ECE 4950 - Sensors, Financials, and Website
AATOF

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Executive Summary:

The purpose of this project was to develop potential solutions to the customer requirements. Thus, students developed the engineering requirements, necessitated by the customer requirements, and determined avenues for testing the feasibility of the engineering requirements. Once the top three proposed solutions were determined by the group, sketches outlining potential implementations of the solutions were developed. This enabled the students to determine the practicality of the proposed solutions for this project from a design and implementation point of view. Not only that, further critique and possible modifications to the proposed designs were mentioned and accounted for. From these sketches, a single solution was selected via a weighted, complex decision matrix as previously defined in the course. This decision matrix, as the one to be pursued and developed by the students for the remainder of this course, is intended to help with the development of a functional prototype by the end of the course. The use of the matrix required an analysis of the components in the design for both the feasibility of the project as well as a detailed documentation of the components' capabilities, with special emphasis on the camera. The most important aspect of the camera being its ability to be interfaced to the arduino and providing sufficient accuracy to determine between different colors. Different colors stickers taken from a sticker pack were used to determine that the algorithm and camera were functioning as intended. A financial analysis of this project was completed to examine the business behind the development and construction of the product in order to form the foundation of a startup business. Finally, a website for the group was developed to enable a concise and comprehensive summary of the status of the project and the expected course of development to have a central location which is readily accessible.

Overall System Design:

Table 1: Mapping Customer Requirements to Engineering Requirements

Engineering Requirements for the Entire Design		
Customer Requirements	Engineering Requirements	Test Methodology
Autonomous System	Able to complete tasks with no human interaction	Run task to completion without interacting with device
Inexpensive	< $100	Total cost to build product is less than $100
	< 1 hour setup time	Time setup of device
Quiet	Noise during operation less than 60dB, at a distance of 3 feet.	This can be tested for via the use of a decimeter.
Robust	The system should still operate correctly after multiple operations	The system should be able to perform the same operation several times in a row.
	Able to operate from 500 - 11000 lux	Run system at 500 lux and at 11000 lux
Fast	Rotation speed at least 4 rads/s	Rotate device and measure speed in rads/s
	Pick up washer in under 500 ms	Measure speed to pick up washer
Efficient	The robotic assembly should make a minimal amount of trips between holes/destinations on the board.	Observe system movement and judge if they ar optimal
	Uses less than 100 Wh	Measure power draw of system
Safe	No hazards exist that are frequent, probable, occasional or remote with a severity rating of critical or catastrophic	Keep detailed records of any potential hazard and how severe these hazards are.
User-friendly	Simple input format for the user	A user with no prior knowledge of the system is able to operate it.

Design Solutions:

1. The first proposed design combines the photosensor and the electromagnet on the end of a fixed distance arm. The electromagnet and photosensor are raised a minimal distance from the surface of the game board; ideally just enough for the washer to clear the board. This is so that the arm does not need to bend to enable the electromagnet and photosensor to get close enough to pick up the washer, as this would complicate the mechanics of this system greatly. The arm would be of acrylic and be light enough to not require additional support beyond that provided by the motor's shaft. The motor would be attached to the game board via angle brackets - depending on the motor housing this may be a part that would best be 3-D printed to hold the motor. The game board would be slightly elevated. This would allow for the power for the motor/electromagnet, as well as the outputs from the photosensor, to be directed through the center of the board so that the wires do not detract from the aesthetics of the game. In this iteration, the photosensor would determine the color of the washer, if present, and the algorithm would determine if the washer is in the correct position or if it needs to be moved. Before placing a washer, the photosensor would need to determine if the spot is already occupied by another washer. If so, an alternate location to put the washer for an intermediary step would be used.

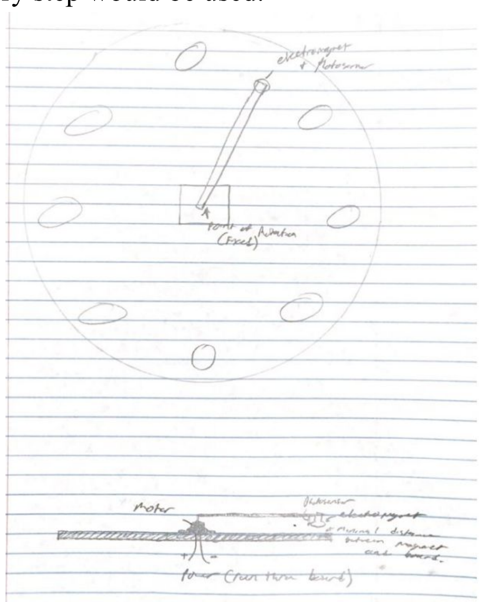

Figure 1: Fixed Distance Arm

2. For the second design idea, a similar approach to the first one was taken. However, this rendition makes use of an arm that was two sided, extending over two holes simultaneously. As such, the photosensor and the electromagnet are on opposite sides of the board at all times. This necessitates more memory for the system and potentially more movement as a full 180 degrees of travel must be completed prior to the magnet being over a known washer. A decided benefit would be the balance of the system due to the reduction in bending on the motor shaft, which should serve to increase long-term reliability of the system. This system would also ensure that the photosensor can be centered over the washer as can the magnet, as the two are not in direct competition for the space.

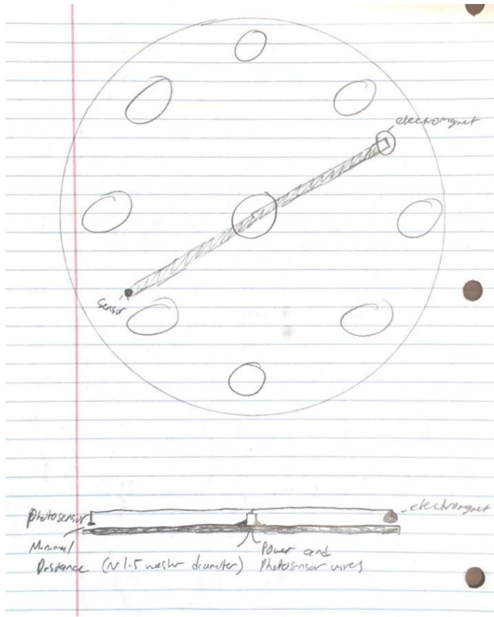

Figure 2: Two-Sided Arm

3. The final concept evaluated was that of a stationary photosensor and electromagnet and a rotating game board. This would reduce the difficulty of routing wires and the ensuing entanglement when rotation happened as all electrical components would be fixed. Difficulty would arise from the need to mount the game board on the shaft of the motor; it also would require the motor to move a substantially greater amount of weight. Further concern would be the balance of the system, especially once washers were congregated to one side of the board, if that were to happen in the course of arrangement. A lazy susan is the type of implementation envisioned below.

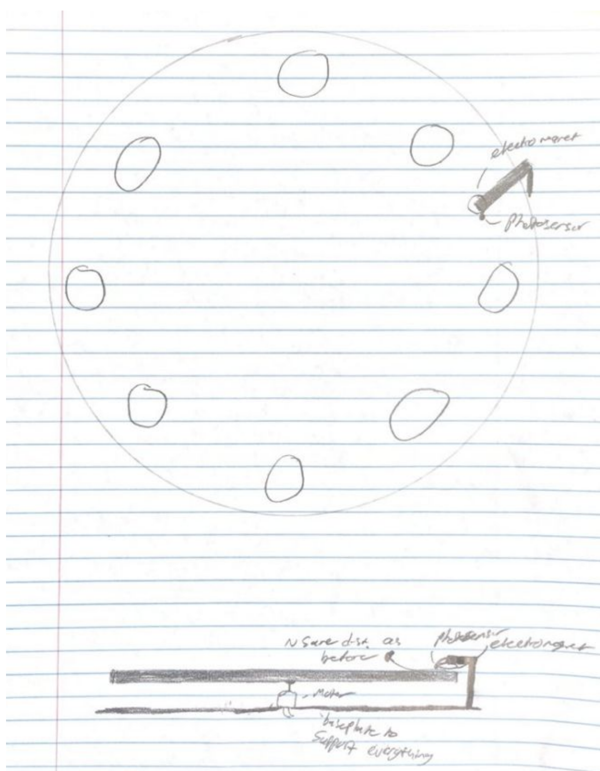

Figure 3: Lazy Susan

Concept Evaluation:

Table 2: Weighted Decision Matrix

		Designs (1-3)		
Criteria	Weights	1	2	3
Ease of Implementation	3	3	1	3
Enables Simple Algorithm to be Used	1	3	1	3
Low Cost	3	3	3	5
Motor Stress (Reliability concerns)	5	3	5	1
Wire Routing	3	1	1	5
Portability	1	3	1	3
TOTAL SCORE		42	42	50

Specific criteria pertaining to the construction of the project and the importance of these criteria to the team members are defined in the above table. Based on the weighted evaluation performed above and the project visualizations vocalized by team members, AATOF decided that option 3, the use of a fixed camera and photosensor with a rotating game board was the design best suited for the project. Without access to the game board and washers, a mockup was made using cardboard to provide a visual aid in understanding the system design as intended by AATOF.

Figure 4: Robot Mockup

Subsystem Design:

Table 3: Engineering Requirements for Camera Subsystem

Engineering Requirements for Camera Subsystem	
Customer Requirements	Engineering Requirements
Accurate	99.9% detection rate
	Produces no false positives
	Detect empty wells vs filled wells
Fast	Process game state in under 100 ms
	Able to be set up in under 5 mins
Robust	Able to operate from 500 - 11000 lux
	Able to calculate a new game state without having to be reset
	Able to operate with up to 3 plastic filters placed in front of the device
	Able to filter out noise in image
Identify numerous colored stickers	Identify up to 9 ¾’’ colored stickers
Detect multiple colors	Be able to detect dark green, red, yellow, and blue
Determine sticker location on game board	Positions will be determined by their angle offset from the starting position within the range of $-180^{\circ} < \theta < 180^{\circ}$. Positive angles are counterclockwise

Document Hardware:

The camera that was used for this project was the Docooler USB 2.0 HD Camera. This camera's specifications include a resolution of 640 x 480 and a frame rate of 30 frames per second. This camera provides a quality of photos and videos that allows the group to be able to analyze both the location and color of the stickers of the test game board file printed on a 8.5 x 11 inch piece of white paper.

As well as the camera, the game board print-out mentioned above uses four distinctly colored stickers: red, yellow, blue, and green. The intensities of these colors are similar to the colors of the metal washers we will receive for continuation of this project so being able to properly analyze these stickers will greatly help in the future.

Figure 5: Docooler USB 2.0 HD Camera

Figure 6: Colored Stickers

To set up the camera, the HD camera was connected to one of the Lenovo Y700 Laptop's USB ports via USB cable. By connecting the camera to the laptop, the camera is able to translate images of the game board to the computer in conjunction with Matlab add-ons Image Processing Toolbox and Image Acquisition Toolbox. For this particular camera type, the Image Acquisition Toolbox Support Package for OS Generic Video Interface was also necessary for the Image Acquisition GUI in Matlab to detect it. With the correct add-ons and support packages installed, the next step was to create an algorithm within Matlab capable of detecting both the color and location of stickers on a white piece of printer paper. An LED light was also used to provide proper light to the game board and reduce noise when performing background subtraction.

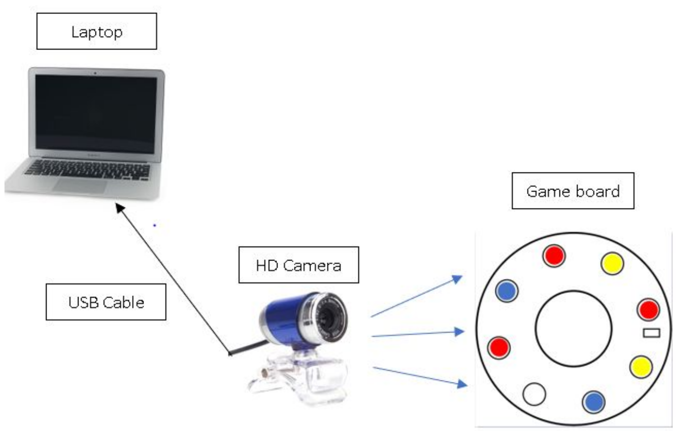

Figure 7: Camera and Laptop Setup

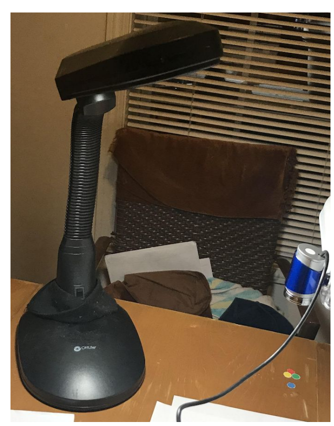

Figure 8: LED Light

Hardware:

Lenovo Y700 Laptop
USB Cable
Docooler USB 2.0 HD Camera
LED Light

Document Software:

The software of this project starts by setting up the camera to be able to take pictures within the program. The webcamlist function was used to sync the camera with the Matlab code. Specifically, webcam_list[2] was used since the Docooler HD camera is the second camera on the list (with number one being the default laptop camera). A camera preview is also included to ensure that the first snapshot is taken correctly.The first snapshot taken will be the background image and the second snapshot will be the game board with the colored stickers. Using Run and Advance in Matlab, the program will wait in between snapshot 1 and 2 until the user clicks Run and Advance again. This allows the user as much time as necessary to prepare the pictures to be taken. Once both snapshots are taken Image Processing begins.

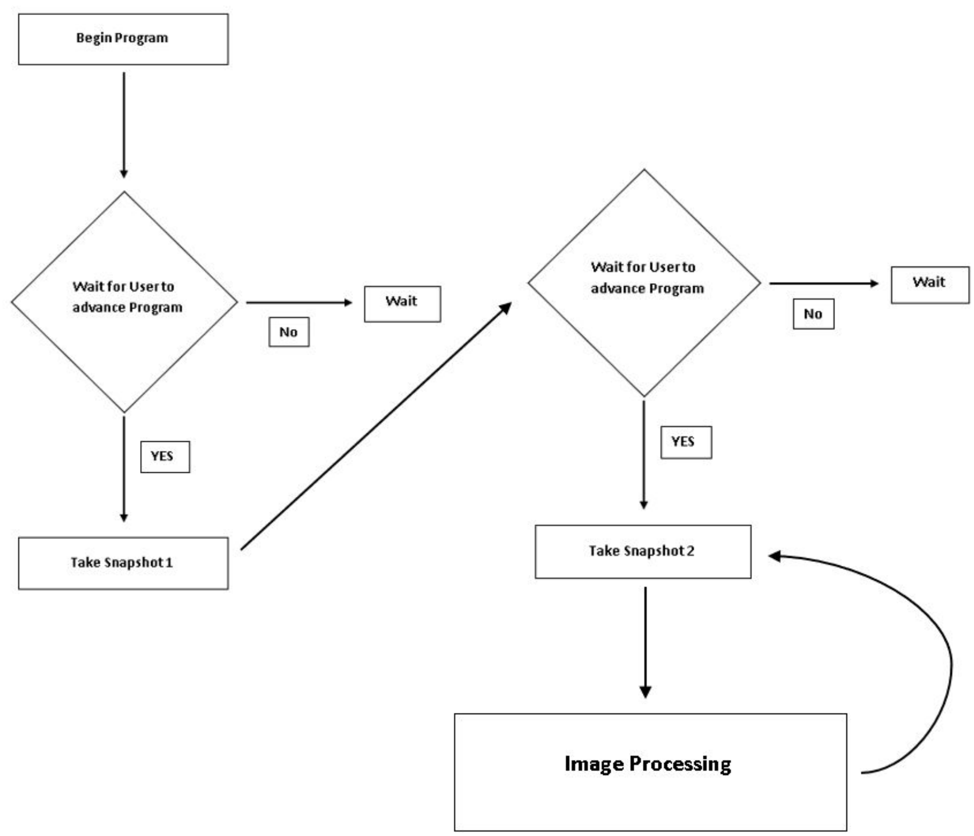

Figure 9: General Algorithm Flowchart

Image Processing:

The image processing technique used for this project in our algorithm was Background Subtraction. Background Subtraction works by subtracting the original image containing the colored stickers from the background image of the empty game board. In an ideal testing environment, this will subtract anything apart from the differences between the two pictures leaving only the stickers. However, noise resulting from human error will be present with the original image including stickers.

Next, the program converts the Background Subtraction image into a Binary Image. This action takes multiple steps to complete. First, every pixel of the Background Subtraction image is checked to see if it is not black. If it is not black, it is converted to a color that the im2bw will capture (green).

With all non-black pixels accounted for, the im2bw function is called once more to convert all green pixels to white. Thanks to the previous step, this binary image will now include all pixels found to be different from the Background Subtraction calculation.

Finally, this binary image must be eroded as well. Image erosion is essential to account for human error in testing. Looking at the figure above, it is apparent that more than just the colored stickers are being captured in these calculations. By using image erosion, our group was able to eliminate most of the pixels remaining from human error while still maintaining accuracy of the colored stickers. Although tested, Image Dilation only hindered the accuracy of our algorithm.

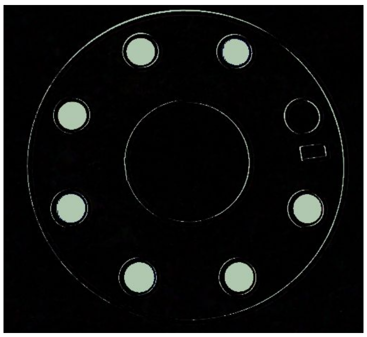

Figure 9: Updated Background Subtraction Image

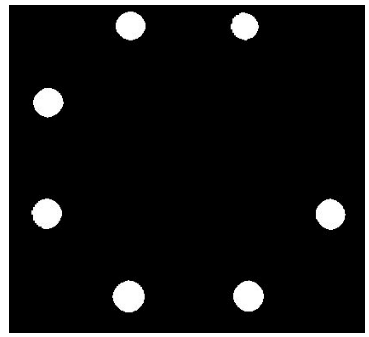

Figure 10: Image Erosion

Data Structure:

The data structure requirements are shown below:

- Color and location of each identified colored stickers.
- Location (pixel coordinates) of the centroid of each identified colored sticker.
- Images used for analysis. Since you are using background subtraction to process your image data, the following figures should be saved:
    - Original (background) image.
    - Current image.
    - Difference image.
    - Difference image after noise removal with detected foreground objects only.
    - Additional outputs from image processing steps used

The data structure created for this project is named gamestate and contains the following information:

gamestate. loc	(x,y) pixel location of every colored sticker centroid
gamestate.angle	Angle in degrees of every colored sticker
gamestate.color	Color of every sticker
gamestate.back_Orig	Background Image (game board without stickers)
gamestate.current	Original Image (game board with stickers)
gamestate.diff	Background Subtraction Image
gamestate.diffrem	Binary Background Subtraction Image

Using the regionprops function with the final Binary image, we are able to obtain a large amount of useful data; specifically the location of the every centroid in the Binary Image (of every colored sticker) These values are stored into our structure in gamestate.loc. The angle calculations follow a -180 degrees to +180 degrees standard measuring from right to left.

These angles were determined using a mathematical computation between the vector of the current centroid location to the center point and the horizontal axis through the center. Finding the colors of the stickers was also something that had to be calculated. Although red, green, and blue were easy to compute, yellow took a relatively close amount of red and green. Our group decided to use a ratio of 0.90/1.10. This means that red and green must be within 10% of each other for the color yellow. It should be noted that currently the color is determined by the pixel at the centroid location. While this works for colored stickers, when using a washer with a hollowed middle, how our group calculates color will have to be altered. Visual representation can be seen in the figure below.

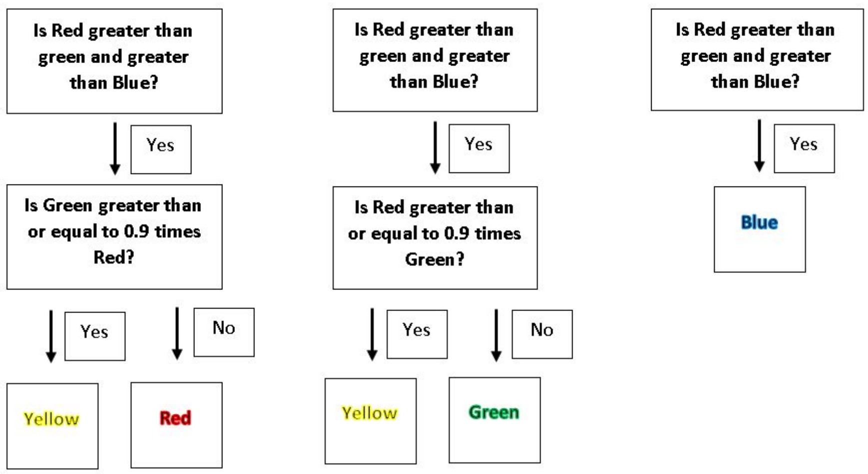

Figure 11: Color State Diagram

With the structure filled with the necessary information for each colored sticker, the centroid locations as well as the center of the picture are put onto the original image.

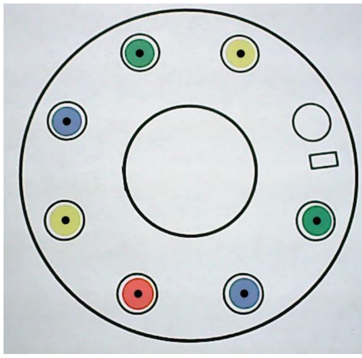

Figure 12: Original Image with Centroid Dots

Software:

Matlab R2020a
Matlab Image Processing Toolbox
Matlab Image Acquisition Toolbox
Matlab Support Package for OS Generic Video Interface

AATOF Engineering
Estimated Financial Scenario

Start-up Costs

Personnel	5 Engineers @ $65K/yr + President @ $75K/yr + Admin. Asst. @ $25K/yr = $425,000
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 $65,000 + $75,000 + $25,000) x 0.38 = $161,000 *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's office (12'x 20') + Reception/office area (16' x 20') = 1064 sq ft Use nominal figure for office space in industrial park sectors of` Clemson area, $9.50/sq ft/yr. 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 @ $2000/set — $14,000 Specialized software — $18,000 Copier, printer — $4,000 Table and chairs for conference room — $3,888 7 telephones @ $35/ea — $245 Total — $55,673
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 \$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 = \$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	\$425,000
FB @ 38%	\$161,500
Building	\$10,087
Furniture	\$55,673
Debt service	\$21,983
Travel	\$76,800
Internet and Phone Service	\$8,232
Total Costs	\$759,275

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)	$243,750
FB @ 36% (FB billable to clients)	$87,750
Total Billable to Clients	$331,500

The remaining salary dollars and FB's must be charged to overhead.
Total Expenses = Total Costs - Total Billable to Clients = $427,775 (Overhead Number)

This implies an Overhead rate of

OH rate = ($427,775/$331,500) x 100% = 129.04%
= (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 234.04% (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

$$=\left[\frac{\text{1 week work}}{\text{52 weeks per year}} \bullet \left(\frac{\text{salary} = \$65\text{K}}{\text{year}} + \frac{\text{FB} = 0.36 * \$65\text{K}}{\text{year}}\right) \bullet \left(1 + \frac{129.04\%}{100\%} + \frac{\text{profit} = 5\%}{100\%}\right)\right]$$

= \$ 3,978.68