ECE Project 2, Design Concept:
Robot Design, Actuation, and Financial Analysis

Group W3 “No Induction Needed”
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Executive Summary

This project provides steps needed toward completing the overall goal of Robot construction and programming implementation through conceptual design. The group shows through brainstorming, testing, and conceptualization, the process can by systematically subdivided and categorically analyzed. Syphoning through the many concepts and limiting the number to five provided a small sample pool to compare within a weighted concept matrix. After deciding on the concept, the key requirements were addressed according to customer specifications and further evaluation. Lastly a complete examination of the financial needs and analysis of performing such a project and overall costs associated with such an engineering practice.

Part 1: Customer Requirements

The customer desires a ROBOT for task completion. The unit must be able to differentiate colors and move along multiple axes. Movement type is not as important as efficient and effective movement. The customer desires speed in the actions but also has limited investment capabilities. The ultimate measuring tool will be how well it performs when provided a sequence of varying colored lights at multiple locations and must be able to recognize and follow the pattern through movement. To verify its capability to do so, there will be "Reset" buttons at each location that must be pressed in the same order the lights were illuminated. The budget limits the amount of investment money. Table 1 illustrates specific customer requirements and compliments them with Engineering concerns and means by which they all may be addressed.

Customer Requirement	Engineering Requirement	Assurance Testing
The module is able to hit the push-button within 5 seconds	Efficient programming Fast actuator	Attach a built in clock and run several trials to calculate the average time
High Performance	Fluid / precise motion while moving on the track	Test the speed of the actuator Accuracy and capability to hit the push-button Consistency that allows for each time to locate the correct station Fail rate is kept to a minimum Variances in the order of stations along the board
Portability and Setup	Light weight parts Easily assembled Limited number of components Climate conditions are subjected to change	Ability to be carried from location to location and quickly setup for testing
Economical and Affordable	Manageable budget Cost analysis chart	Financial budget spreadsheet
Safety	Circuitry is wired correctly Follows IEEE standards	Take different measurements Consult the manufacture's specification spreadsheets
Maintenance	Long term reliability Properly lubricated moving parts	Install a counter to monitor usage Monitor operating hours Lubrication levels before and after each run
Programming Language Compatibility	Cross-platform Device compatibility	Attempting to run the program under different conditions and software

Table 1: Customer and Engineering Requirement Table

The design team collectively brainstormed to generate several design options. The location and residence of the arm relative to the board, the direction the arm may move and the means by which the arm's housing moves along the determined axes are a few of the questions asked during brainstorming sessions. The team made an effort to generate functional, idealistic and nearly ludicrous concepts with the intention of finding "good" ideas within all suggestions.

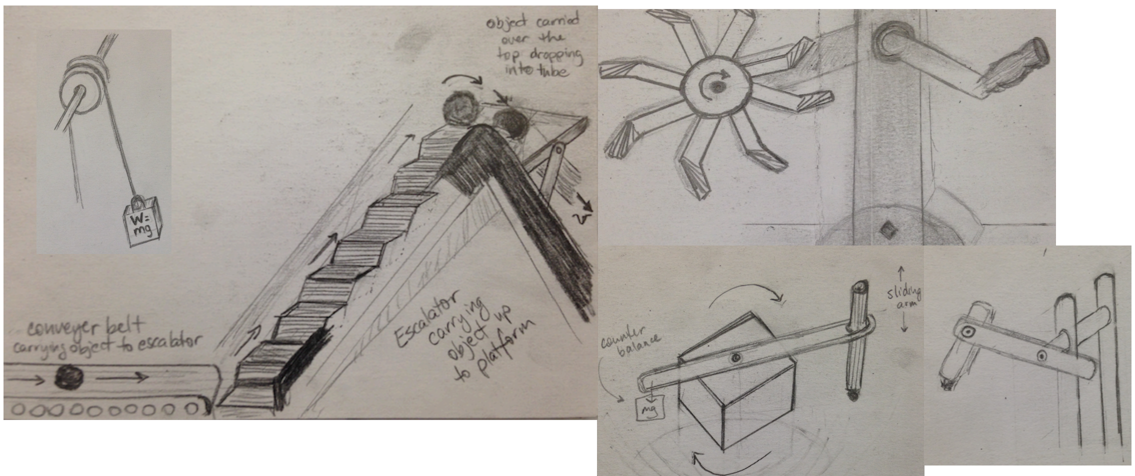

Figure 1: Assorted concepts. Left sketch has a choice of conveyer belt or crane pulley with escalator. Top right shows a spinning wheel with attached "Whackers" to press the button with quantity over quality technology. The bottom left sketch empowers the turntable concept with counterweighted arm. The bottom right sketch shows an arm that rotates about the y-axis along the z-axis on a fixed stand/tower.

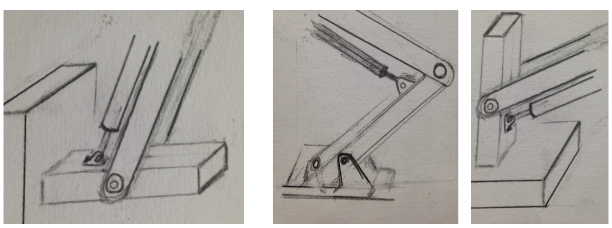
Figure 2: Showing possible arm mounting

The brainstorming stage produced numerous ideas, and ultimately brought the list to a more manageable number for further evaluation. The five conceptual finalists were:

- Single Joint Linear
- Double Joint Linear
- Double Joint Pivot
- Single Joint Magnet
- Double Joint Magnet

These 5 designs were weighed in a comparative matrix, but only after they were systematically analyzed to offer characteristic value assignment.

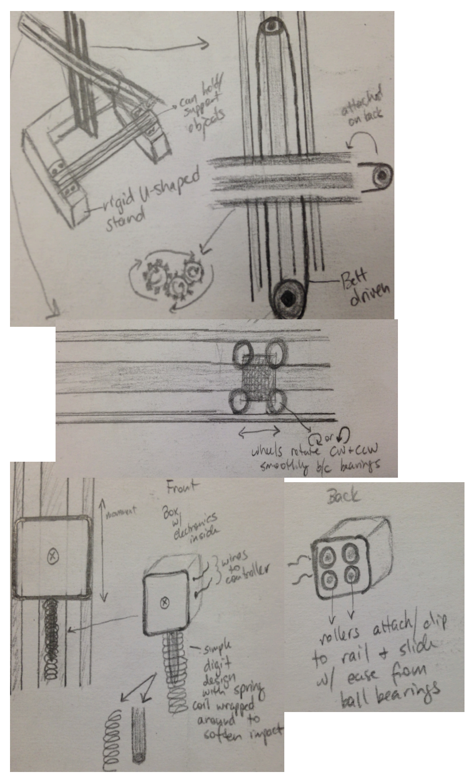

Figure 3: Showing a unit modeled after a homemade 3-D printing machine

Single Joint Linear

- This design uses a linear actuator and a single joint arm that will move from left to right, while the arm while the joint will go up and down to press the push-button.

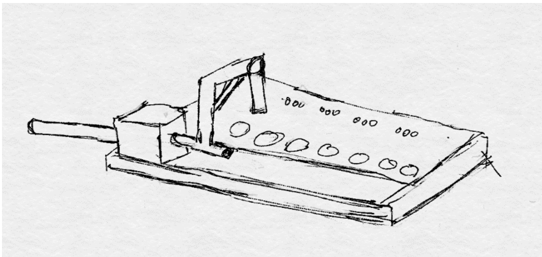
Figure 4: Single Joint Linear sketch

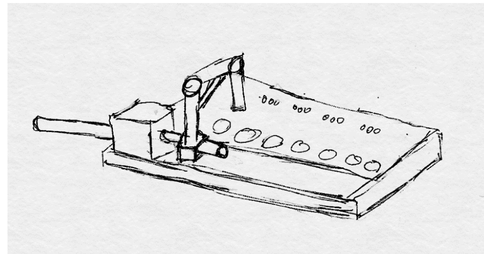
Figure 5: Double Joint Linear sketch

Double Joint Linear

- The double joint allow for the arm to not only move up and down at the vertical joint but to twist from left to right in a 180 degree manner.

Double Joint Pivot

- The Pivot actuator was able to accomplish what the other linear actuators could do and more with a wider range of motion while staying in place. It could sit in the middle of the board and move to each individual button.

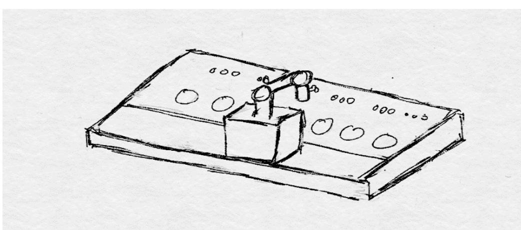
Figure 6: Double Joint Pivot

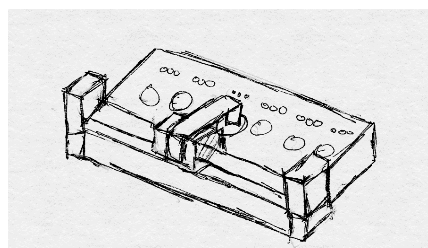
Figure 7: Single Joint Magnet Sketch

Single Joint Magnet

- The magnets allow for the arm to be push and pulled from left to right depending on the induced magnetic field, then with the single join to go up and down for the push-button.

Double Joint Magnet

- With the final design, it is identical to the previous single joint but it allows for it to move from left to right with greater angles due to the additional joint just above the moving platform.

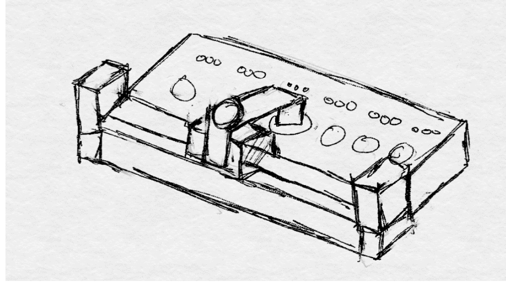
Figure 8: Double Joint Magnet sketch

The Complex Concept Evaluation Matrix, as shown below, is an entire overview of how the team weighed each option of our final design project. Ranging from speed to portability, the Matrix was based off of seven key factors. The module must be affordable to construct, easily replicable and move quickly from end to end on the board in a short amount of time. The design should also make regard for non-strenuous programmability.

Considering construction, the main focus included an easy to build mockup and final board. Consistency and reliability were major factors in deciding on the final design choice. Simply stated, if the project does not function, the cost and ease of production are futile. Also, portability did not play a major role in our decision making process. Having it move from place to place for setup and operation would not be too difficult, but the need for portability is not very great.

Each category has its own "desired" number, the most ideal, based on our requirements. The scale ranges from 1 – 5, where 5 is the best possible result and 1 the worst. From our brain storming session, we generated several ideas for our final design. Although some of the variations are subtle, each contained its own benefits to the overall process. The most pivotal characteristic in decision-making was the number of joints, should it be single or double jointed? Secondly the question arose, which style of actuator should be implemented, pivoting pneumatic, linear electromagnetic, a basic solenoid, etc. The evaluation proved the single-joint with magnetic force would provide the most efficiency for our specific needs.

Analyzing the seven categories shows it possible to sacrifice certain aspects to compensate for others. For example, if denoted a 5 on cost and consistency then speed and construction could be valued lower. The chart suggests the "Single Joint Magnet Actuator" design as the best choice, scoring 97, with the Single Joint Linear Actuator being a close second at 91. Overall the final design will be made of a metal conductive track with magnets at both ends, employing magnetic force to push/pull our single joint unit into the correct position. The arm will have a "drop-down" solenoid actuator to press the board's push-button. From minor testing in the lab, this design did not show enormous difficulty in construction or control over the electromagnetic waves.

Characteristic	Desired Value	Single Joint Linear	Double Joint Linear	Double Joint Pivot	Single Joint Magnet	Double Joint Magnet
Fast	3	3	3	5	5	5
Low Cost	5	5	3	3	1	1
Programming	3	5	3	1	3	1
Construction	3	3	3	1	5	3
Consistency	5	3	3	1	5	3
Reliability	5	3	3	1	5	3
Portability	1	3	3	3	3	3
Score		91	60	49	97	65

Table 2: The Complex Concept Evaluation Matrix

The construction of this design scored very highly in the matrix. Based on the complex decision matrix results it is clear that the single joint, linear actuator design will satisfy the requirements in the most efficient manner.

Engineering Requirements for Major Actuator (or Sensor Concept)

The device shall include an actuator attached to the arm for the purpose of resetting the activated lights during performance runs. The unit will move by means of an induced magnetic field pushing a housing platform along a metal rail.

Actuator
The metal Push-Pull Actuator is a DC Solenoid Electromagnetic Design with rated voltage of 4.5 V_{DC}.
Measurements/ Ratings:

- Force and Stroke: 40g/2mm with an energized rate at 25%
- Body/ Housing: 20 x 12 x 11mm / 0.8" x 0.47" x 0.43"
- Plunger Bar: 3 x 40mm / 0.12" x 1.6"
- Cable Length : 10cm/3.9"
- Weight 12g

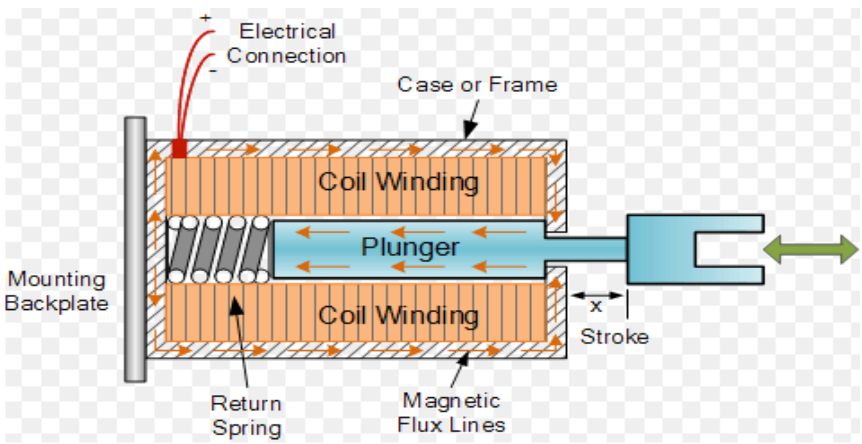

Figure 9: Diagram showing the mechanics of a linear solenoid. (Electronics-tutorials.ws)
{http://www.google.com/url?sa=i&source=imgres&cd=&cad=rja&uact=8&ved=0CAgQjB0wAGoVChMIy6PR6eKNyAIVjJ6ACh0S5AMk&url=http%3A%2F%2F

The device has copper coil wound tightly within its housing and around the “plunger” element. This enables the current-like magnetic flux to encompass the, which empowers the mechanical movement. An outside electrical current that is fed to the device by a wire through a circuit board excites the system. The board is also the interface board that communicates throughout the entire workstation.

This design required amplification but after being given proper voltage the actuator performed effectively. After hitting the target voltage the “plunger” would extend and stay. Given the same performance parameters the device would retract, displaying its ability for both Push and Pull technique.

Linear Rail Movement

The robotic arm and linear device will track along a metal rail/ rod by means of electromagnetic force (EMF). Figure 10 depicts the cause and effect relationship that will generate enough force to propel the device along its path. Much like the actuator, there is copper wire tightly wound which enables the induced field. This is accomplished by an outside power source. Figure 11 shows how an outside DC power supply will provide the initial current needed. After the current is provided the device will be attracted or opposed to the magnetic poles situated at each end. By manipulating the charge and distance of the poles will allow for the speed of the device to also be manipulated. The tentative plan is to have “magnetic stops” along the rail which will allow the device to stop and go efficiently and effectively along its path.

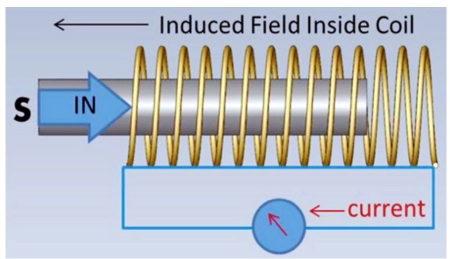

Figure 10: Image illustrating the electromagnetic force used to propel the device (2015, Electronic Design) { http://electronicdesign.com/components/what-s-difference-between-voice-coil-actuators-and-solenoids}

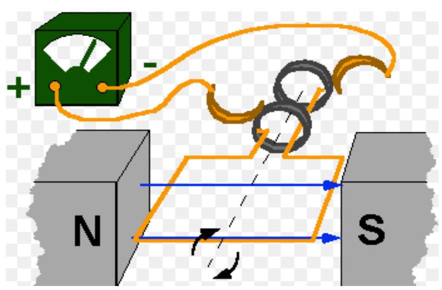

Figure 11: Image displays the proposed magnetic field design where alternating poles will attract or oppose the devices movement (2015, Govt Technical Training Institute Pindi Gheb Attock) {http://gttipg.blogspot.com/2014_05_01_archive.html?view=classic}

No Induction Needed 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* • *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 = $5,040/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 Bellsouth, 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 \$3,000 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 $$M = P\,\frac{(I/q)(1 + I/q)^q}{(1 + I/q)^q - 1} = \$74{,}726$$ 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	\$76,800
Internet and Phone Service	\$8,232
Total Costs	\$ 675775

Overhead Calculations

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	\$280,500

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 (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

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

= $47,304.24