Internal Luggage Scale

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1 Introduction

1.1 Objective

Most major airlines charge additional fees for passengers with extra luggage or whose luggage exceeds a specific weight limit. For example, American Airlines charges passengers from $100 to $200 in luggage fees for all luggage exceeding 50 pounds on a domestic flight [1]. According to the U.S. Bureau of Transportation, U.S. airlines alone generated 4.6 billion dollars in profits from the enforcement of luggage fees in 2018 [2]. For passengers looking to avoid paying fees incurred from excess luggage weight, packing can be a hassle. The weight of the suitcase is unknown until fully packed and weighed as a single unit, and going over the limit requires repacking and reorganizing until the limit is met.

Current methods of weighing luggage include using a regular bathroom scale, a portable luggage scale, or the standard luggage scale available at the airport. The first two options are ideal in situations where a person wants to avoid the inconvenience of repacking in line at the airport. However, some people do not have access to bathroom scales. This is particularly common among out-of-state college students. Furthermore, while portable scales are more convenient, they also require stabilizing the scale by lifting and holding luggage that can reach up to fifty pounds for a few seconds.

We propose to build a suitcase with an internal scale to provide a more convenient packing experience. As the user loads items into his or her suitcase, load sensors hidden in the bottom layer will detect the weight of the items and the detected weight will be displayed to an LCD screen on the case. Ideally, the user will be aware of the weight in real time without having to resort to repacking or inconvenient weighing methods to meet the airline weight limit.

1.2 Background

Looking at products currently available on the mass market, few exist that match the convenience of our design. Most luggage products with built-in scales rely on the portable scale model. That is, they still require the user to lift and hold the luggage for a few seconds to get a weight reading [3].

We intend to differentiate our design by making it more convenient to use than existing designs. Rather than forcing the user to exert physical effort to weigh his or her luggage, we intend to build the scale into the luggage such that the user can place objects in the luggage and get a weight reading without ever resorting to lifting the luggage off the ground. While we did find a handful of companies that sell products similar to the design we proposed, some of them failed while still in the startup stage and others are still in the initial stages of raising funding to mass produce their products [4].

1.3 High-level Requirements

- The weight measurements produced by the system will fall within +/- 1 pound of a comparable weight reading produced by a standard luggage weight system. A standard luggage weight system would be a bathroom scale, portable luggage scale, or airport luggage scale.
- The full system will add no more than 7 pounds of additional weight to the existing suitcase.
- The suitcase should meet federal airline regulations for both carry-on and checked-in luggage.

2 Design

Our design consists of four major components: a power subsystem, a control unit, a weight module, and a user interface. The power subsystem is responsible for powering the other system components with a 5V supply regulated according to the power needs of each component. The control unit serves as the interface between the hardware components and performs the necessary computations to convert electrical weight readings into numbers for the display. The weight module contains the hardware components necessary to sense the objects the user places in the suitcase. Finally, the user interface displays data for the user to read and allows the user to interact with the system by zeroing the scale when the power switch is turned off and on again. The full system will be constructed by making physical modifications to an existing suitcase.

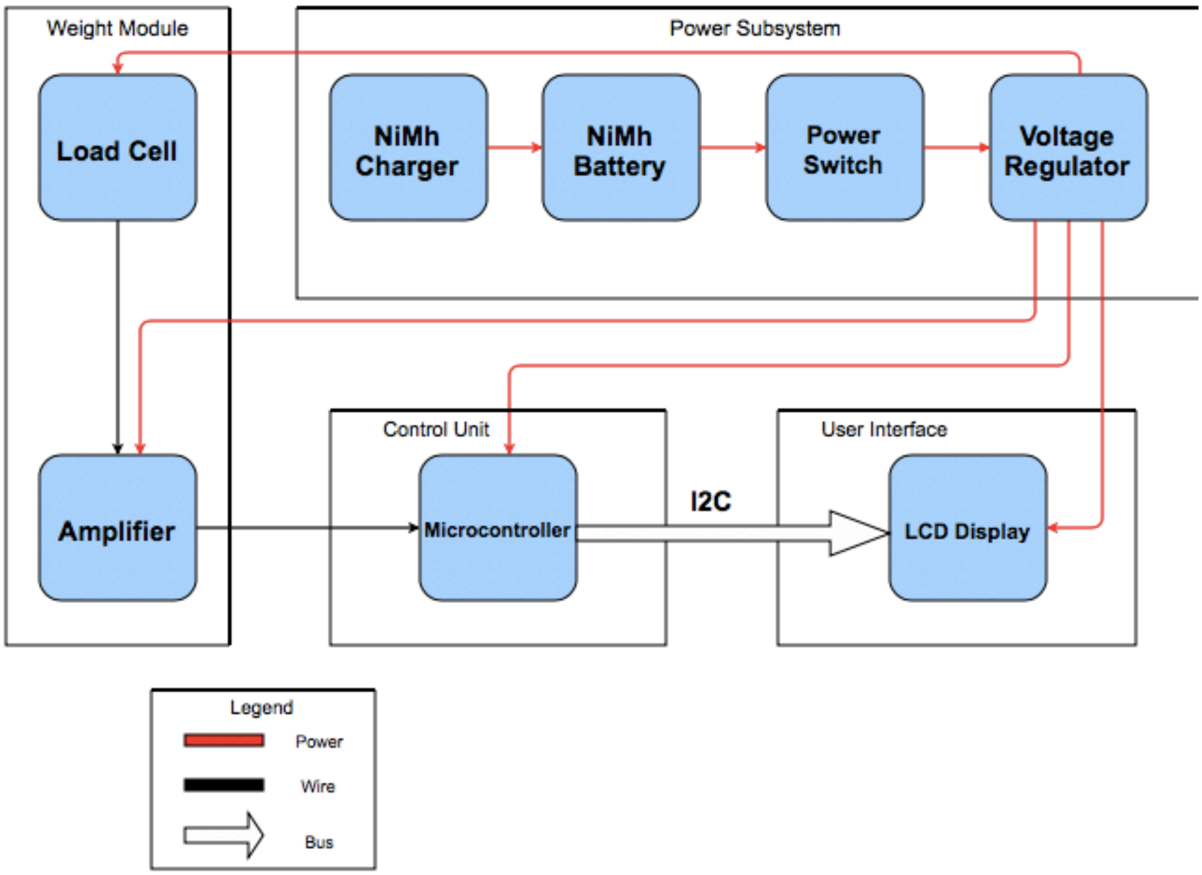

Figure 1. Block Diagram

Regarding the actual physical design of the suitcase seen in Figures 2-4, we intend to build our scale into an existing suitcase with a single compartment for packing items. As seen in the diagram, the bottom layer of the main compartment will contain the scale portion of the system constructed from load cells sandwiched between rigid acrylic plates. The PCB and power system will be attached to one of the inner walls of the suitcase. The LCD will be either attached to the outside of the suitcase wall facing the user, or built into the side of the case such that it can be wired to the PCB. As seen in the diagram, the green component represents the battery case, the blue component represents the PCB, the grey components represent the weight sensors, and the orange component represents the LCD screen. The dimensions of the suitcase are 28 inches by 18 inches by 10 inches. The dimensions of the acrylic panel inside the suitcase are 27 inches by 17 inches by 0.06 inches.

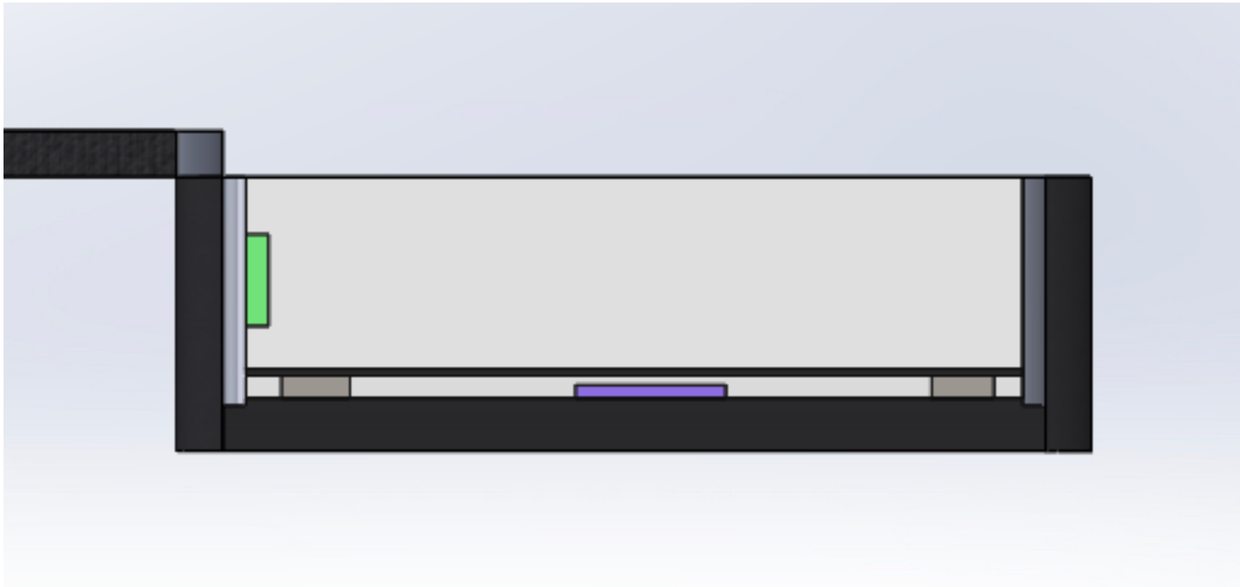

Figure 2. Physical Design Side View

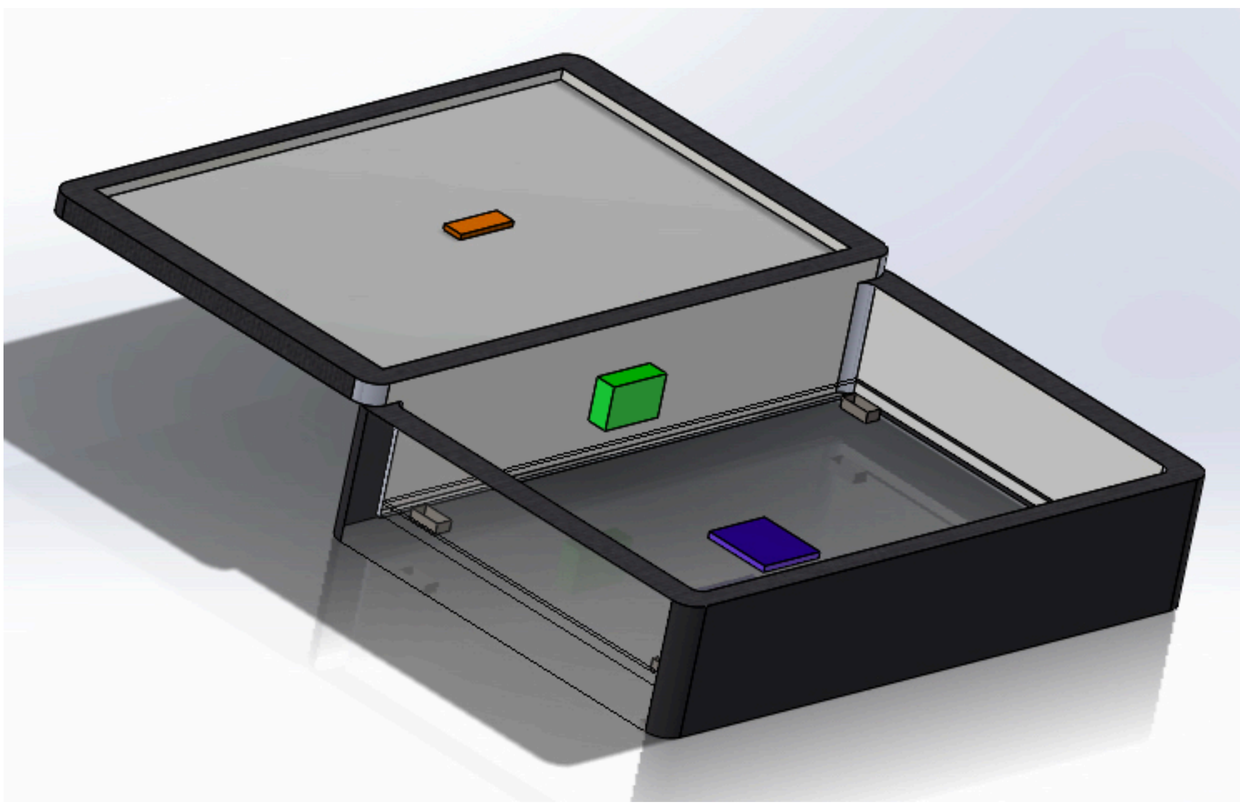

Figure 3. Physical Design Diagonal View

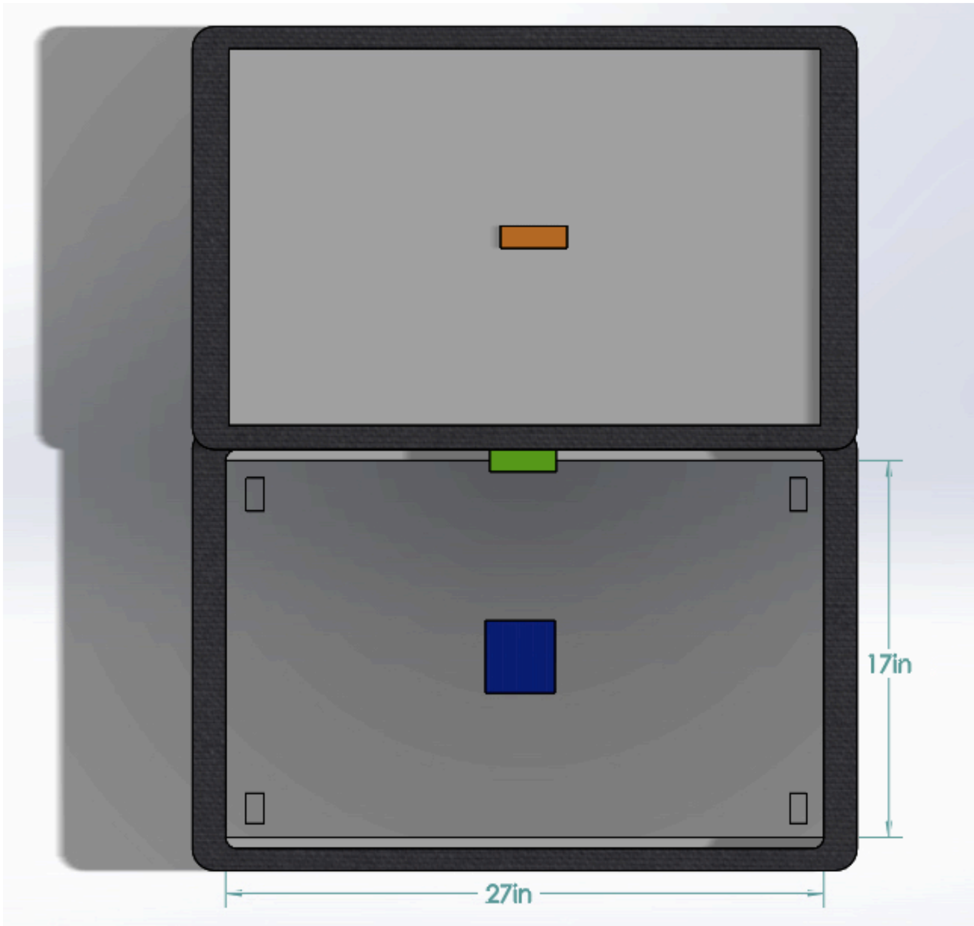

Figure 4. Physical Design Top View

2.1 Power Subsystem

Our design requires a power subsystem to produce readings from the load cells and convert them into a weight reading for the user. The power subsystem will consist of rechargeable NiMh batteries that can be charged using a standard power outlet. The batteries will then power the system whenever the user requires a weight reading while packing. A voltage regulator is used to ensure that the voltage supplied by the battery is distributed appropriately according to the different electrical components of the system.

2.1.1 NiMh Battery Charger

The NiMh battery charger IC, BQ24401, will fast charge the battery pack when inserted. Fast charge is terminated by rate of temperature rise over time, maximum temperature, and maximum charge time. Fast charge can be calculated by $I_{max} = 0.05/R_{sns}$ where R_{sns} is a resistor value chosen by us to indicate what I_{max} is desired for fast charge. Wanting a fast charge of 110mAh, we choose R_{sns} to be about 450mΩ. This allows us to fully charge the battery within three hours with a battery capacity of 330mA. Once fast charge is terminated, it drops the current down to 1/16 of the fast charge current. The battery has high-frequency switching control for an efficient and simple battery design. For safety precautions, a 10uF capacitor is recommended to be added to the voltage input so that there are minimal voltage ripples and to maintain a constant charge [5].

	Requirement	Verification
1	NiMh battery is charged to 4.8V - 5.2V when a 5V-7V voltage source is applied [5].	1. Discharge a NiMh battery to 4V. 2. Charge the battery at its supply-voltage input with an input of 5V. 3. At the end of the charging cycle when fast charge dissipates, measure the voltage potential of the battery and ensure it is between 5.7V and 6.3V.
2	Terminate fast charge when battery is fully charged.	1. When verifying that the charger is able to successfully charge the battery, monitor the current with an oscilloscope. 2. Fast charge is indicated by a constant current of 110mA +/- 5%. 3. Once the current drops below 104mA, fast charge has ended.
3	Maximum current and voltage can be held at a temperature below 125°C.	1. An IR thermometer will check the IC to verify the temperature is below 125°C when operating at a max current and voltage.

2.1.2 NiMh Battery

The NiMh (Nickel Metal Hydride) button cell battery, RS PRO 525815 must be able to keep the scale powered for the duration of the user's packing when turned on by the power switch [6]. Packing does not take more than a few hours so it does not need to store a high level of charge. This type of battery also meets federal airline regulations for both carry-on and checked-in luggage [7]. The battery is rated at a current capacity of 330mA, a voltage capacity at 6V, and a discharge rate of 66mAh [6].

	Requirement	Verification
1	Stores a charge > 132mA of charge for a packing time of 2 hours. [6]	1. Connect a fully charged NiMh battery (5V) with positive terminal at VDD and negative terminal at ground. 2. Discharge the battery at 330mA for 2 hours.

2.1.3 Power Switch

The power switch will allow for power to flow from the battery to the voltage regulator when the switch is turned on. The switch is important because there are only certain times when this device needs to be on. The switch is rated at 10A and 120VAC which is the standard for wall outlets in home so it is safe for our circuit. A 0.33uF capacitor is recommended to be added to the voltage output so that there are minimal voltage ripples to maintain a constant charge. [8].

	Requirement	Verification
1	Must be able to allow 6V +/- 5% and 66mA +/-5% to pass through when the user turns the switch on.	1. Connect a fully charged NiMh battery (6V) with positive terminal at VDD and negative terminal at ground. 2. Turn the switch on by pressing down on the “I” side. 3. Use a voltage probe by measuring the output of the switch at positive and ground at negative and ensure the output is between 5.7V-6.3. 4. Use a current probe by measuring the output of the switch and ensure the output is between 62mA-70mA.

2.1.4 Voltage Regulator

The voltage regulator supplies the circuit with a constant voltage to keep the system powered. It drops voltage from the battery at 6V to 3.3V. This voltage regulator, L7800, can handle a maximum of 35V and a maximum of 1.2A, which is more than the battery's capacity [9].

	Requirement	Verification
1	Must be able to take input voltage between 5.7V - 6.3V and regulate a constant output of 5V +/- 4%.	1. With a fully charged battery and an ‘ON’ power switch, use a voltage probe and ensure the output is between 4.8V - 5.2V.
2	Can operate currents between 0A - 0.35A.	1. When verifying the voltage regulation, use an oscilloscope to confirm the current range is between 0A - 0.35A.
3	Maintains a temperature below 125°C.	1. During the voltage output verification, use an IR thermometer and ensure that the IC is below 125°C.

2.2 Control Unit

The control unit consists of a microcontroller to interface between the different hardware components of our system. Since our weight subsystem produces only analog signals as readings, the microcontroller is needed to perform analog-to-digital conversion to get a numerical weight reading that a user can actually understand. A separate connection for the LCD allows the micro controller to display this reading.

2.2.1 Micro-controller

The microcontroller (ATMega328) receives the amplified load cell signal and converts it to a digital value with an internal ADC [10]. This data is then transferred to the LCD.

	Requirement	Verification
1	Software converts digital output of ADC into matching unit of weight in both kilograms and pounds.	1. Place various loads of known weight into suitcase and observe corresponding weight outputted onto computer console.

2.3 Weight Module

The weight module consists of all the sensors and components required to generate an analog electrical signal proportional to the weight of the suitcase contents. Four strain gauge load cells will be used to produce four different electrical signals from the corners of the suitcase when a weight is placed inside. These signals will be aggregated into a single signal through the use of a wiring configuration known as a combinator. The signal will then be fed into an amplifier to produce a stronger analog reading.

2.3.1 Load cells

A strain gauge load cell is a component that measures force based on the idea that weight applied to the unit will create a deformation in the material. Specifically, the load cell consists of wire organized into a grid pattern within a more rigid metal structure. The metal structure compresses in response to an applied weight such that a change in the electrical resistance of the wiring is produced. This results in a varying electric signal based on the quantity of the load [11].

Since we intend to test configurations of more than one load cell at a time, a method is needed to connect multiple strain gauges to produce a single reading. This configuration can be accomplished through the use of a Wheatstone bridge. A Wheatstone bridge is a specific wiring configuration of strain gauges that results in a combined electrical signal formed from the contributions of each individual strain gauge. Figure 5 shows a Wheatstone bridge configuration with four load cells similar to what we will be building for our design.

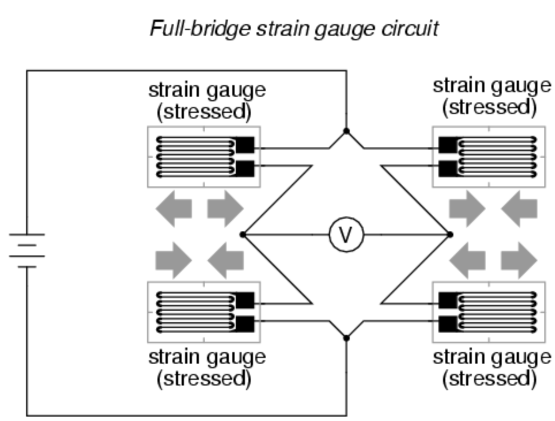

Figure 5: Wheatstone Bridge Configuration [20]

	Requirement	Verification
1	Accurately weigh load of up to 60 lbs with an accuracy and precision of +/- 1 lb.	1. Using a comparable measuring system such as a bathroom scale or a portable luggage scale, calibrate the comparable system. 2. Pack approximately 20 kilograms of clothing or similar items into a zippered bag. 3. Weigh the bag with the items in it. 4. Using this base weight value, weigh the same bag in a similar position and configuration in the suitcase and compare the weights. 5. Error should fall within +/- 1 pound.
2	Different orientations of the the same weight should have readings that do not deviate more than +/- 1 lb.	1. Rotate the same object between the four corners of the suitcase. 2. Record the weight when the object is in each corner. 3. Compare the weight readings.

2.3.2 Amplifier

An amplifier is used to increase the strength of an electrical signal. It is specifically required in this design because the output signal of a load cell is weak by standard. In order to ensure greater accuracy and utility, we will be using an amplifier to increase the electrical signal output before being sent to the ADC in the microcontroller [12].

	Requirement	Verification
1	Amplify voltage from load cell by a gain of 1000 +/- 1.	1. Use a multimeter to probe voltages at the input and output of amplifier. 2. Apply pressure to load cells to sweep output voltage from 0 to 2.72 V and ensure that amplifier output corresponds to a gain of 1000 +/- 1.

2.4 User Interface

The user interface will consist of an LCD display to let the user see a weight reading for the contents of the suitcase as well as a power switch to turn the system on and off as needed. The power switch will also serve as a method to calibrate the scale. Turning it on will default the scale to zero to prepare for packing.

2.4.1 LCD Display

The LCD display will be a 2x16 LCD that displays the total weight of the luggage [13].

	Requirement	Verification
1	Able to display correct weight in pounds up to the tenths place. For example, it should display 42.5 lbs instead of just 42 lbs.	1.Test different weights and verify number matches LCD.

2.6 Schematics

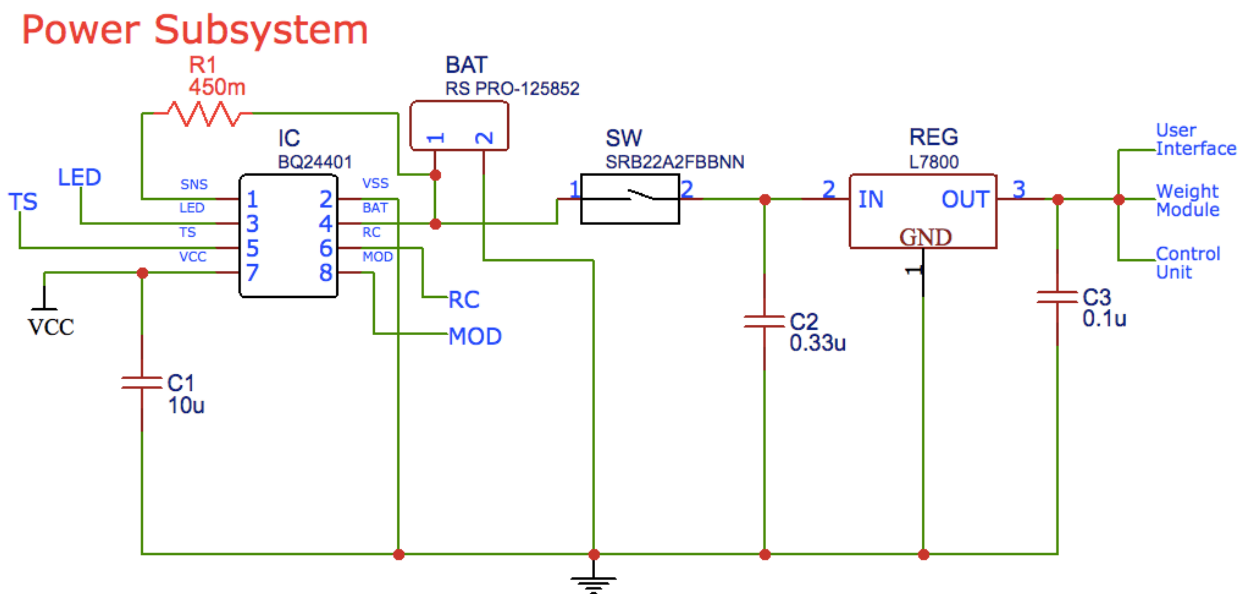

Figure 6: Power Subsystem Schematic

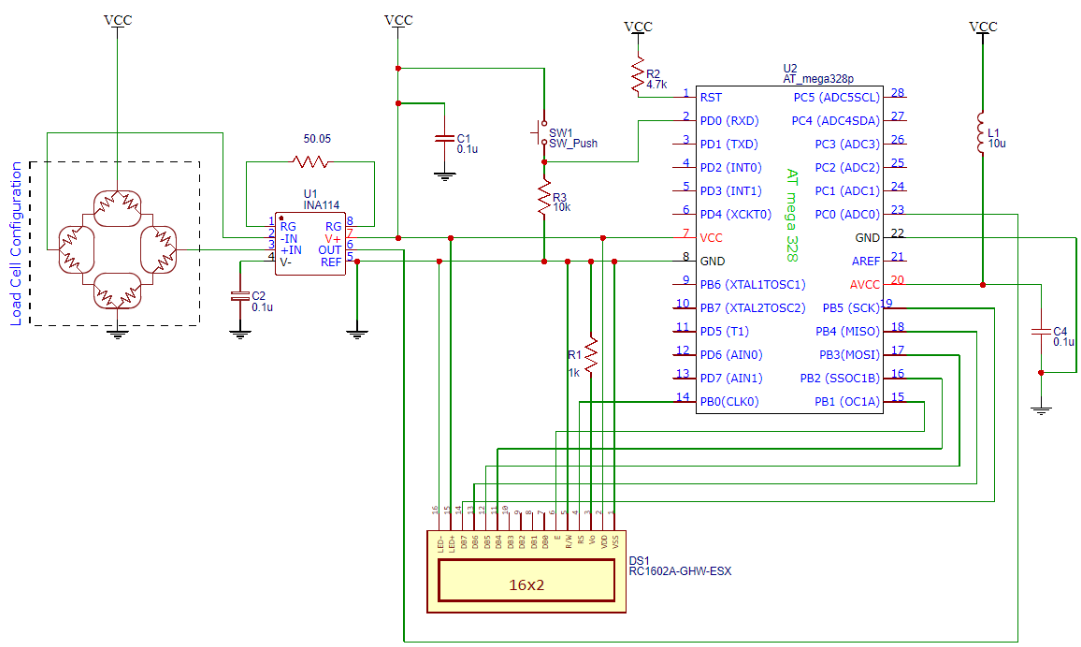

Figure 7: Control Unit and Weight Subsystem Schematic

2.7 Tolerance Analysis

Grossly inaccurate weight measurements negate the utility of our product. Therefore, the load cells pose the highest risk to the successful completion of our design as they are responsible for the actual sensing of the weight placed in the suitcase. Unstable mounting of the load cells in the suitcase can lead to some of the load cells producing more accurate readings than others. Furthermore, the orientation of the load cells relative to the distribution of the objects in the suitcase can cause variation in the weight readings. In order to mitigate these issues, we will need to ensure the load cells are mounted in the appropriate orientation between two plates of rigid material. The material must be rigid enough that weights placed on top of it are distributed in a relatively even fashion across the surface to ensure a more accurate reading.

In terms of the specific orientation of the sensors, it will be necessary to experiment with different arrangements and numbers of weight sensors to see what leads to the most accurate result. For example, rather than simply placing four load cells in the corners of the bottom of the suitcase to form a single scale, we could split the bottom of the suitcase into multiple smaller sections each with their own individual scale system. The total of these scales would be summed into a single reading for the user. The goal is to figure out the optimal number and arrangement of load cells and plate configurations for the final design.

For the load cells, we can complete a more numerical tolerance analysis based on two main factors: scaling the output of the load cells for readability and how the distribution of weight across a rigid plate may affect the readings.

For the scale values for the load cells, we can first calculate the sensor calibration factor [14]. This factor represents the ratio of response from the load cell relative to the excitation voltage and range of weight the cell can read. This calibration factor can then be directly scaled to an output in kilogram as demonstrated in Figure 5. This graph shows how the a larger gain corresponds to an increased sensitivity for changes in weight. For example, with a gain of approximately 1, a single load cell will only be able to respond to changes in weight of around 12 lbs. As the gain increases, the system can detect smaller changes in weight of around 0.01 lbs. This tells us that it is possible for us to achieve a weight sensitivity detection much smaller than 1 lb, and therefore meet the requirements for having a total weight error of +/- 1 lb. The equations for determining the scaled output are demonstrated in Equations 2 and 3.

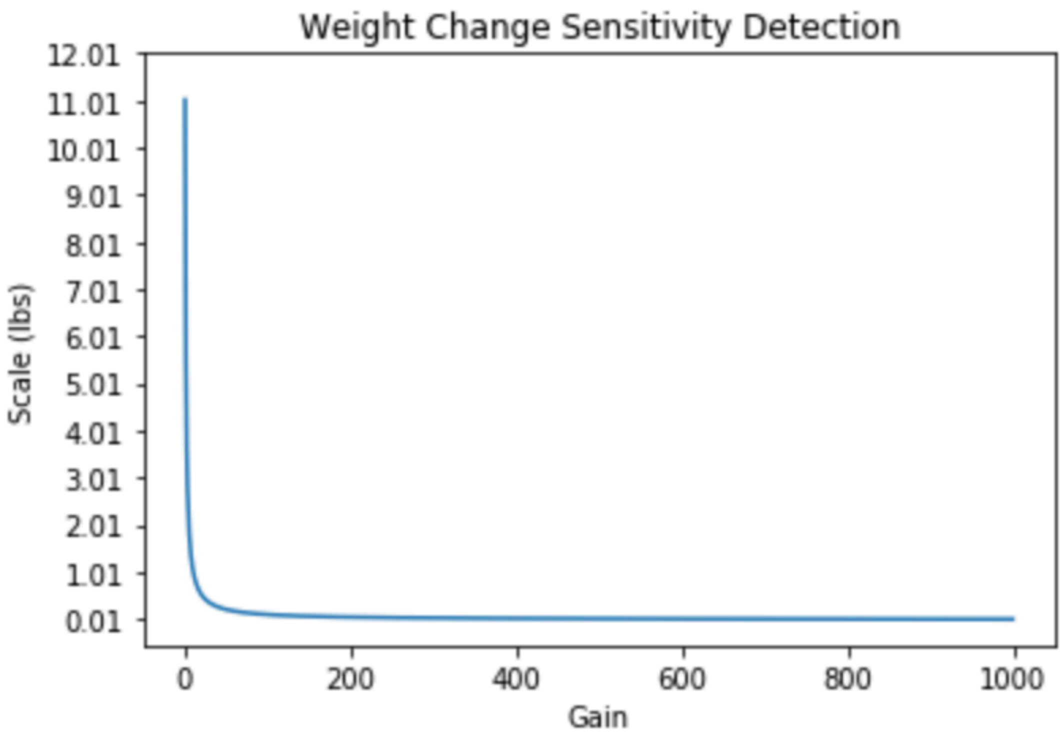

Figure 9: Scaling Output

$$Calibration\,factor = \frac{Output\ Sensitivity * Excitation\ Voltage}{Load\ Cell\ Range} = \frac{1.0 * 5}{50} = 0.1$$ Equation 2

$$Scale = \left(\frac{ADC_{range}}{ADC_{resolution} * ADC_{gain}}\right) / Gen_{scale} / Calibration\,factor$$ Equation 3

A full weight simulation for tolerance could not be performed due to a lack of experimental data or formulaic description of weight distributions and their effect on load cell output. Instead, a process to simulate these values after building a physical prototype of a single load cell will be described. The load cell will be clamped between two rigid plates and an object will be placed on the scale in a specific starting position. The response of the load cell will be recorded relative to this configuration. The object will then be moved across the scale incrementally on the x and y planes such that the object covers a pre-decided set of locations across the whole scale. The response of the load cell relative to each of these coordinates can then be plotted to determine how uneven weight placement will effect the system as a whole.

3 Costs

The table shown in Figure 7 details the component costs required to build the suitcase as a prototype. Bulk manufacturing costs are also demonstrated assuming that the suitcase can be mass manufactured. Accounting just for the physical component costs, the prototype will cost approximately $121.97 to build as compared to $89.81 when considered as part of bulk manufacturing.

Part	Cost (prototype)	Cost (bulk)
Acrylic sheets	$21.32	$14.50
Microcontroller (ATMega328)	$1.96	$1.16
Assorted resistors	$5.00	$0.20
PCBs (PCBWay)	$3.10	$0.10
NiMh batteries	$11.95	$9.92
Load cells (4x)	$3.56	$0.68
Power switch	$0.65	$0.51
Voltage regulator	$0.95	$0.52
LCD	$3.84	$1.59
NiMh charger	$3.95	$1.86
Battery case	$5.00	$2.00
Amplifier	$10.69	$6.77
Suitcase	$50.00	$50.00
Total Cost	$121.97	$89.81

Figure 7. Prototyping and Bulk Costs

Equation 4 shows the labor cost breakdown for our prototype construction for the semester. With three people working on the project 10 hours per week for 9 weeks and at a rate of $40.00/hr, total labor costs will add up to $10,800.

$$3 * \frac{\$40}{hr} * \frac{10\ hrs}{wk} * 9 = \$10,800.00 \qquad \text{Equation 4}$$

Looking at the total cost with labor and components, our prototype construction for the semester will cost $10,921.97.

4 Schedule

Week	Ryan	Shivani	Jonathan
10/8/18	Document data from test circuit and plot out results in Matlab to find percent error in weight readings for a single load cell	Build test circuit with connections for one load cell and an amplifier to view output on oscilloscope	Prototype circuit schematics and initial PCB layout
10/15/18	Extend test circuit with connections for four load cells and test responses from multiple cells at the same time	Build test circuit with micro controller and LCD	Version 1 of micro controller programming; finalize Version 1 PCB design
10/22/18	Build Matlab simulation to determine effect of weight distributions relative to load cell configuration based on experimental data	Run tests on Version 1 of PCB design	Test microcontroller programming with combined load cell and LCD test circuits to see if value on LCD changes according to applied pressure
10/29/18	Build prototype of scale plate with load cells oriented according to test results	Test scale plate configuration of load cells for output to determine effect of weight distribution and responsiveness	Continue testing microcontroller programming; finalize Version 2 PCB design
11/5/18	Debug/update scale plate design or load cell configuration for greater accuracy	Build casing for battery and other components if necessary	Help test new scale plate configuration for output
11/12/18	Make necessary mechanical changes to attach scale to bottom of suitcase	Make necessary mechanical changes to attach battery in case to suitcase	Make necessary mechanical changes to attach LCD to suitcase; update PCB and retest if needed
11/19/18	Fall break	Fall break	Fall break
11/26/18	Run tests on power subsystem in full suitcase configuration	Run tests on weight subsystem in full suitcase configuration	Run tests on control unit in full suitcase configuration
12/3/18	Prepare final presentation, make final changes to suitcase design	Prepare final presentation, make final changes to suitcase design	Prepare final presentation, make final changes to suitcase design
12/10/18	Prepare final report	Prepare final report	Prepare final report

Figure 8. Individual Member Work Schedule

5 Ethics and Safety

Since our product is intended to be transported on an airplane, it is important to take a look at the safety considerations related to the use of the NiMh battery under those conditions. Inappropriate storage and use conditions can lead to battery fluid leakage. According to safety specifications, leaked battery fluid from a NiMh battery can cause respiratory, eye, skin, and organ irritation if ingested.

To mitigate these hazards, we conducted an analysis of standard airline conditions and their correspondence with NiMh battery safety specifications.

One major consideration is temperature. Storage conditions for the standard NiMh battery dictate that the battery should not be stored in high temperatures for extended periods of time. The temperature threshold for short shipment periods is 60 °C. Standard airline cargo holds are pressurized and maintained at a minimum temperature of 7 °C [16]. While the temperature can spike up to 18 °C depending on weather conditions, this is far below the maximum temperature limit for NiMh batteries [17]. Therefore, the temperature conditions in an airline can be considered safe with our design.

A second consideration is pressure. Passenger airlines pressurize both the cabin and cargo hold to approximately 11 psi [18]. For reference, air pressure at sea level is about 14.7 psi. Overcharge pressure for a NiMh battery occurs at about 50 psi, which causes the battery to be less functional but does not lead to fires or explosions [16]. Therefore, a standard airline pressure situation would be considered safe for a NiMh battery.

Finally, the NiMh batteries should be permissible for use on both long and short-haul flights as carry-on or checked-in luggage. According to TSA regulations, dry cell rechargeable batteries including NiMh batteries are permitted on carry-on and checked-in luggage with no restrictions about installation or use during travel. Specifically, the batteries can be transported in loose disconnected form or while in a state of charge and powering a circuit. [7]

To mitigate any possible issues arising from physical damage of the battery, we intend to build a secure casing around the battery in the suitcase. This casing will protect the battery from damage incurred while packing or transporting the suitcase. We also intend to make recommendations to the suitcase user about the necessity of replacing the battery if major damage does occur.

Ethically, our project has few issues due to its minimalistic design and effect on the user. By IEEE Code of Ethics, #1 we should “hold paramount the safety, health, and welfare of the public [...] and [...] disclose promptly factors that might endanger the public or the environment” [19]. This means disclosing the safety hazards related to the use of the NiMh battery.

According to the IEEE Code of Ethics, #3, we have an obligation to “be honest and realistic in stating claims or estimates based on available data” [19]. IEEE Code of Ethics, #9 further proposes that one should “avoid injuring others, their property, reputation, or employment by false or malicious action” [19].

For our design, this means avoiding the falsification of the weight estimates we provide for items packed into the suitcase and being open about the margin of error expected for these estimates to help users avoid paying fees or redistributing packed items at the airport. We also have an obligation to design the physical suitcase such that the electronic components are safely packaged and do not cause harm to the user or the user's property.

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