FORCE TRANSDUCER FOR INVENTORY MANAGEMENT

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Senior Project

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San Luis Obispo

2015

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Force Transducer for Inventory Management	
Austin Adee Trever Hoye EE 460-01	Wayne Pilkington 1. I agree to supervise this senior project. __WCP____ 2. The specifications are **[1]-[2]**: ✓ **Implementation Free—Describes <u>what</u> project should do, not how.** ✓ **Bounded—Identify project boundaries, scope, and context** ✓ **Complete—Include all the requirements identified by the customer, as well as those needed to define the project.** ✓ **Unambiguous—Concisely state one clear meaning.** ✓ **Verifiable—A test can prove if system meets specification.** ✓ **Traceable—Each engineering specification serves at least one marketing requirement.**
ADVISORS: Please initial above, if you agree to supervise this senior project. Also, please check applicable boxes above. Comment below, if requirements or specifications require revision.	

Abstract

Inventory management for small parts such as electronic components remains time consuming and costly to implement, yet required for efficient business operations. Currently there exists no solution to this problem that is both automated and inexpensive. This project provides a solution by developing an accurate and wireless force transducer for automated inventory management systems. The device works by laying on the bottom of an inventory storage container and measuring the total weight of the items. The device then wirelessly transmits this weight to a receiver where it is stored in a database. Afterwards, the database compares the most recent weight with the known weight of an item and calculates the quantity of items in stock.

The project accomplished a proof of concept inventory system that accurately measures up to the weight of 1.5 grams. However the cost of the device needs to be significantly reduced to provide market feasible product. Cost improvements are discussed in the conclusion.

Introduction

Currently there exists no convenient solution for inexpensive and easily implemented automated inventory management systems. Practical inventory management consists of either routinely logging items in stock, or tracking arriving and departing items. Both of these options consume time and suffer loss of accuracy if neglected. Other automated management systems either tag every item individually (RFID) or handle the parts directly, which cost an extreme amount to implement and maintain.

This project details the development and application of a force transducer for inventory management. As a whole, the system works by placing a slim force transducer in the bottom of each inventory bin, which wirelessly transmits the total weight of the items in the container. The system then translates the weight into the number of items in inventory and stores the results into an inventory database.

Customer Needs Assessment

The requirements and customer needs were determined by talking with representatives from the R&D segments of various companies involved in the electronics manufacturing industry, who have experienced problems associated with inventory management systems. As students and interns, we have also experienced firsthand pains associated with inventory management solutions. Through studying these two mediums, we are confident that a product meeting the specifications outlined below yields an effective solution to the problems experienced by our customers.

Requirements and Specifications

The product needs to provide the customer with a solution for inventory management that is reliable, accurate, easy to use, and cost effective. The solution also needs to easily adapt to existing storage solutions already in place, and not require modification during installation. Based on this information, the following list in Table 1 outlines the requirements and specifications the product needs to abide by.

Table 1: Requirements and Specifications

Marketing Requirements	**Engineering Specifications**	**Justification**
1,2,8	The device measures the number of items present in a container.	This product develops a method to track small parts inventory in containers without hassle.
1,2	The device measures weight to an accuracy of +/- 2.5 grams, with a precision of 1 gram.	The customer needs an accurate and reliable product. The sensor measures weight to within 2.5 grams with a precision of 1 gram. This will accurately measure most items that are stored in a container compatible with the device's specification.
1,2	The device measures up to 250 g.	The products needs to withstand industrial applications, such as nuts and bolts.
2,3,4	The device handles a maximum permissible force of 500 g without damage or change in accuracy	The product has a weight safety factor of 2x for durability.
5,6	The device consumes power only wirelessly.	The device needs to easily install and adapt to the customers preexisting inventory solutions.
5,8	The device transmits data wirelessly.	Easy installation of the product into preexisting containers without modification requires a wireless configuration.
7	The product costs less than $0.50 per square inch of tag to manufacture.	The product must provide the customer with an affordable and cost effective solution.

Marketing Requirements	Engineering Specifications	Justification
2,3,4,7	The product lasts 2.5+ years under use within the device's permissible weight, not to exceed 100 item adjustments per day.	The customer needs a reliable product that doesn't introduce a weak link into their inventory management chain, that lasts long enough to have a positive ROI.
5,7,8	The product comes manufactured in several sizes from 1"x2" to 6"x8"	The customer needs a universal solution that fits preexisting storage solutions.
1,2	The device accurately updates inventory changes in under two minutes.	The customer needs a solution that doesn't misinform the user because of delayed information.
5,7	The device communicates up to 30' wirelessly.	Multiple cabinets in the same room should only require one base station to connect to the DB.
2,7	The device operates between temperatures of 50F – 100F.	The device remains reliable, regardless of environmental conditions.

Marketing Requirements

1. Accurate
2. Reliable
3. Long operating lifetime
4. Durable
5. Easy installation
6. Low power
7. Cost Effective
8. Fits preexisting containers

Functional Decomposition

Level 0 Block Diagram

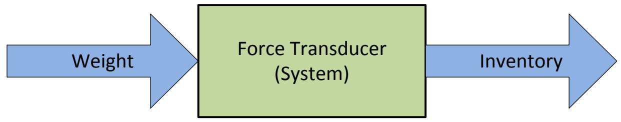


Figure 1: Level 0 Block Diagram of force transducer system

Figure 1 shows the top level functional diagram of the force transducer system. The system translates weight caused by the items in the container to the quantity of parts available in inventory. Table 2 summarizes the inputs and outputs of the system.

Table 2: Level 0 Functional Composition

Module	**force transducer (system)**
Inputs	Weight caused by items in the inventory container within the specifications in Table 1.
Outputs	Inventory amount
Functionality	The device reads weight value from the sensor to determine how many items lie in the container, and displays them on the computer.

Level 1 Block Diagram

Figure 2 outlines the next functional level in the system. The figure shows the inventoried items as an input to the transducer which outputs the weight of the items to a Wi-Fi module. The Wi-Fi module communicates wirelessly with an access point connected to a database. The database then determines the quantity of items in the container, and updates the customer's inventory accordingly.

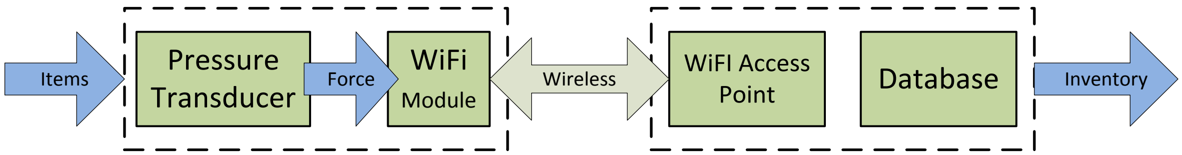


Figure 2: Level 1 Block Diagram

Table 3: Level 1 Functional Composition

Module	**Force transducer: Level 1**
Module Inputs	Weight caused by items in inventory Battery Power
Module Outputs	Wireless Data: - Weight information
Module Functionality	The module reads the weight applied on the sensor caused by items in stock, and outputs the associated weight to a wireless access point.
Access Point Inputs	Wireless Data: - associated weight for specific Wi-Fi module
Receiver Outputs	Database inventory

Level 2 Block Diagram

Figure 3 outlines the level 2 block diagram. A Photon Particle (Wi-Fi module device) reads the force sensor values, and converts the raw value into a digital value via an ADC. The photon particle is powered by an external battery so that it can transmit information. After the value has been converted the Wi-Fi module transmits the information to an access point. Once the information has been transferred, including the unique Wi-Fi module identification, it is saved into a database where it can be parsed for actual weight information. The front end user interface (UI) is powered by a PHP based web application structured on a Model, View, and Controller (MVC) framework.

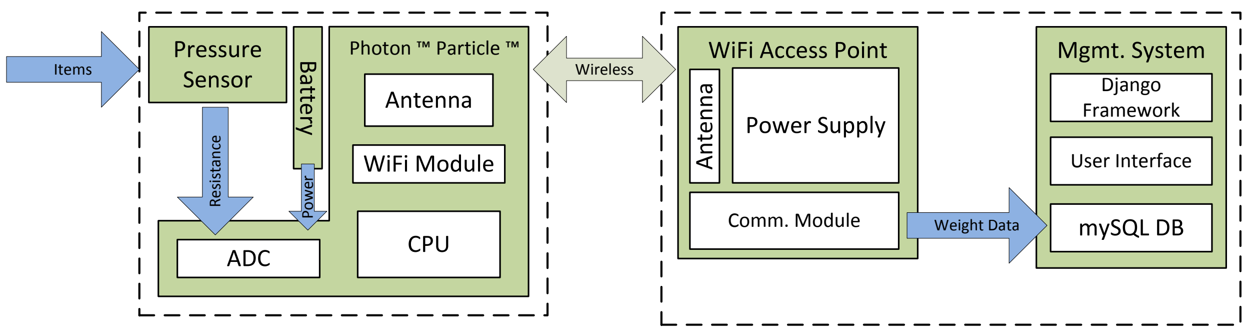


Figure 3: Level 2 Block Diagram

Module	**Force transducer: Level 1**
Sensor Inputs	Force applied from weight of inventory
Sensor Output	Voltage corresponding to weight.
Sensor Functionality	The sensor reads the amount of force being applied to it and outputs a corresponding voltage, for the Photon Particle to read.
Photon Particle Inputs	Raw sensor value Power (Supplied via external battery)
Photon Particle Outputs	Force applied to sensor is sent to the access point.
Photon Particle Functionality	The Photon Particle is the intermediate between the sensor and the access point so that the database can determine the number of the product.
Management System Inputs	Photon Particle info - Unique ID - digital info
Management System Outputs	Item inventory information
Management System Functionality	The management system take the photon particle information and converts it into the quantity for each part. The system then displays the known quantity to the users.

User Interface

The typical use case scenario can be broken into two categories, setup and operation. Setup requires calibration which begins with installing each sensor platform into its designated container and plugging in the external battery (Figure 4 : PCB Board Desgin in Container).

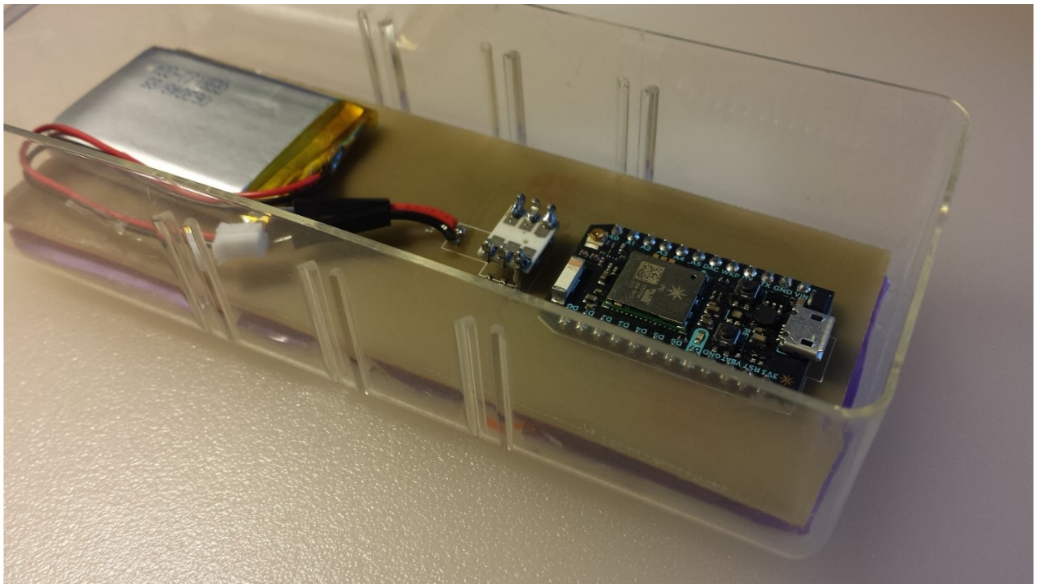


Figure 4 : PCB Board Desgin in Container

After this is completed cover lid is placed on top (Figure 5: Comlpete system inside Container) and calibration can begin.

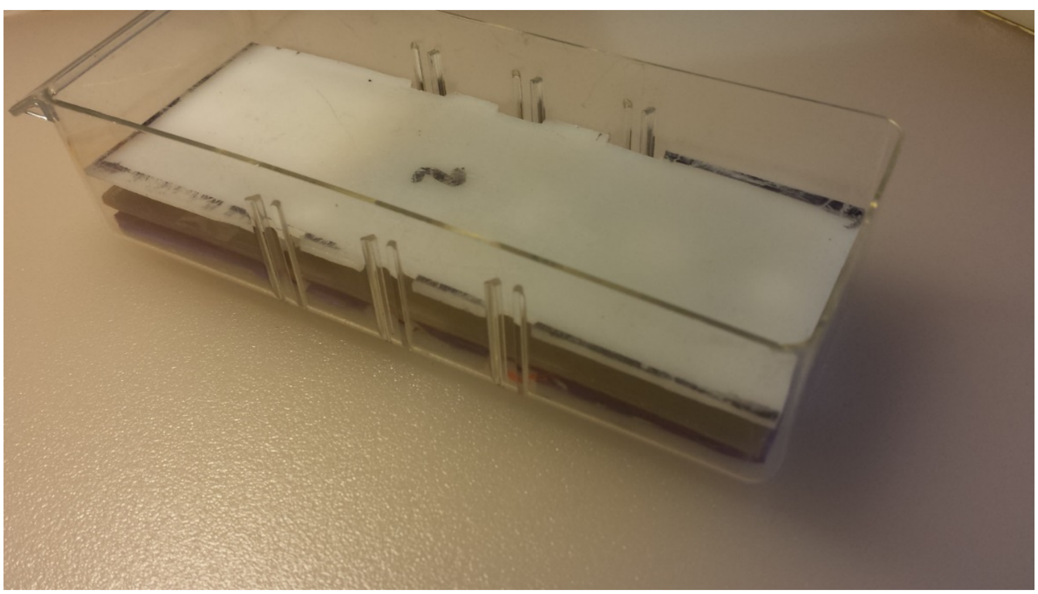


Figure 5: Comlpete system inside Container

First, click add container from the administration page (Figure 6: Django Administration Home Screen) then enter the device ID, access token, container name, empty value, and current value (Figure 7: Add Container Screen).

Figure 6: Django Administration Home Screen

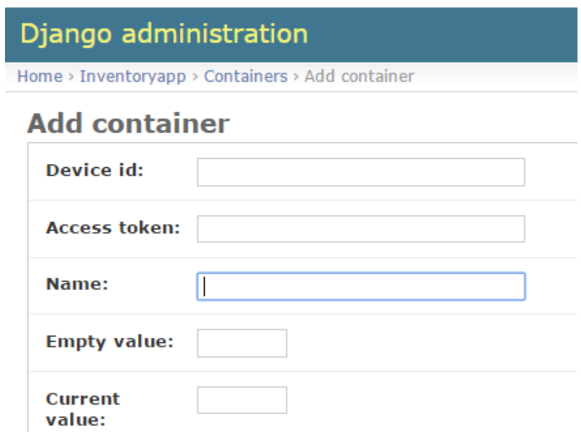


Figure 7: Add Container Screen

Next calibrate through use of the add item button (above) and then selecting item name, inputting the unit weight, and selecting the correct container (Figure 8 : Add Item Django Screen).

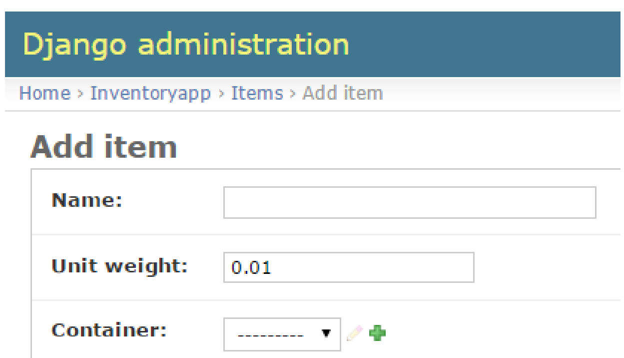
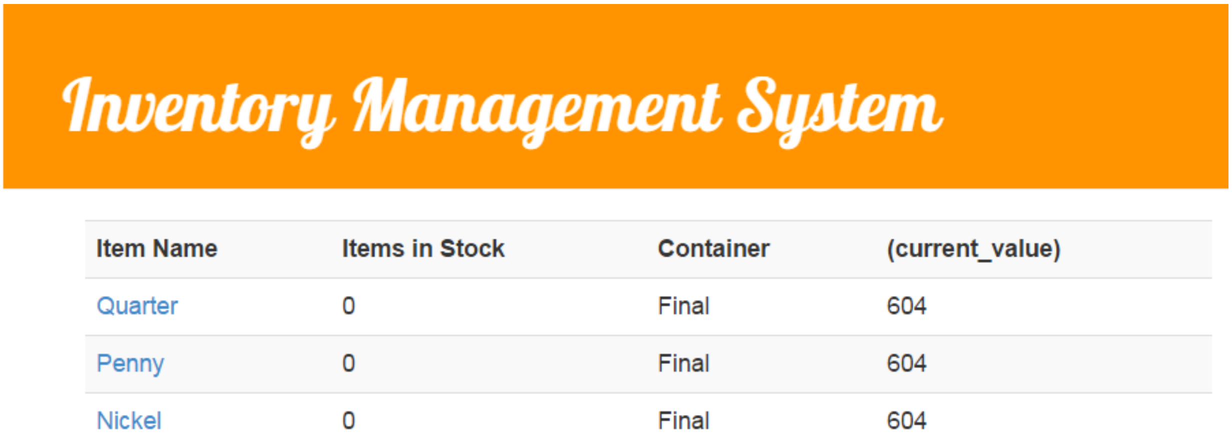


Figure 8 : Add Item Django Screen

Normal operation involves logging into the online database and checking quantity in the container (Figure 9: Inventory Database Display). If the container is used for a different item, recalibration will be required.



Inventory Management System

Item Name	Items in Stock	Container	(current_value)
Quarter	0	Final	604
Penny	0	Final	604
Nickel	0	Final	604

Figure 9: Inventory Database Display

Project Planning

Gantt chart

The projects timeframes and deadlines visualized in Figure 10, Figure 11, and Figure 12 are for Winter, Spring, and Fall quarters of 2015.

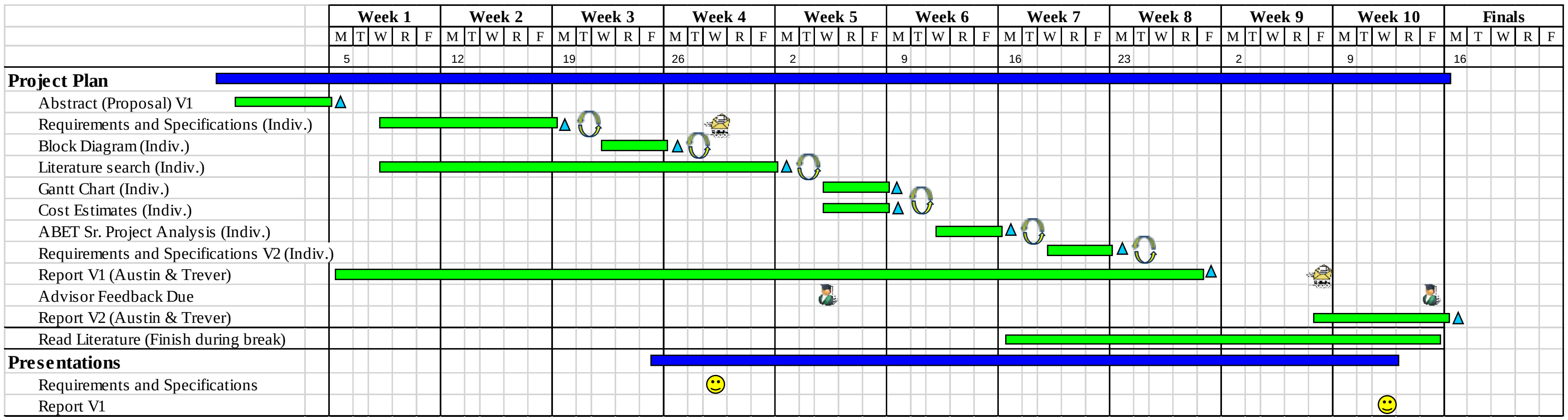


Figure 10: Gantt chart EE 460

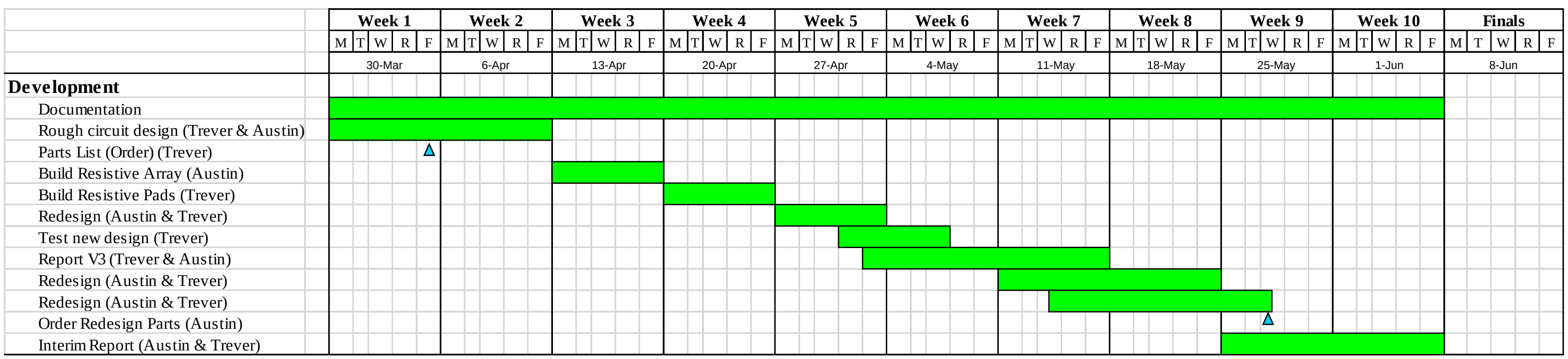


Figure 11: Gantt chart EE 461

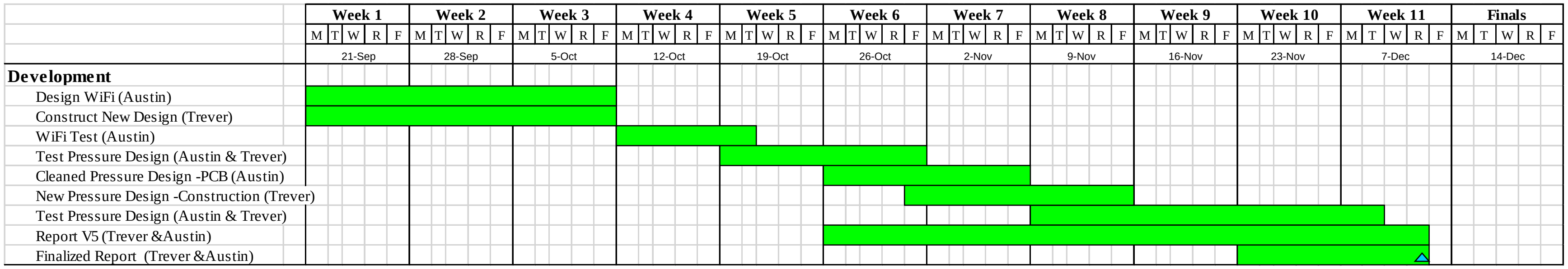


Figure 12: Gantt chart EE 462

Cost Estimate

The projects estimated and actual costs are shown below in Table 4: Cost Estimates. As seen in the table, the project costs considerably more than originally estimated.

Table 4: Cost Estimates

Cost Estimate				
Task/Item	**Time Estimate (Hours)**	**Time Actual (Hours)**	**Cost Estimate**	**Cost Actual (To Date)**
Project Plan				
Abstract (Proposal) V1	1	6	$ 25.00	$ 150.00
Requirements and Specifications	2.5	5	$ 62.50	$ 125.00
Block Diagram	0.5	0.5	$ 12.50	$ 12.50
Literature search	4	6	$ 100.00	$ 150.00
Gantt Chart	1.5	4.5	$ 37.50	$ 112.50
Cost Estimates	1.5	3.5	$ 37.50	$ 87.50
ABET Sr. Project Analysis	5	12	$ 125.00	$ 300.00
Report V1	5	5	$ 125.00	$ 125.00
Report V2	5	32	$ 125.00	$ 800.00
Development				
Parts		**0**	**$** 1,000.00	**$** 631.91
Reading Literature	10	20	$ 250.00	$ 500.00
Rough circuit design	30	14	$ 750.00	$ 350.00
Parts List (Order**)**	2	6.5	$ 50.00	$ 162.50
Building 1st design	10	8	$ 250.00	$ 200.00
Testing and ordering new parts		5	$ -	$ 125.00
Building 2nd design	10	10	$ 250.00	$ 250.00
Branch best & redesign/test	30	35	$ 750.00	$ 875.00
Programming	10	10	$ 250.00	$ 250.00
WiFi Implementation	10	7	$ 250.00	$ 175.00
Testing / Calibraition	5	6	$ 125.00	$ 150.00
Finalized Report	20	4	$ 500.00	$ 100.00
Totals	163	213.5	$ 5,075.00	$ 5,969.41
Hourly Wage	$ 25.00			

Purchased Materials

The items listed in Table 5 were purchased for the project.

Table 5: Purchasssed Materials

Purchased Materials			
Item	**Quantity**	**Cost**	**Date**
Velostat	6'x3'x4mil	$ 21.60	3/31/2015
Square FSR Interlink 406	1	$ 7.95	3/31/2015
DIY Sensor Film Kit	1	$ 18.00	3/31/2015
Shipping		$ 4.97	3/31/2015
CONN Headers	10	$ 6.85	4/24/2015
16CH Mux	2	$ 2.08	4/24/2015
16CH Mux	2	$ 1.60	4/24/2015
SOIC Breakout	4	$ 22.23	4/24/2015
Shipping		$ 5.00	
Scissors	1	$ 2.50	5/9/2015
Tape	1	$ 1.50	5/9/2015
Alum. Foil	1	$ 4.64	5/9/2015
PCB Board	1	$ 4.81	5/9/2015
HDPE 12x24x.125	1	$ 10.02	5/18/2015
HDPE 12x24x.06	1	$ 7.55	5/18/2015
Locker Lock	1	$ 5.00	5/18/2015
Sensors	4	$ 43.00	9/28/2015
Refunded		$ (43.00)	
Photon WiFi	2	$ 47.14	9/23/2015
Sensors	2	$ 34.60	9/28/2015
Goop & Batteries	1	$ 11.38	10/15/2015
Switches	2	$ 5.40	10/15/2015
Battery Holder	1	$ 8.08	10/22/2015
Button Cell Batteries 1.5 V	2	$ 8.62	10/22/2015
New Batteries LiPo	2	$ 32.07	10/22/2015
PCB	1	$ 42.36	11/5/2015
Total		**$ 315.95**	

Project Designing

Design Choices

After preliminary research, we found several different possible technologies to implement for our design. Each technology's strengths and weakness were analyzed in order to choose an optimal design.

1. Piezo Electric
    a. Piezo electric sensor use the 'piezo electric effect' in order to make a voltage or current upon dynamic physical changes to the sensor. By keeping track of the cumulative change in energy caused by the sensor, we could potentially track total forces applied to the sensor.
2. Capacitive
    a. Capacitive sensors use a variable dielectric based on force / material width to change a capacitors value, which can be measured to determine the force applied to the sensor.
3. Piezo Resistive
    a. Piezo resistive sensors change resistance based upon force applied to a resistive element sandwiched between two conductors. As the force changes, the resistance between the conductors changes, which can be measured to calculate force.
4. Load Cells
    a. Load cells are very accurate, often based on proprietary strain gauge sensors. Often large in size, due to mechanical requirements of the strain gauge.
5. Fluid Pressure
    a. Fluid pressure sensors are very accurate and usually based on extremely small monolithic strain gauge sensor.

Design Decisions

Originally, we wanted a device that was thin and flexible that could be dropped in to a generic storage container. This eliminated load cells due to their size and mechanical requirements. It also eliminated fluid pressure sensors because of the physical need for a contained fluid. This left us with Piezo Electric, Capacitive, and Piezo Resistive sensors as options. To maintain the thin and flexible *requirement*, the chosen technology would need to be implemented in an array of much smaller sensels covering the surface of the sensor, as was the method of several interface / touch / skin sensor applications [3].

Piezo electric sensors only respond to dynamic events, meaning the sensor only responds to *changes* in force. To track the total force applied to the sensor the output would have to be continuously integrated, similar to tracking position with an accelerometer. This process is prone to deviation and would require frequent recalibration. Effectively defeating the purpose of the product.

Capacitive force sensors can provide relatively accurate force information, but require advanced fabrication processes, and are only linear for very small sensels. Additionally, being implemented in an array fashion would add parasitic capacitance which could completely overshadow the value of the sensel we need.

Piezo resistive sensors can provide a relatively sensitive force information, which can be easily implemented into arrays without too much parasitic influence. For this reason we reason we originally chose the piezo technology for our sensors.

The original plan for construction was to print conductive ink onto a force sensitive resistive material, such as shown in Figure 13, and sum the total force. After researching force sensitive materials, we came across two materials that seemed promising. The first was a proprietary "carbon based" (the actual name was never disclosed to us) material which claimed to have superior linear properties. The second was a material commercially available by the name *velostat*. After building sensors out of both materials we found that velostat held the most stable resistive value for a given load. The proprietary material turned out to be poorly manufactured as can be seen in Figure 14.

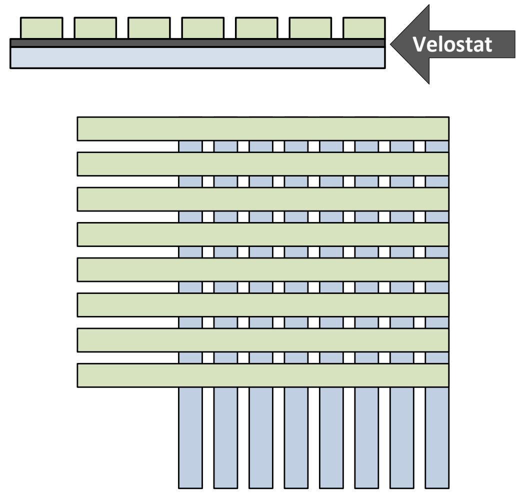


Figure 13: Resistive Array Approach

Next we contacted the Graphics Communication (GRC) department to print an 8x8 (over a 2"x2" surface) conductive band array directly onto the velostat, however their conductive printing capabilities weren't as mature as we needed. In the meantime, we had ordered the analog muxes (Figure 15) we needed to use to address each sensel. Once we received these, we realized the parasitic resistances of the switches was on the order of 180 Ohms – which, under force, can be on the order of the same magnitude of the velostat. Further, the cost of the analog switches (regardless of order quantity) would throw the price of the tag over the desired manufacturing price of $0.50. With both of these issues on the table, it was time to reconsider the options.

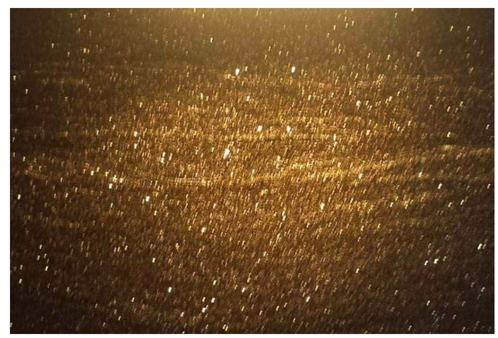


Figure 14: Proprietary force sensitive material held to light

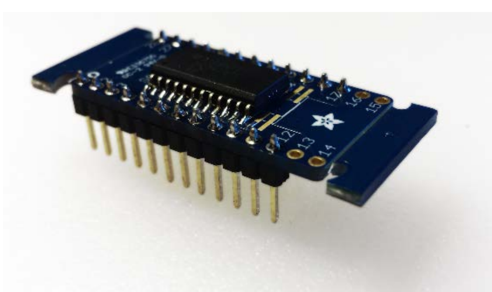


Figure 15: Analog Mux

The capacitive approach was runner up, but shared the same issues with the cost of the required muxes. No amount of fiddling/tuning would yield the product we needed, so as Meadows suggests in "Places to intervene in a system" we decided to modify the rules of the system – mainly the *requirement* that our device had to be thin and flexible like a sheet of paper. The reason we italicize *requirement* is that nowhere in the specifications or customer needs was this constraint we placed on ourselves. While it won't be as *slick* or *cool* with a rigid frame, the device loses no functionality by breaking this ill formed constraint.

This brings us to the second iteration of our product: the rigid frame with force sensitive pads supporting the device (See Figure 16 and Figure 17). Using the same piezo resistive sensor as previously chosen. The material required for the rigid frame needs to be stiff enough that a load in the center will not sag the device to the point of relieving force from the corner sensors. The material property that measures this is flexural modulus. Searching for high flexural modulus materials yielded G10/FR4 and HDPE sheets. Both materials were obtained for comparison, and G10/FR4 proved to be more rigid.

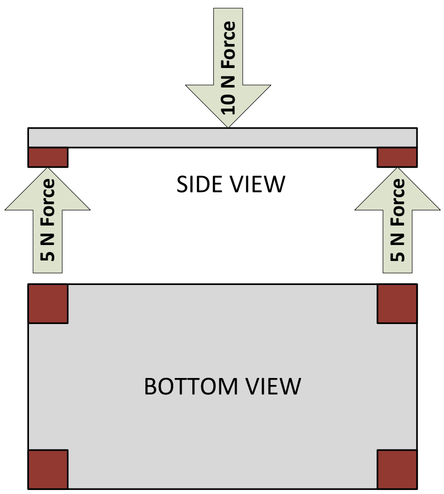


Figure 16: Rigid fame approach

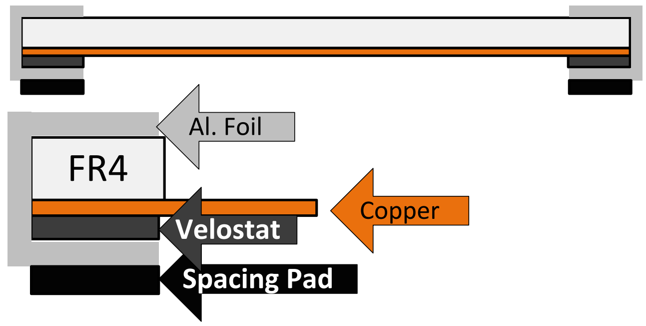


Figure 17: Rigid frame, pad detail

Both the HDPE (Figure 18) and FR4 (Figure 19) based designs preformed similarly, but per material thickness, the FR4 was more rigid which allowed the design to be slimmer.

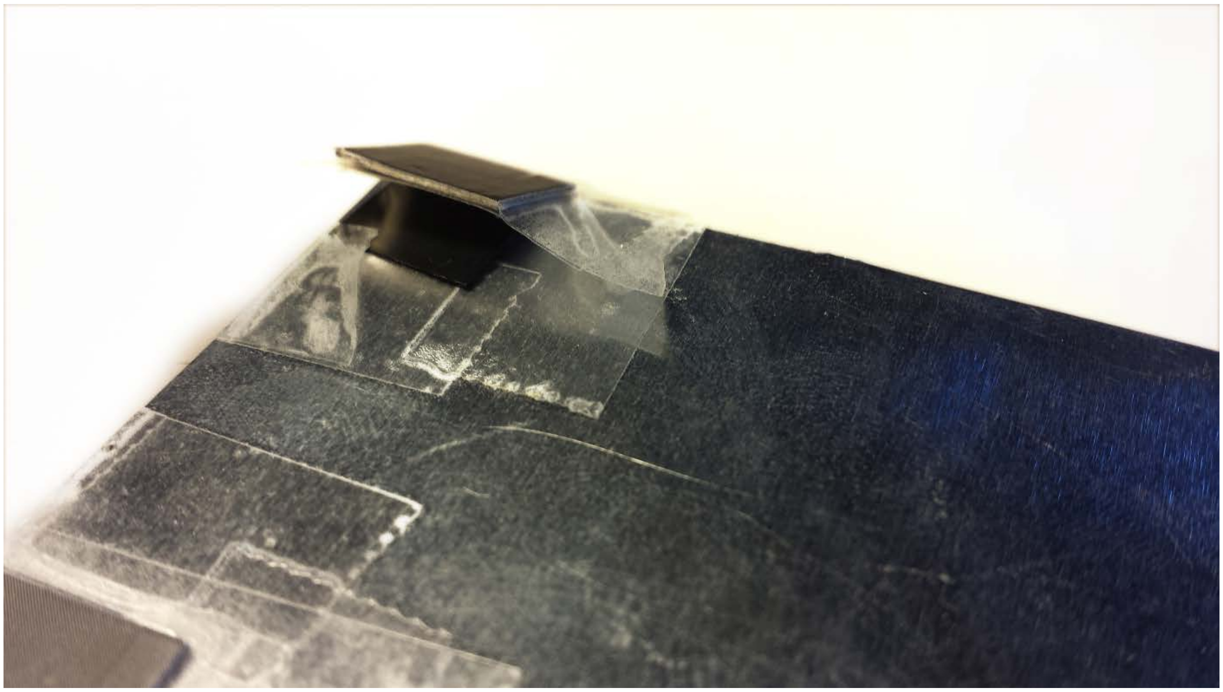


Figure 18: HDPE Based Design

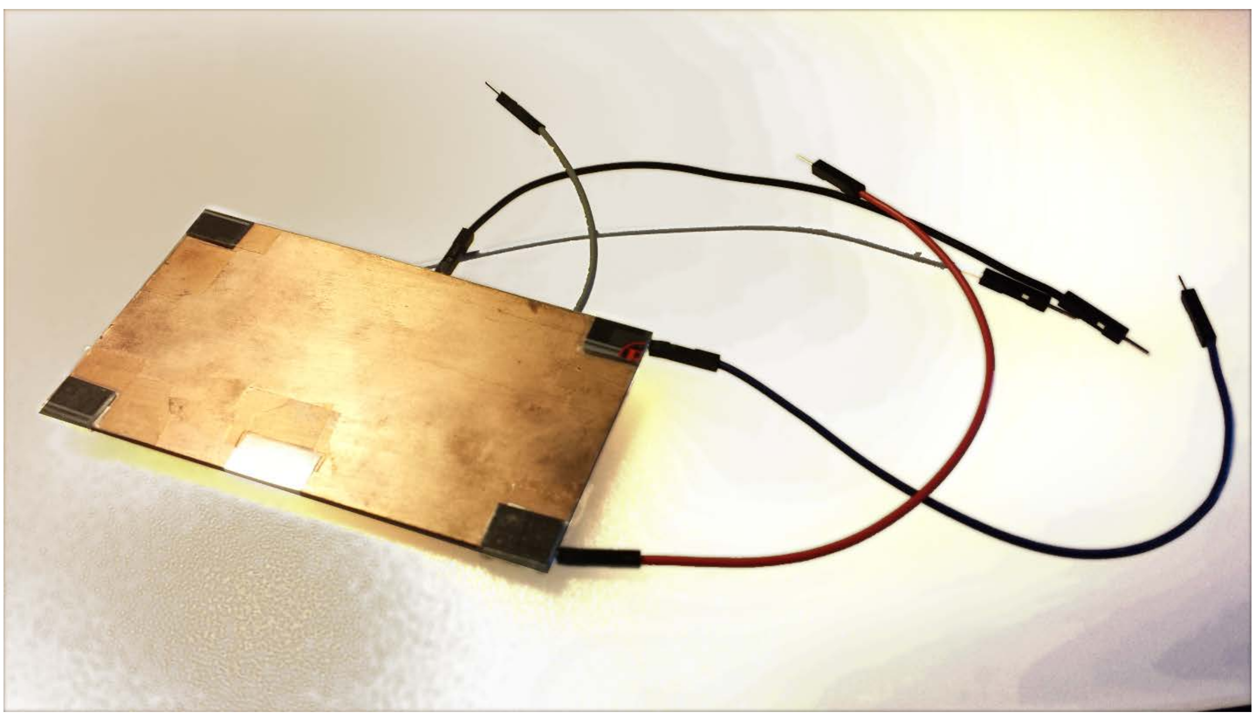


Figure 19: FR4 Based Design

This designed was more successful than previous designs, but was still inconsistent. Although they are sensitive, they suffer from a seemingly random hysteretic effect. The same force applied to the sensor multiple times yields several different resistances each time, sometimes by as much as 30%. This may be due to manufacturing techniques (the sensors are handmade), or to a deeper more fundamental issue. In the time spent studying this problem however, we thought of alternative techniques to circumvent this problem altogether.

The first proposed solution was an already fabricated surface mount force sensor. Honeywell makes such a sensor, the FSS-SMT (Figure 21), but the sensor costs around $60 each * 4/board = $240 / board. Unrealistic.

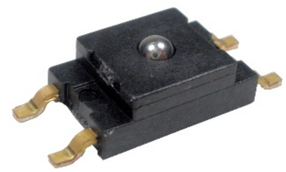


Figure 21: Honeywell SMT force sensor

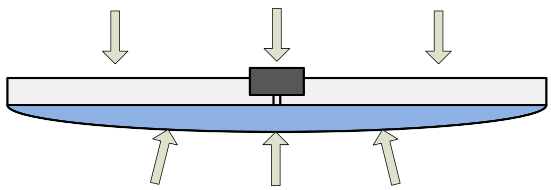


Figure 20: Bladder based pressure design

The second proposed solution was to use a commercially available pressure sensor on a bladder (Figure 20). In bulk, these sensors can be obtained for $0.60 each; slightly more than the target price, but still realistic. However, this idea would have stability issues when unevenly loaded. Also, as the force changed and the area of the contacting bladder changed, the pressure would no longer be a linear function due to the fact that Pressure = Force/Area.

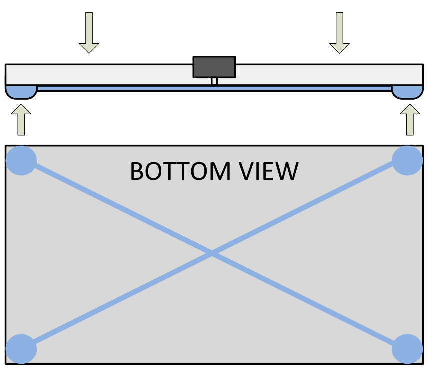


Figure 22: Improved Bladder Design

However, an improvement to this method could fix both of these problems by using pads with equalizing tubes (Figure 22). The sensor would read the pressure within the tubes, which would be directly proportional to the total force on the platform and area of the feet. A neat feature of consequence with this design is that a single ranged pressure sensor could cover a wide range of applications. By simply increasing the area of the pads, the pressure in the bladder system decreases for the same total force applied on top. Conversely, for more weight sensitive applications, reducing the area of the pads would yield a more sensitive system by increasing pressure.

With this design come three crucial flags - atmospheric pressure changes, material, and manufacturing. For barometric pressure changes, a pressure sensor which measures relative to the atmosphere would be insensitive atmospheric pressure fluctuation; and filling the bladder with fluid would prevent these fluctuations from changing the volume or shape of the bladder. The material used would need to be durable, not deforming to pressure stress, but still malleable enough that force translates through its medium. Vinyl film used in inflatable pools, floaty toys, etc. meets this specification. Finally, fabrication would be similar to that of “Bubble Wrap.” Heated vacuum molds could shape the vinyl into its functional shape whereupon it could be melted to its surface.

Design Choice Chosen

Our final prototype used the pressure senor on the bladder design, which proved to be relatively reliable and met specifications. The bladder was made from vinyl with air as the pressure medium.

In future design there are several things we would likely improve, the first being the design of the bladder. We would like to use four pads on the corners as previously mentioned. This would give us a more linear reading and mechanically stabilize the system. Additionally we would like to change the medium in the bladder to an inert liquid so that atmospheric pressure and temperature changes would have little effect on the system.

Database Structure

Ideally we would like to use RFID to communicate with system. Unfortunately due to time constraints this was not possible, so we used a WiFi module instead. This device reads the pressure sensor information and transfers it via WiFi to an online database, where the information is utilized by the inventory management software. The software is written in Python, on the Django web framework. Functionally, the program is fairly straight forward – read the database for the most recent value of each container, compare it to the calibrated empty value, and divide the difference by the unit weight.

Items In Container = (Container Weight – Empty Weight) / (Unit Weight)

To handle multiple containers, with multiple types of items, the database structure is laid out as shown in Figure 23.

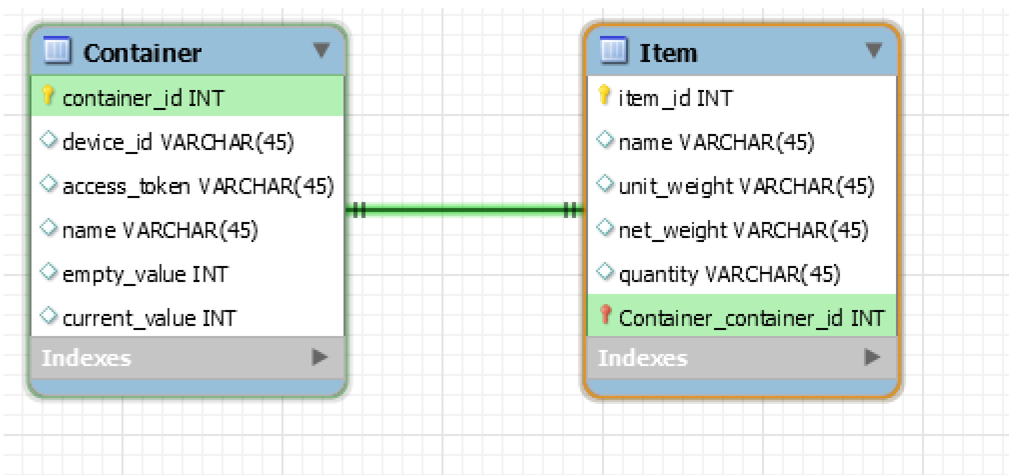


Figure 23: Database Schema

The access_token key and device_id are used to access the Particle ™ API associated with each drawer. Once the system is revised to use RFID, these API keys could be removed from the schema.

To save on bandwidth and power, the software on each Particle ™ is set to only update its status when specifically requested. The update interval can then be configured to the customers liking with a CRON job or other scheduled event.

Physical Construction

After settling on the final design concept of using a PCB board to mount the circuitry, construction involved soldering through-hole components and forming an air tight seal with the board. After trying several methods to make an airtight seal, the following proved to be most successful:

1. Rough the edges of the PCB board with a scratchpad to aid in material adhesion
2. Spray the back of the PCB board with a flat lacquer to further seal any potential leaks in the solder joints and provide a better material for the glue to stick to.
3. Place a bead of hot glue around the edges of the PCB board.
4. Place vinyl over the back of the board where the hot glue resides, and seal with a hot iron.

Figure 24 and Figure 25 show the top and bottom of the final design. Mounting the vinyl with an airtight seal, as shown in Figure 25 proved to be the most difficult aspect of construction.

Figure 24: Top of PCB with components mounted

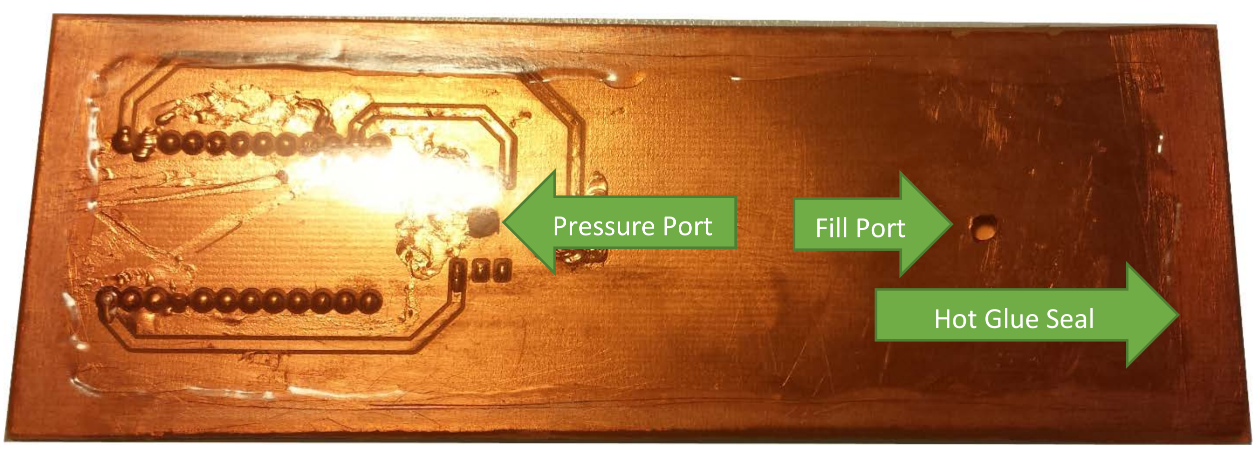


Figure 25: Vinyl covering PCB board showing physical construction

Following these steps, we filled the air bladder through a hole in the PCB board (See Figure 25 and sealed with a mild adhesive tape.

Commercial Construction

Commercially fabricating the device will result in a more consistent seal. This will work by using a heated vacuum mold on the vinyl to adhere it directly to the board without the need for glue, or a fill port. Additionally, with a vacuum mold we can adjust the size of the pads to match the application's sensitivity requirements.

Results

Using the fabrication techniques described in the previous section, we were able to accurately measure single items to about 2.5 grams, approximately the weight of a penny. A few of the measurements were off, but could be rounded accurately to the nearest *known* unit of measurement.

To characterize the performance of the device, we placed up to ten pennies, nickels, and quarters in single increments on the device, and measured the value, as shown in Table 6: Test results for Pennies, Nickels, and Quarters. Graphing the results as shown in Figure 26, Figure 27, and Figure 28 reveals that the device is prone to a small amount hysteresis which is most likely caused by the tension on the vinyl required to maintain shape (alternative manufacturing could reduce the effect of this.)

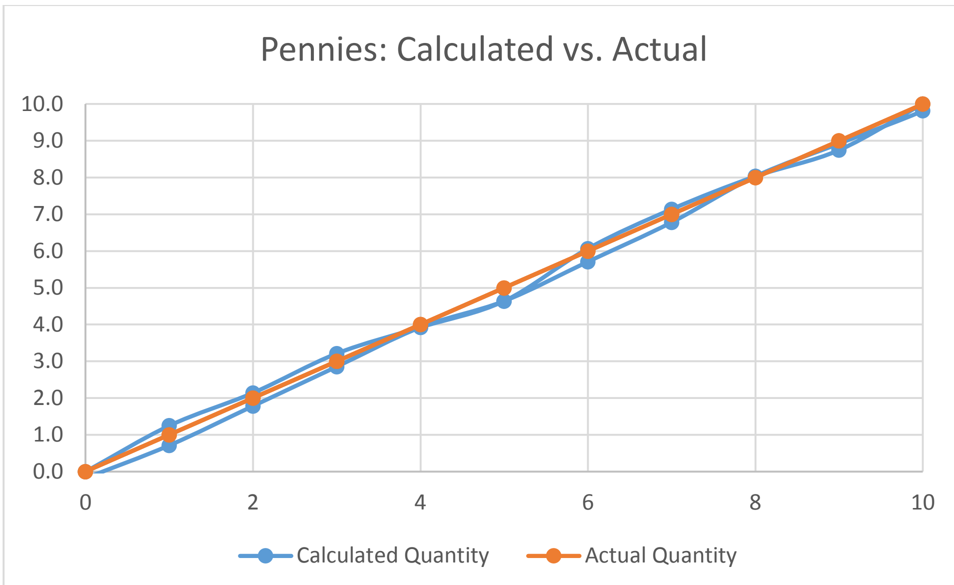


Figure 26 : Test results for Pennies (2.5 grams)

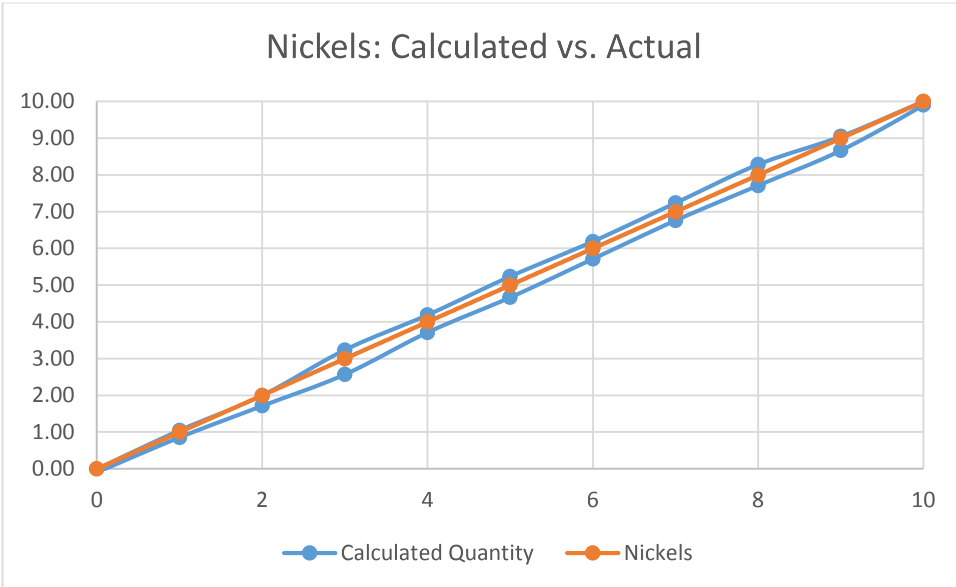


Figure 27 Test results for Nickels (5 grams)

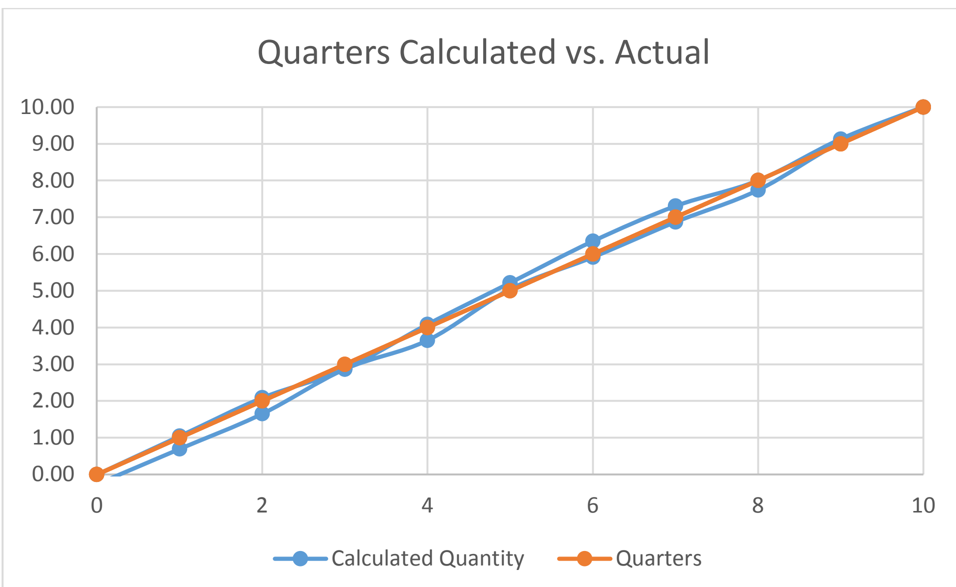


Figure 28: Test results for Quarters (5.67 grams)

Table 6: Test results for Pennies, Nickels, and Quarters

Actual Quantity	Pennies		Nickels		Quarters	
	Raw Value	Calculated Quantity	Raw Value	Calculated Quantity	Raw Value	Calculated Quantity
0	611	0.00	609	0.00	609	0.00
1	618	1.25	620	1.05	621	1.04
2	623	2.14	630	2.00	633	2.09
3	629	3.21	643	3.24	642	2.87
4	633	3.93	653	4.19	656	4.09
5	637	4.64	664	5.24	669	5.22
6	645	6.07	674	6.19	682	6.35
7	651	7.14	685	7.24	693	7.30
8	656	8.04	696	8.29	701	8.00
9	660	8.75	704	9.05	714	9.13
10	667	10.00	714	10.00	724	10.00
10	666	9.82	713	9.90	724	10.00
9	661	8.93	700	8.67	713	9.04
8	656	8.04	690	7.71	698	7.74
7	649	6.79	680	6.76	688	6.87
6	643	5.71	669	5.71	677	5.91
5	637	4.64	658	4.67	667	5.04
4	633	3.93	648	3.71	651	3.65
3	627	2.86	636	2.57	642	2.87
2	621	1.79	627	1.71	628	1.65
1	615	0.71	618	0.86	617	0.70
0	610	-0.18	608	-0.10	606	-0.26

Conclusion

We built a system that accurately measured the number of items in an inventory container. The system is relatively adaptable to different containers, however the target cost was not achieved. This is due to prototyping with a WiFi platform rather than developing with an RFID system. Additionally the WiFi platform requires active power, which introduced the need for a battery on the system, another commercially prohibitive detail of this design. The highlighted specifications in Table 1 are design requirements that were not met.

To make the product commercially viable the system needs to use RFID for communication, to reduce the manufacturing cost and the requirement of active power. Time constraints prevented us from being able to develop and implement this, due to previous sensor designs not working. This type of system would resemble the WISP platform described in the references below [5, 15]. A Level 2 block diagram of this design could resemble that of Figure 29.

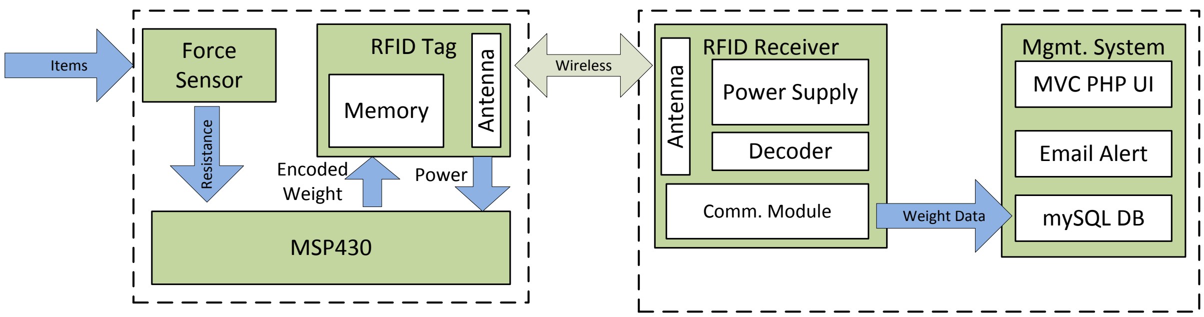


Figure 29: Level 2 Block Diagram of RFID based system

To further improve the reliability of the device, future designs would implement a heat formed vacuum mold for the vinyl bladder. This would have several advantages over the current design; first, it would allow the contact points to be sized according to the required sensitivity (a force on a smaller area increases pressure, allowing better sensitivity). Second, the vinyl wouldn't be under tension to retain its shape, eliminating most issues caused by atmospheric conditions. Additionally, the bladder would be filled with a nonreactive liquid to reduce the effects of temperature on the volume of the bladder. A liquid filled bladder would also completely remove the effects of atmospheric deviation. Finally, using a heated mold would improve the manufacturability, by eliminating the need for glue and a filling port, similar to how bubble wrap is manufactured.

References

Books:

[1] Klaus Finkenzeller, RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and near-Field Communication, 3rd ed. John Wiley & Sons, New York, NY, USA 2003

- I chose this book as a source because it will give a good introduction to RFID tags, which will be essential when we implement them into our senior project.
- The publisher John Wiley & Sons is most well-known for publishing for students and instructors in higher education. This author also has 210 citations to his name with only 2 publications to his name.

IEEE:

[2] Sander, C.S.; Knutti, James W.; Meindl, J.D., "A monolithic capacitive pressure sensor with pulse-period output," Electron Devices, IEEE Transactions on , vol.27, no.5, pp.927,930, May 1980 Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1480751&tag=1

- This article will be beneficial for understanding the mechanics of building and interfacing with capacitive pressure sensors.
- IEEE Electron Devices is a scholarly industry based Newsletter/Transaction that publishes scientific contributions relating to the theory of electron devices.

[3] Papakostas, T.V.; Lima, J.; Lowe, M., "A large area force sensor for smart skin applications," Sensors, 2002. Proceedings of IEEE , vol.2, no., pp.1620,1624 vol.2, 2002
Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1037366

- This article describes the application of peiezoresistive sensors over a large area, similar to what we want to do, with the exception that our application will be summing rather than mapping total forces.
- IEEE Proceedings is the most highly cited general interest journal in EE and CSC.

[4] "IEEE Code of Ethics" IEEE Policies, Section 7 - Professional Activities (Part A - IEEE Policies). Available: http://www.ieee.org/about/corporate/governance/p7-8.html

[5] "Design of a Passively-Powered, Programmable Sensing Platform for UHF RFID Systems" [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4143524&tag=1

[6] Jin-Sup Kim; Sang-Gi Byeon; Won-kyu Choi; Yong-Cheol Kang; Eun-ju Lee, "An active RF-ID tag for container management," Microwave Conference Proceedings, 2005. APMC 2005. Asia-Pacific Conference Proceedings, vol.5, no., pp.4 pp.,, 4-7 Dec. 2005.

- This article goes over RFID for container management which is similar to what our project will be doing when we use an RFID.

- Was published by IEEE which is the most highly cited general interest journal in EE and CSC

Manufactures Datasheets:

[7] Author Unknown, "Comparison of Interface Pressure Measurement Options," Tekscan: South Boston MA Available: http://www.tekscan.com/pdf/IDL-Comparison-Pressure-Measurement-Options.pdf

- This datasheet is more accurately a manufactures documentation on pressure sensor types and the advantages of their application. This is informative for choosing the method of sensing in our application.
- Tekscan, the author of the datasheet is a leader in industry for producing the most advanced thin-film, tactile pressure and force sensors on the market today.

Issued US Patents:

[8] Norikazu Oizumi, "Piezo-resistive pressure sensor," U.S. Patent 8 661 911, June 16, 2011 Available: https://www.google.com/patents/US8661911

- This patent may be helpful for our project if we decide to construct our pressure sensor using piezoelectric material.
- The author has published a book before on Motion Monitoring of MEMS Actuator with Electromagnetic Induction. His patent also makes sense from a technical perspective.

[9] Jean-Pierre Wilssens, "Apparatus and method for measuring the pressure distribution generated by a three-dimensional object," U.S. Patent: EP 0970657 A1, Jul 10, 1998 Available: ttp://www.google.com/patents/EP0970657A1?cl=en

- This patent may be useful when working on our project because it gives a good way to calibrate the pressure distribution generated by an object
- The author of this patent is a doctor who has also filed 3 other patents in the last 10 years. His patent also makes sense from a technical perspective.

Articles:

[10] Byunghoone Bae et al, "Design optimization of a piezoresistive pressure sensor considering the output signal-to-noise ratio," J. Micromech. Microeng, vol.14 no.12, August 23 2004

- This article will be useful in getting more accurate result from our sensor by eliminating noise from the sensor.
- The article was published in the institute of physics and science, and is cited by more than 20 other journal articles. Both authors at the time were professors at universities, including University of Illinois at Urbana-Champaign.

[11] Andrew DeRouin et al, "A Wireless Inductive-Capacitive Resonant Circuit Sensor Array for Force Monitoring," J. of Sensor Technology 2013

- This article deals with a project very similar to ours, with the exception that they are only working with two sensors. Insights they have on wirelessly powering and reading a force sensor will be directly applicable to our project.
- The article was published in the Journal of sensor Technology, and found in the Scientific Research Library.

[12] GE Measurement & Control Solutions, "Trench Etched Resonant Pressure Sensor: TERPS," GE Measurement & Control Solutions, UK LE6 0FH, Available: http://www.ge-mcs.com/download/pressure-level/TERPS-White-Paper.pdf [Accessed: Jan 31, 2015].

- This source was chosen because it looks a pressure sensing via resonating techniques, which is another viable method that we may use when doing our project.
- This is a valid source because it was published by GE Measurement & Control which is a leading company on sensor based measurement.

[13] S. Meenatchisundaram, "Sensitivity Analysis of Different Models of Piezoresistive Micro Pressure Sensors," Manipal Institute of Technology, Manipal, Karnataka, India, 2013, Available: http://www.comsol.com/paper/download/182787/meenatchisundaram_paper.pdf [Accessed: Jan 31, 2015].

- This source looks at the different models of piezoresistive sensors, which will be helpful if we decide to use a piezo sensor in our project.
- The author has 13 years of experience in teaching and industry as well as having a master's degree in Digital Electronics and Advanced communication. The author is also now pursuing a Ph.D. Micro Pressure Sensors.

[14] Christian Rendl, "PyzoFlex: Printed Piezoelectric Pressure Sensing Foil," University of Applied Sciences Upper Austria, Hagenberg, Austria, Available: http://mi-lab.org/files/2012/10/pyzoflex-final-online.pdf [Accessed: Jan 31, 2015].

- This source gives a more in depth look at how pressure sensing works and how piezoelectric material is a very valid option for pressure sensing.
- The source was published from a university in Austria and the author has a doctorate degree in computer science.

[15] "WISP: A Passively Powered UHF RFID Tag with Sensing and Computation" [Online]. Available: https://sensor.cs.washington.edu/pubs/2008-HBK-WISP-withcitation.pdf

Wikipedia:

[16]Wikipedia contributors. (2015, January 31). Piezoelectric sensor. [Online]. Available: http://en.wikipedia.org/wiki/Piezoelectric_sensor

- This article was chosen because it gives a good overview of how a piezoelectric sensor may be a good way to achieve our goals in our project.
- Many people can view and alter this article which mean it has the general consensus of what is true about piezoelectric sensors

ABET Senior Project Analysis

Project Title: Force Transducer for Inventory Management
Student's Name: Austin Adee **Student's Signature:** ____________________________
Advisor's Name: Wayne Pilkington **Initials:** ___WCP__ **Date:** __3_/_16__/_15__

• 1. Summary of Functional Requirements

This project develops a force transducer for inventory management purposes. The device works by placing a transducer in the bottom of storage containers. The device then wirelessly transmits the weight of the items in stock to a database. This database then converts the received weight into the number of items available in storage, and updates the user's inventory list.

In order to provide an effective solution for inventory management system, the device needs to provide a reliable and accurate count of the number of items in storage. The device should also provide a cost effective solution to the user and easily adapt to existing storage systems already in place without requiring modification during installation.

• 2. Primary Constraints

The product needs to provide the customer with a solution for inventory management that is reliable, accurate, easy to use, and cost effective. The solution also needs to easily adapt to existing storage solutions already in place, and not require modification during installation.

In order to provide a reliable solution, the device needs to accurately measure the total force present on the transducer. In many applications however, the inventoried items may not provide uniform force on the transducer, causing error in the measured weight. To resolve this, the device may need several small transducers covering its surface. To ensure the product's durability, it needs to withstand commercial activity on a daily basis.

For the device to work with existing solutions, the product requires wireless power and communication for easy installation. Other constraints include finding a thin material that functions as a pressure sensitive substance, durable enough to withstand industrial use or a sensors small enough to fit under a hard, thin material.

• 3. Economic

The successful implementation of this product results in a major increase in inventory efficiency for commercial organizations. This includes reducing the number of man hours required to inventory items in stock, as well as increasing the accuracy of the inventory. For urgent projects this system saves the user considerable amounts of time usually lost in the ordering and shipping of parts thought to reside in stock, as well as money in the form of fuel spent chasing parts, and the resulting downtime. One negative economic side effect of the device, is its potential to eliminate inventory management positions. This result benefits companies because it removes a fairly significantly salary, but clearly hinders people who would fill up these positions.

The cost of commercial manufacturing estimates to have an order price of $0.50 per sensor. If the final cost for the customer is $1.50 per sensor, the ROI for a company with 200 containers occurs when the device alerts the user of an item's low inventory. This estimate assumes an engineer making ~$50/hour, spending about half an hour looking for a part that is out of stock ($50/hr*0.5hr*10 = $250 = investment). The time frame this occurs depends on the initial efficiency of company in inventory management, and how often they use parts in stock.

After installation, the device costs very little to maintain. With a product cost of $1.50, the customer will most likely replace the product upon failure. Other maintenance-like costs include setup time and recalibration if the item associated with the device is changed. Finally the user may choose to upgrade software packages in the future.

• **4. If manufactured on a commercial basis:**
When introducing this product to the market, it will not likely have a linear diffusion rate. However for a 5 year market entry plan the product will be focused towards labs and companies with R&D divisions, where the product will dramatically improve inventory management in crucial situations. The market entry goal at this phase plans to sell to 100 companies per year with an average of 1000 tags per company. At a dollar markup, this yields $150,000 gross revenue per year, with $100,000 gross margin per year before sales, advertising, distribution, support and administration costs. As the business matures, the number of clients will increase to meet a demand of around 350 companies per year (approximately one new client per day).

Near the end of this first 5 year period, the company plans to develop a more durable sensor for heavy duty industrial applications, such as hardware stores, machine shops, and smaller fabrication businesses. Next the company will market towards military applications for in-field ammunition storage information. Finally as the product hits its market capacity the company will offer services related to inventory management, such as custom database/inventory management software, and yearly services.

Manufacturing the device will require processes similar to RFID tag manufacturing. Initially, due the capital required to fabricate tags, the manufacturing will be outsourced to existing 3rd party RFID tag fabricators. After the tags are made they will be shipped to a warehouse where they can be redistributed as purchased. The warehouse will also act as the company's headquarters where logistics and support are managed.

• **5. Environmental**
The commercial version of this product consumes copper, silicon, synthetic polymers (plastic), and paper. The copper used in the product forms the wireless antenna, and electrical connections and between the sensors. The semiconducting medium that runs the device consists of silicon doped with microscopic amounts of arsenic and phosphorous. The synthetic polymers compose the semiconductor packaging, and potentially the shell/case of the sensor. The paper offers another medium of encasing the product, depending on the required durability of its application.

The targeted container for this device resides in an inventory parts drawer, measuring approximately 5.5"x2" or 11 square inches. The amount of paper required to cover a single sensor measures twice this, at 22 square inches. For a commercial goal of 100,000 units per year, this product consumes approximately 2.2 Million square inches of paper. Assuming a paper weight of 20 lbs., commercial production of this device uses approximately (4.5g/ (8.5x11)*(2.2M)) = 105Kg of paper = 231 lbs. of paper per year. Not an appalling number, but enough to make it a company policy to responsibly replace what resources we can.

Other resources in the product such as copper and synthetic polymers may be gathered at the end of the products lifecycle and reused. Silicon has the ability of reuse as well, however the energy required to repurpose the silicon in the product may only contribute to an overall increase in entropy as compared to manufacturing new silicon from sand.

• **6. Manufacturability**
The ability to manufacture the device remains unknown in full detail, as no design implementations have been chosen, however from a basic understanding of the product's functional requirements, manufacturing the device does not pose much more difficulty than current RFID cards.

Sourcing the expected parts to assemble the product occurs without difficulty because the technologies used in the device have high accessibility. Further the device uses ROHS compliant parts, making exporting, safety, and recyclability much easier.

The device transports easily by postal service because of its small size and weight. The devices transportation however should occur in a stiff walled container such as a cardboard box to prevent damage. If the shipping container retains integrity, vibration and shock should not affect the device. Never the less, the devices should be packaged to prevent movement within the container.

• **7. Sustainability**
One of the challenges associated with maintaining the product are ensuring the device remains powered wirelessly without issue; container material type, distance between the reader, and the number of active sensors all affect power requirements. Also if excess pressure breaks the sensor, the user may not know until he runs out of the item monitored by the broken device.

Successful implementation of this project means significantly less driving around for individual parts. The parts can arrive via bundled orders with other components instead. These savings in driving contribute to an overall reduction in fuel consumption, and consequently greenhouse emissions.

Upgrading the design would most likely entail making the device more durable and more accurate. Other upgrades may include implement adding an LED to the sensor so that if it resides in a large storage cabinet with other sensors the user could activate the led from a computer to make finding the desired part easier. Unfortunately, due to the nature of the device *upgrades* and *repairs* will actually be *replacements*, resulting in more environmental waste.

• **8. Ethical**
Although this projects goal is to increase efficiency, it doesn't come without a cost. As more and more companies implement the product into their inventory chain, the number of inventory management jobs decreases. From a utilitarian perspective, this loss of employment poses a moral issue. However, a company using the device will operate more efficiently, allowing the company to grow and ultimately employ more people. This ultimate gain in employment provides a greater good for more people.

The product has the potential to support mission critical applications, such as hospital supply management and military ammunition inventory. Although it is capable of supporting these applications, as suppliers of the system we must adhere to the IEEE code of ethics and state its potentially lethal effects if the product malfunctions at any point in time [4]. Further, if at any time we knowingly support mission critical applications, we must accept responsibility for the reliability of the device and any repercussions.

• **9. Health and Safety**
This product has two main points of health and safety concern – First it needs to never emit harmful EM radiation under normal use, or interfere with other devices in the same frequency band. It should also not be used for inventorying items, where life and death situations can arrive from misinformation caused by the system malfunctioning, such as in a medical application field.

When looking at safety for commercial manufacturing, the safety rules need to be in place to ensure a safe working environment for the people building the devices or running the machines that fabricate the devices. To ensure the safe operation of this machinery, all personal will be required to complete safety courses prior to operating machinery. Neglecting this safety protocol poses an ethical issue, as described in the IEEE code of ethics section 1 [4].

• **10. Social and Political**
As described in the ethical section of this document, the device's drawback comes down to the nature of it causing a reduction in the number of people required to inventory items. This could have adverse effects on those currently in inventory management positions. If implemented correctly many people may lose their jobs, which for the adopting company shows them in a bad light.

This device does however benefit the adopting company economically as it saves them large sums of money and allows them to operate at a higher level of efficiency. In the long run, this makes the company stronger, ultimately allowing them to expand and hire more people than originally laid off. This growth will help the company regain public opinion, although its gratification is delayed significantly from first adoption.

• **11. Development**
While designing this project, we learned about pressure sensor technology, RFID tags, and inventory management. We also learned a considerable amount about designing low power systems.

Finally this project improved our project planning knowledge greatly since it became the 1st major project we did that encompassed several months. It has taught us to budget time correctly and caused us to make decisions about cost over productivity, for the first time in a project we have designed.

Electrical Files

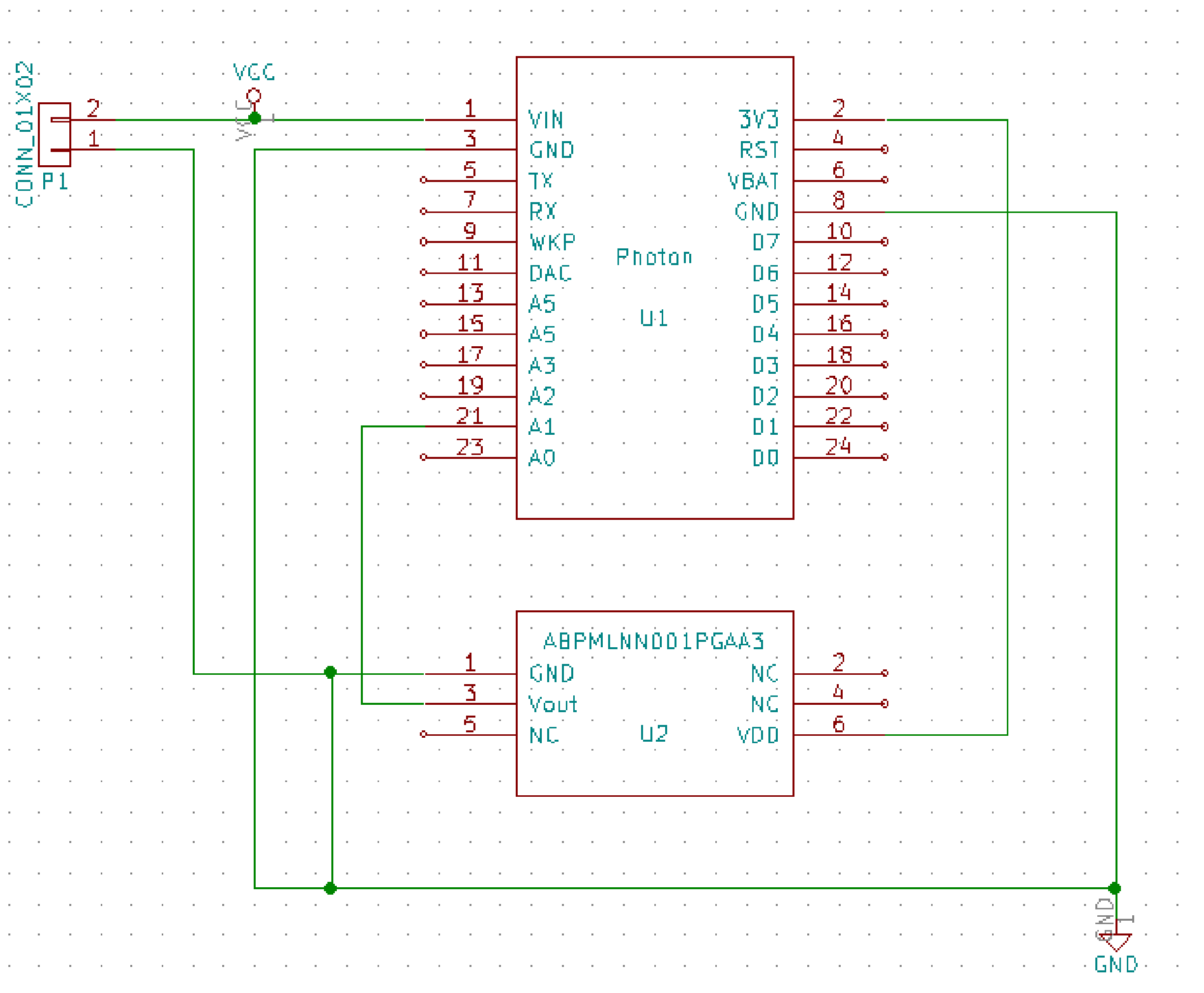


Figure 30: Schematic

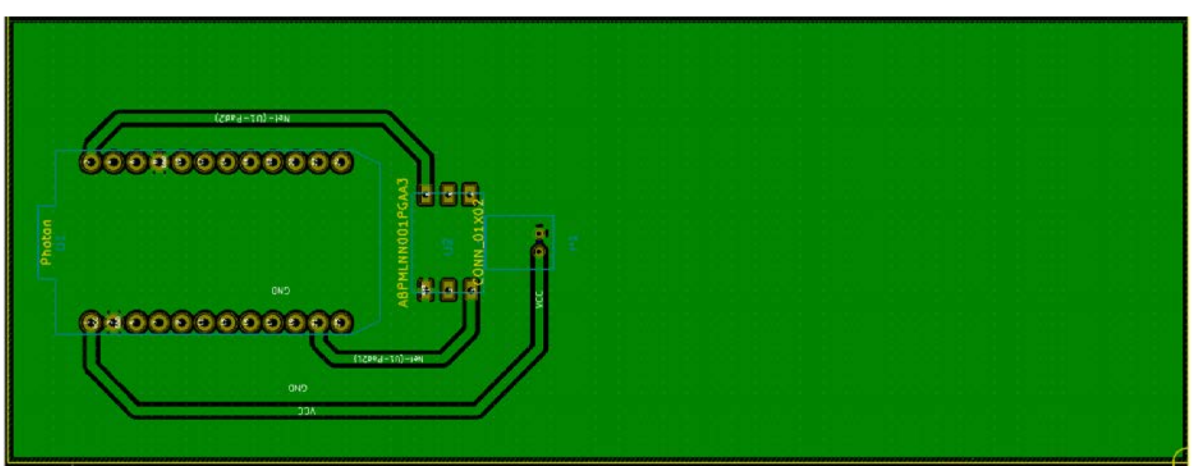


Figure 31: PCB Layout

Code

Views.Py

```
from django.shortcuts import render
from .models import Item, Container
from django.shortcuts import get_object_or_404
from .forms import ItemForm
from django.http import HttpResponseRedirect

def inventory_home(request):
    items = Item.objects.all()
    return render(request, 'inventoryapp/inventory_list.html',
{'items':items})

def refresh_inventory(request):
    containers = Container.objects.all()
    for container in containers:
        container.refresh_value()

    #TODO: Redirect to inventory_home...
    items = Item.objects.all()
    return render(request, 'inventoryapp/inventory_list.html',
{'items':items})

def calibrate(request, item_id):
    if item_id is not None:
        item = get_object_or_404(Item, pk=item_id)
    else:
        item = Item()

    if request.POST:
        form = ItemForm(request.POST, instance=item)
        if form.is_valid():
            num_items = form.cleaned_data['num_items']
            item.calibrate(num_items)

            form.save()

            #redirect_url = reverse(calibration_sucess)
            return HttpResponseRedirect("/inventory/")
            return inventory_home(request)
    else:
        form = ItemForm(instance=item)
        return render(request,
"inventoryapp/form_calibration.html",{'form':form})
```

urls.py

```
__author__ = 'Austin'

from django.conf.urls import url
from . import views


urlpatterns = [
    url(r'^$', views.inventory_home, name = 'inventory_home'),
    url(r'^refresh/', views.refresh_inventory, name='refresh_inventory'),
    url(r'^calibrate/(?P<item_id>[0-9]+)/$', views.calibrate, name='detail'),
    url(r'^calibrate/', views.calibrate, name='calibrate'),

    #url(r'^calibrate/(?P<item_id>[0-9]+)/$', views.calibrate,
name='detail'),
]
```

Models.py

```
from django.db import models
from django.contrib.gis import admin
from django.shortcuts import redirect
import requests
from string import Template
from django import forms

# Create your models here.

class Container(models.Model):
    device_id = models.CharField(max_length=255)
    access_token = models.CharField(max_length=255)
    name = models.CharField(max_length=20)
    empty_value = models.IntegerField()
    current_value = models.IntegerField()

    def __str__(self):
        return self.name

    #Tare the container
    def calibrate(self):
        json_result = self.__fetch_sensor()
        print(json_result)
        self.empty_value = int(json_result['result'])

    def refresh_value(self):
        json_result = self.__fetch_sensor()
        print(json_result)
        if "error" in json_result:
            pass #Dont change the value if we can't connect.
        else:
            self.current_value = int(json_result['result'])
        self.save()

    def __fetch_sensor(self):
```

```
        s =
Template('https://api.particle.io/v1/devices/${dev_id}/analogvalue?access_tok
en=${token}')
        url_get_variable = s.substitute(dev_id=self.device_id,
                                        token=self.access_token)
        try:
            r = requests.get(url_get_variable)
        except requests.exceptions.Timeout:
            # Maybe set up for a retry, or continue in a retry loop
            return redirect('ConnectionError')
        except requests.exceptions.TooManyRedirects:
            # Tell the user their URL was bad and try a different one
            return redirect('ConnectionError')
        except requests.exceptions.RequestException as e:
            return redirect('ConnectionError')

        return r.json()

class Item(models.Model):
    name = models.CharField(max_length=255)
    unit_weight = models.DecimalField(decimal_places=2, max_digits=7,
default=0.01)
    container = models.ForeignKey(Container)
    net_weight = property(lambda self: self.container.current_value -
self.container.empty_value)
    quantity = property(lambda self:
                        int(float(self.net_weight)/float(self.unit_weight))
if self.net_weight > 0 else 0
                        )

    def __str__(self):
        return self.name + "-" + str(self.quantity)

    def calibrate(self, num_items):
        self.unit_weight = self.net_weight / num_items
        return redirect('sucess message...')

admin.site.register(Container, admin.OSMGeoAdmin)
admin.site.register(Item, admin.OSMGeoAdmin)
```

Inventory_list.html

```
{% extends "inventoryapp/base.html" %}
{% block content %}
    <table class="table table-hover table-striped">
        <tr>
            <th>Item Name</th>
            <th>Items in Stock</th>
            <th>Container</th>
            <th>(current_value)</th>
        </tr>
    {% for item in items %}
        <tr>
            <td><a href="calibrate/{{item.id}}">{{item.name}}</a></td>
            <td>{{item.quantity}}</td>
            <td>{{item.container.name}}</td>
            <td>{{item.container.current_value}}</td>
        </tr>
    {% endfor %}
    </table>
{% endblock content %}
```

Form_calibration.html

```
{% extends "inventoryapp/base.html" %}
{% block content %}
    <form action='./' method='post'>{% csrf_token %}
        {{ form.as_p }}
        <input type='submit' value='Submit' />
    </form>
{% endblock %}
```

Base.html

```
{% load staticfiles %}
<html>
    <head>
        <title>Inventory System</title>
        <link rel="stylesheet"
href="//maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap.min.css">
        <link rel="stylesheet"
href="//maxcdn.bootstrapcdn.com/bootstrap/3.2.0/css/bootstrap-theme.min.css">
        <script
src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.3/jquery.min.js"></scr
ipt>
        <script
src="http://maxcdn.bootstrapcdn.com/bootstrap/3.3.5/js/bootstrap.min.js"></sc
ript>
        <link
href='//fonts.googleapis.com/css?family=Lobster&subset=latin,latin-ext'
rel='stylesheet' type='text/css'>
        <link rel="stylesheet" href="{% static "inventoryapp/style.css" %}">
    </head>

    <body>
        <div class="page-header">
            <h1><a href="/">Inventory Management System</a></h1>
        </div>
        <div class="content container">
            <div class="row">
                <div class="col-md-8">
                {% block content %}
                {% endblock %}
                </div>
            </div>
        </div>



    </body>
</html>
```

Style.css

```css
h1 a {
    color: #FCA205;
    font-family: 'Lobster';
}
body {
    padding-left: 15px;
}
.page-header {
    background-color: #ff9400;
    margin-top: 0;
    padding: 20px 20px 20px 40px;
}
.page-header h1, .page-header h1 a, .page-header h1 a:visited, .page-header h1
a:active {
    color: #ffffff;
    font-size: 36pt;
    text-decoration: none;
}

.content {
    margin-left: 40px;
}

h1, h2, h3, h4 {
    font-family: 'Lobster', cursive;
}

.date {
    float: right;
    color: #828282;
}

.save {
    float: right;
}

.post-form textarea, .post-form input {
    width: 100%;
}

.top-menu, .top-menu:hover, .top-menu:visited {
    color: #ffffff;
    float: right;
    font-size: 26pt;
    margin-right: 20px;
}

.post {
    margin-bottom: 70px;
}

.post h1 a, .post h1 a:visited {
    color: #000000;
}
```