variation in amount of power needed for the actuator function.	Ensure the actuator fires with consistent force.
Compatible with Sensor System/Software	There cannot be compatibility issues between the actuator and sensor in the final design.	Design a subsystem containing just the actuator and sensor being used to test compatibility.
Size Requirement	Actuator must be able to fit on to final robot design.	Check that the actuator can be mounted easily.

Figure 8. Key Actuator Requirements

Figure 8 shows the requirements generated for the key actuator in the final design. As the group determined when they brainstormed ideas for the final design, the actuator subsystem's primary purpose will be to use a robotic arm to strike buttons on the game board. Thus, the most important condition above is the ability of the chosen actuator to do so. To operate effectively the actuator must also function with low power (less than five volts) and be easily mountable to the board. As given in the project specifications, it cannot be a motor and must interface with the Quanser Q4 board. It should be able to survive multiple test runs and fire with consistent force when a constant voltage is applied to it. Lastly, it should be able to work with the sensor chosen in the final design. All of these requirements are easily tested.

VI. Actuator Design Solutions

1. Hydraulic Cylinder

For this design we would use a hydraulic cylinder like the one in Figure 9 in order to move the part of the arm, which will push a particular button, which will then turn off a light in that button's section. This will essentially "whack" the mole. The hydraulic cylinder itself would consist of a piston gas chamber, which would be connected to a metal rod. An outer layer of metal would protect all of these components.

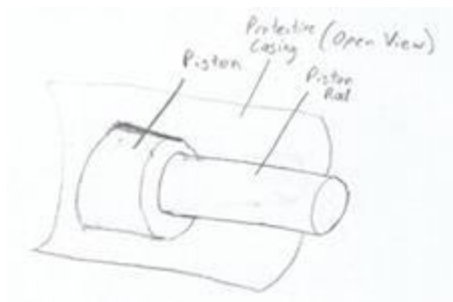

Figure 9. Hydraulic Cylinder Diagram.

2. Solenoid

For this design we would use a solenoid as shown in Figure 10 in order to move the part of the arm, which will push a particular button, which will then turn off a light in that button's section. This will essentially "whack" the mole. The solenoid would consist of a coil of wire which would act like an electromagnet on one end, and a movable rod on the other end. When an electric signal is sent to the solenoid, the current running through the coil would create and electric field, which would push the rod outward. This rod would then push the required button.

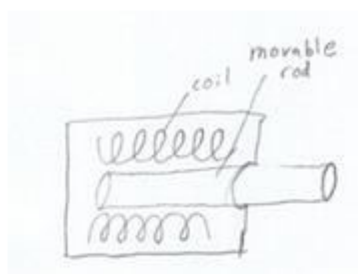

Figure 10. Solenoid Diagram

3. Electromagnet

For the electromagnet design, the "pushing" arm will have an electromagnet on one end, which when at rest will be attached to a stationary electromagnet. The electromagnet is shown in Figure 11 on the next page. Once the camera senses the light it was looking for, the electromagnet trigger will move horizontally on a track to a position above the button it will hit. A signal will be sent to the stationary magnet to stop putting out a charge. Once this happens, the arm with the electromagnet will fall, hitting the proper button. A following signal will be sent to the electromagnet, telling it to turn back on, and it will retract the arm back up, and then move back to the starting position on the track.

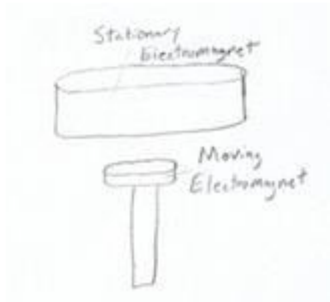

Figure 11. Electromagnet Diagram.

4. Pneumatic

This design involves using a pneumatic trigger system as shown in Figure 12 in order to push the required button ("whack the mole"). The pneumatic system would involve an air chamber, a trigger, an air transport portion, as well as a longer rod, which the trigger would push. The longer rod would be that part that hits the button. Once a signal is sent to the pneumatic system, air pressure, which was held in a chamber, would be sent through the air transportation portion until it hits the trigger. Once the air pressure activates the trigger, it would hit the rod, which would hit the required button and turn off the light.

Figure 12. Pneumatic Valve Diagram.

5. Thermal

This design involves using a pneumatic trigger system in order to push the required button ("whack the mole"). The pneumatic system would involve an air chamber, a trigger, an air transport portion, as well as a longer rod, which the trigger would push. The longer rod would be that part that hits the button. Once a signal is sent to the pneumatic system, air pressure, which was held in a chamber, would be sent through the air transportation portion until it hits the trigger. Once the air pressure activates the trigger, it would hit the rod, which would hit the required button and turn off the light.

Figure 13. Thermal Valve Diagram.

VII. Key Actuator Concept Evaluation

Actuator Complex Decision Matrix						
	Weight	Hydraulic Cylinder	Solenoid	Electromagnet	Pneumatic	Thermal
Ability to Move Arm Precisely	[5]	1	5	3	3	3
Availability	[1]	5	5	5	3	3
Low Cost	[3]	1	5	5	1	1
Low Weight / Easy to Mount	[5]	3	5	5	3	3
Low Power Consumption	[5]	1	5	3	1	1
Complexity to Implement	[1]	3	5	3	1	1
Total Score	-	36	100	78	42	42

Scores	Meaning
[1]	Does not meet Criterion
[3]	Partially meets Criterion
[5]	Completely Satisfies Criterion

Figure 14. Complex Decision Matrix for Key Actuator.

Figure 14 shows the complex decision matrix used for the Key Actuator. The actuator subsystem in the design will be used to move the robotic arm to strike buttons on the game board. One of the enjoyable things about using the overall laser printer design is that the subsystem only has to move the arm minimally with one degree of freedom, so almost any actuator is functionally suitable. However, as the complex decision matrix above reveals and once speed is considered as a factor, a subsystem based around a moderately sized solenoid is the clear winner. Using a solenoid with around half an inch of throw will allow for the arm to rest with comfortable clearance while it is in motion and allow for immediate button strikes when the subsystem is engaged. A solenoid will be very easy to mount to our design and should consume minimal power. A subsystem with a hydraulic cylinder could accomplish the same end goal, but the cylinder itself has way too much pressure on its throw and would probably break the game board. An electromagnetic subsystem could be just as effective as a solenoid subsystem, but would be much harder to implement and hold the Laser Printer's arm at rest with. Pneumatic and Thermal subsystems could possibly work, but would have delayed arm movement while they heat up or gather air. A solenoid based subsystem is the easiest, most effective way to go.

VIII. Actuator Prototype Evaluation and Conclusion

To test the Quanser Q4 board's ability to operate and interface with third party components, the sensor and actuator subsystem shown in Figures 15 and 16 was designed and tested. This circuit used a small condenser microphone to read input sounds as voltages and output to a small 3.8 volt pull type solenoid. The microphone was cheap and inefficient so it did not pick up too much ambient noise and kept at a relatively constant amplitude until completely covered when the amplitude reduced by a factor of ten. Therefore, we ended up using the microphone as a push button of sorts (as it would read the sound of a tap). The actuator subsystem was designed to charge the solenoid until the microphone read in a sound. After starting the circuit and pushing in the solenoid, an engineer could get it to fire by tapping the microphone, which caused it to cut the voltage to the solenoid.

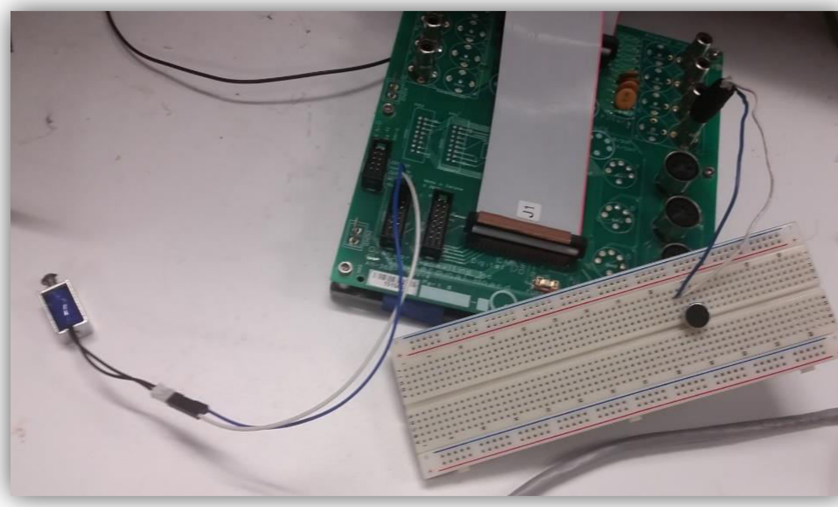

Figure 15. Actual Prototype Circuit Setup.

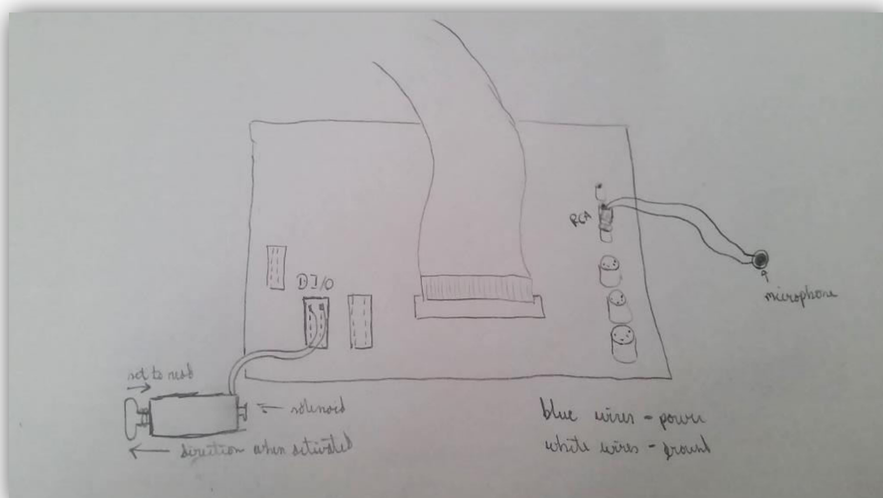

Figure 16. Prototype Diagram with Specifications.

The solenoid used was a small 3.8 volt pull type solenoid purchased from sparkfunelectronics.com. The solenoid was a pull type solenoid. To verify its functionality, the engineers hooked it directly to a Q4 board output and pulsed a square wave to it. The group found that giving it four volts energized and magnetized the spring, causing the pin to stick to the side of the solenoid when it was pushed in. At this point, removing the voltage from the solenoid released the magnetic field, causing the spring to push the pin back into a rest position and firing the pin.

Because the solenoid only needed either four volts or ground across it to operate, and the Q4 board was sufficient for supplying either voltage, the solenoid was wired directly to one of the digital outputs of the Q4 board. The idea here was for the Q4 board to send the solenoid four volts while the system was at rest. Then, when the microphone triggered the circuit, the board would stop supplying four volts to the solenoid and briefly supply ground for long enough for the solenoid to fire.

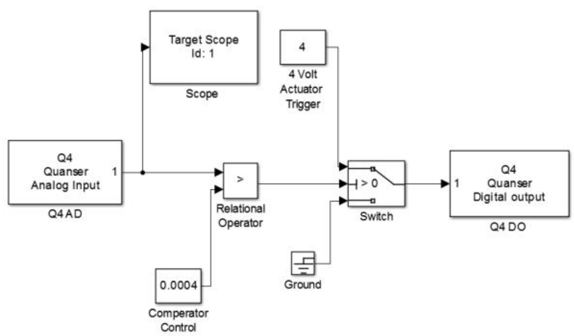

Figure 17. Simulink Prototype Circuit Setup.

The above ideas were easily accomplished in Simulink as seen in Figure 17. A comparator was set up inside of the circuit to weight the current voltage on the microphone input (analog input zero) against its value at rest. This comparator was hooked into the control for a four and zero volt switched, whose output was sent to digital output zero for use with the actuator. Whenever the voltage of the microphone increased due to a noise, the comparator would activate and cause the switch to move the voltage on the actuator from four volts to zero volts. This caused the actuator to fire.

Finally we were able to get the prototype to function properly and fire when the microphone was pressed. It became clear how being able to set up a sensor/actuator system will help us in the future in developing our final product as both these mechanisms will be essential to fulfill our customer's needs. Though we will probably be using more sophisticated systems, this prototype helped our team get our toes in the water and see how sensors and actuators can be combined to perform functions.

BBBBPE-TEK Engineering
Estimated Financial Scenario

Start-up Costs

Personnel	**5** Engineers @ $55K/yr + President @ $75K/yr + Admin. Asst. @ $25K/yr = **$375000**
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 = $ **135000** *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 $/mo = $**420**/yr The remaining equipment, furniture and software expenses are estimated to be about **7** computers @ $1500/computer $**10,500** **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 $**8232**
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 $**400** and the cost per out-of-state trip is $6,000 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 **Fehler!** = $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	$**21,983**
Travel	$**76800**
Internet and Phone Service	$**8,232**
Total Costs	$ **675775**

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)	$206250
FB @ 36% (FB billable to clients)	$74,250
Total Billable to Clients	$280,500

The remaining salary dollars and FB's must be charged to overhead.
Total Expenses = Total Costs - Total Billable to Clients = $395,275 (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
149.92% (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

=

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

= \$ 47,304.24

X. References

[1] A. Kapadia. ECE 4950 - Integrated System Design [Online]. Available: http://people.clemson.edu/~akapadi/ece4950_references.html. Cited: 9/22/2015.

ECE495 - Project 2 – Design Concept

Group Name ________

Score	Pts		ABET Outcomes
	5	General Report Format - Professional Looking Document/Preparation a) Fonts, margins (11pt, times new roman, single spaced. 1" margins all sides). b) Spelling and grammar are correct c) Layout of pictures – all figures need captions and must be referenced in text d) Follows the page limitations below. e) References. Use IEEE reference format.	g
	5	**<u>Page 1: Title, Group Name, Group Members, and Date</u>** a) Executive Summary (abstract) of the report (~ 1 paragraph). Be sure to provide a description of the solutions you choose as a result of the design process.	g
		The following should be a <u>narrative</u> report that describes your design decisions and final design, e.g., don't just have a flowchart without text that explains it.	
	15	System Design **<u>Page 2: Engineering Requirements for Entire System</u>** (~1 page) Make a three column table that lists a Customer Requirement in the first column and a resulting Engineering Requirement in the second column. a. One customer requirement may branch to multiple engineering requirements. Include in the third column the Test that will be done on the prototype to verify that your design meets each requirement, e.g., measure the maximum and minimum height. **<u>Page 3-4: Design Solutions</u>** (~2 page) • Use a brain storming session to generate concepts. Document your top five ideas with sketches and brief descriptions. Communicate the main features of each concept. **<u>Page 5: Concept Evaluation</u>** (~1 page) • Use a Complex (Weighted) Concept Evaluation Matrix to show how you chose your final solution from your five best ideas. Include description of the scale. a. Use your six most important criteria in the matrix, e.g. cost or speed b. Be sure that you provide a weighting factor (the importance) for each criterion • What is your final design choice? Describe your final decision, it may include more than just the Decision Matrix result (1 paragraph)	b
	20	Actuator Design **<u>Page 6: Engineering Requirements for Key Actuator or Sensor</u>** (~1 page) Make a three column table that lists a Customer Requirement in the first column and a resulting Engineering Requirement in the second column. a. One customer requirement may branch to multiple engineering requirements. Include in the third column the Test that will be done on the prototype to verify that your design meets each requirement. **<u>Page 7-8: Design Solutions</u>** (~2 page) • Use a brain storming session to generate concepts. Document your top five ideas with sketches and brief descriptions. Communicate the main features of each concept. **<u>Page 9: Concept Evaluation</u>** (~1 page) • Use a Complex (Weighted) Concept Evaluation Matrix to show how you chose your final solution from your five best ideas. Include description of the scale. a. Use your six most important criteria in the matrix, e.g. cost or weight • What is your final design choice? Describe your final decision, it may include more than just the Decision Matrix result (1 paragraph	b
	20	**<u>Pages 10-11: Actuator Prototype Evaluation and Conclusion</u>** (~2 pages) a) Describe your prototype with circuit drawings, mechanical drawings (sketches), etc. This is not your final design but rather a description of what you built as a prototype. This should be a narrative (like a report) that guides the reader through your design b) Test results - how well does it meet the requirements? c) Will you continue to refine this design?	c
	10	**Pages 12-14 <u>Financial Analysis</u>** Provide a financial analysis of that examines turning your group into a start-up company. Use the spreadsheet provided to make calculations and report your results on the MS Word template.	h
	25	Laboratory demonstration of your robot mockup. Does it demonstrate the proposed concept? Laboratory demonstration of your robot mockup and actuator prototype • Does it demonstrate the proposed concept? • Is it well built? Neat wiring? • Robustness	c