Grain Quality Measurement Kit

By

Adam Long

Kevin Villanueva

Joan Brown

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TA: Luke Wendt

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Abstract

The Grain Quality Measurement Kit is used to monitor corn quality with automated methods. Modules include user input, display, real-time clock, GSM, SD card, battery charging, temperature and humidity, and weight measurement. Quantitative results of moisture, impurity concentration, and density are wireless sent to a Farmer's portal via text message for quality analysis. Successes in all modules with the exception of weight measurement provide functionality to the user, along with easy to follow directions for using the kit.

Contents

1 Introduction

This project is an interdisciplinary research collaboration between Beckman Institute for Advanced Science and Technology and the Institute for the Prevention of Postharvest Loss in the College of Agricultural, Consumer and Environmental Sciences (ACES) under the direction of Mr.John M Hart. The Grain Measurement Quality Kit, or GMQ, is used to tackle the problem of inadequate grain quality monitoring methods in developing countries and assist in establishing quality standards. Users, typically farmers, have the ability to quantitatively observe the quality of their product, while all the data is automatically stored and sent to local researchers for analysis. This paper goes through an overview of the kit, its design, verification of designs, and costs. The final product created for demonstration and presentation implements all modules with the exception of weight measurement. A discussion of uncertainties and future work are included in the conclusion of the paper.

1.1 Purpose

The Grain Measurement Quality Kit involves the implementation of automated data collection and communication technologies to address the problem of food loss due to inadequate grain storage and quality monitoring methods, crucial to farmers in developing countries such as Brazil and India. The only available kits similar are used for rice and require all testing and data to be obtained and documented by hand. With the proper resources, such farmers would be able to analytically show the quality their product, supporting an establishment of quality standards, which would allow these farmers to adjust the cost of their product.

1.2 Objectives

The kit will automatically collect and transmit data directly relating to its quality, including moisture, impurity concentration, and density, using electronic sensor systems and methods. Moisture content indicates the potential for mold growth and insect infestation, impurity concentration indicates the amount of degradation of the product as well as how much of the sample may be susceptible to mold growth, and density indicates the amount of damage the corn has sustained from mold and insects. Easy to follow directions for the kit and conducting tests are provided to the user through a display, which can be navigated through buttons. Test results are stored with an SD card and are wirelessly sent to a local university for tracking and analysis via GSM. The micro-controller is responsible for properly recording, storing, and sending data from any testing, and handles all IO of the kit, discussed in the Design portion of this paper.

The kit is in the form of a battery-powered, portable, durable, waterproof briefcase with multiple components. A sample size of approximately one quart is used for measurements and is sieved into sections of whole kernels and large plant material, broken kernels, and dirt and other small particles. Sieve sizes used are 12/64" and 8/64" as recommended by advising faculty of the project from the College of ACES. The sieved sections are poured via a funnel into a weighing container, which has the temperature and humidity sensor (used to determine moisture) inside and lies on top of the weight sensor. Inset in foam, an enclosure houses the PCB with the display and buttons for user input inset the lid.

2 Design

Each module of the block diagram of the project is discussed. See Enclosure and PCB of the Appendix for photos of the physical setup of components.

2.1 Block Diagram

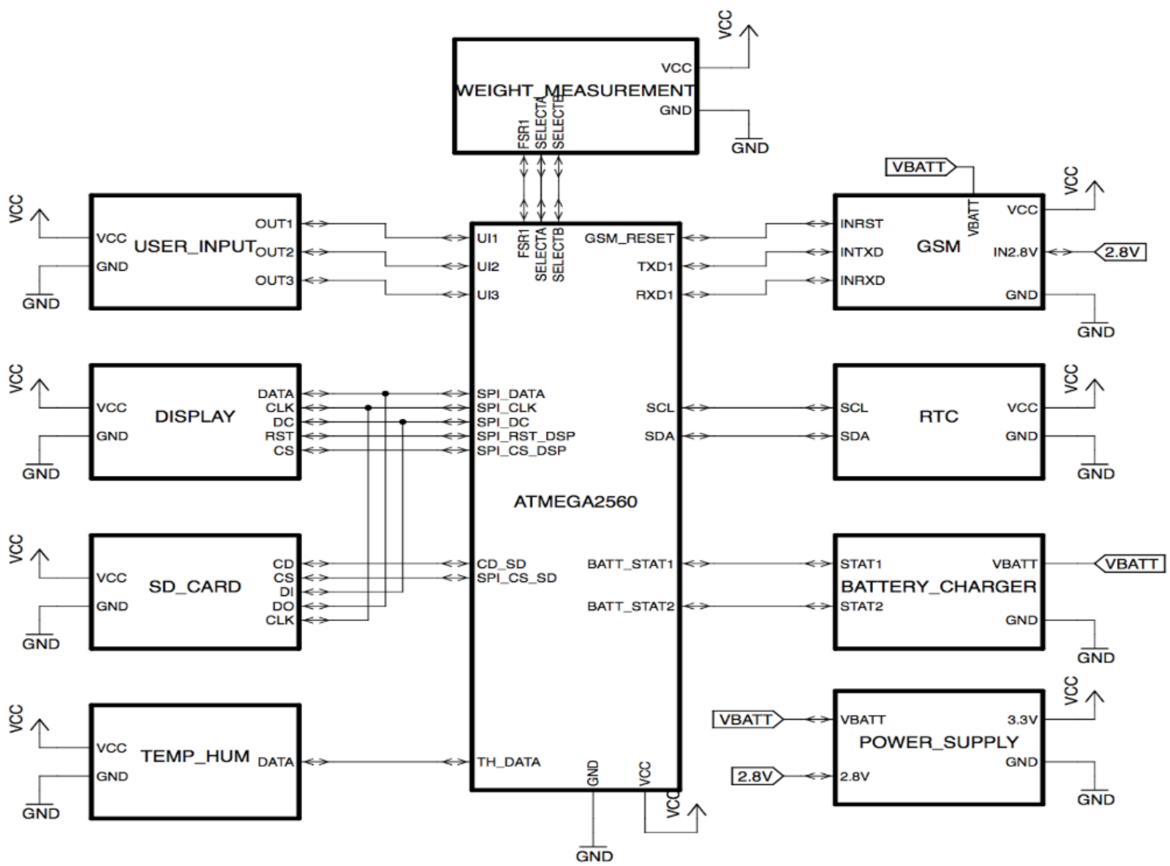

Figure 1: Block Diagram of GMQ Kit

2.1.1 Microcontroller

The microcontroller is responsible for collecting information from the sensors/inputs, storing result data, driving the display, instructing the GSM module, reading/writing from the SD card and setting/reading the current time from the RTC. To serve these purposes, the ATmega2560 will be used for its relatively large 256 kBytes of on-board flash memory (necessary for the display and SD card) and 24 IO pins.

The ATmega2560 is powered by a regulated +3.3V as discussed in Battery Charging and Power Supply, which also sets the reset pin on the ATmega. The interfaces for major components can be seen in the block diagram below. Note that not included are four indication LEDs are each tied to DIO pins on the ATmega, providing basic indication of its status. Refer to the Software Flowchart in the Appendix for more information.

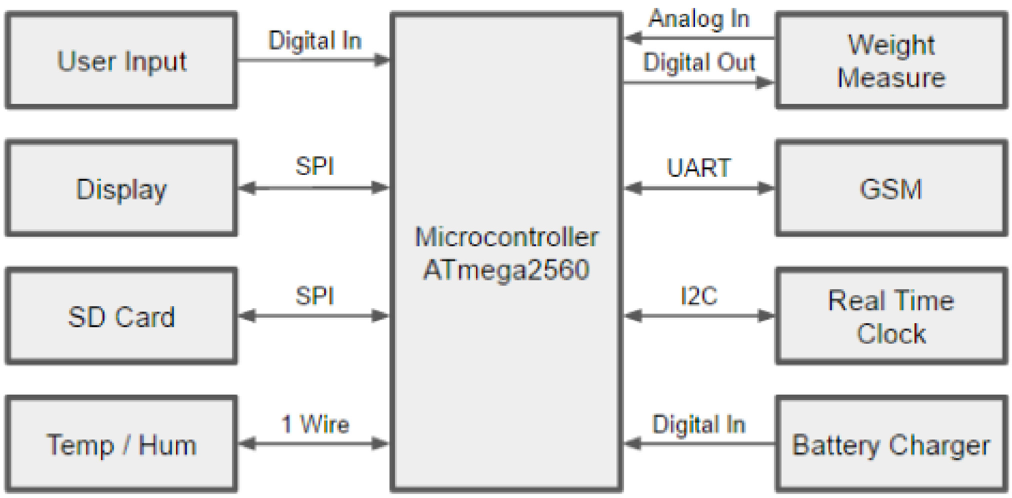

Figure 2: ATmega2560 interfaces all components with communication protocols

An external 16MHz crystal oscillator shown below is used instead of the ATmega's internal RC oscillator. This provides a more accurate clock for the ATmega, which is necessary when using the internal UART to communicate with the GSM module.

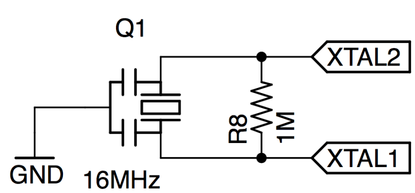

Figure 3: Crystal Oscillator Schematic

A 6-pin ICSP header, shown below, is also be placed on the PCB to allow for reprogramming of the microcontroller. The header is directly connected to the MISO (PB3), SCK (PB1), RESET, $+3.3V$, MOSI (PB2) and GND pins on the microcontroller.

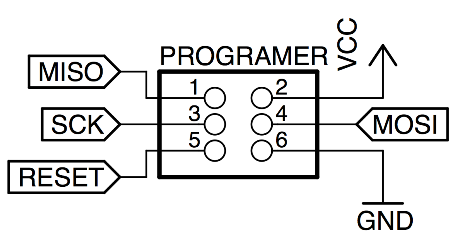

Figure 4: 6-Pin Header Schematic

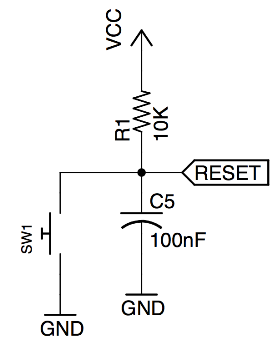

Figure 5: Reset Switch Schematic

External circuitry for an operational reset button are shown above. Refer to Enclosure and PCB of the Appendix to see photos of the resulting printed circuit board (PCB) used in the project.

2.1.2 User Input

Three selection buttons as well as an on/off switch are accessible to the user. The buttons allow the user to navigate the user interface and initiate tests as well as configuration parameters. The buttons are connected to the microcontroller via digital IO (DIO) pins with proper debounce circuitry. An on/off switch is available to the user to cut power to the device and is discussed in Battery Charging and Power Supply.

The figure below shows the schematic for the three buttons. A low-pass filter is placed on DIO of the microcontroller to provide debounce protection. The capacitor will charge when the button is not pressed pulling DIO to VCC, and discharges when pressed, bringing DIO to ground. Values of R($10k\Omega$) and C($100nF$) are chosen to provide .001 sec of debouncing time for the button. A $1k\Omega$ resistor is placed between each button and capacitor to prevent high-frequency voltage noise when discharging the capacitor. The value of this resister must be significantly less than that of the one used in the low-pass filter. Refer to Enclosure and PCB to see photos of the physical setup of the buttons in the device.

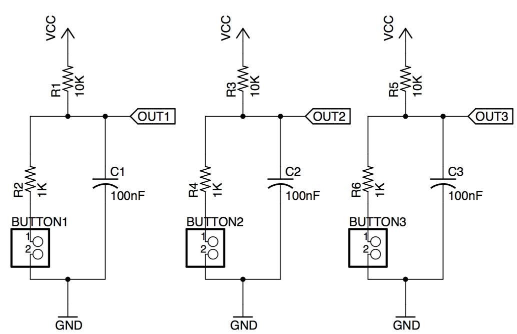

Figure 6: Three Button Debounce Schematic

2.1.3 Display

The display is a monochrome 1.3" 128x64 graphic display capable of printing ASCII characters as well as some basic images. The text and images assist the farmer conduct tests as well as read the results.

The SSD1306 monochrome display communicates with the microcontroller using SPI. The display is internally level shifted and is fully compatible with the DIO pins on the microcontroller. The following is the schematic for the display module to the microcontroller. Note that the data line (DATA), clock (CLK), data/command (D/C), reset (RST), and chip select (CS) are directly connected to DIO pins on the microcontroller for use with SPI.

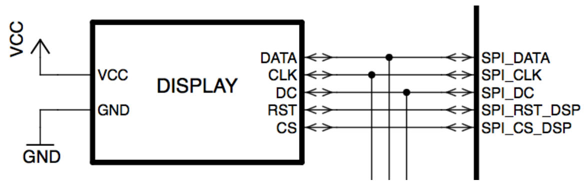

Figure 7: Display Module connections to ATmega microcontroller

To write to the display we forked and modified Adafruit's SSD1306 library[1]. We added methods that were essential in creating our user interface

.

Refer to Enclosure and PCB of the Appendix to see photos of the physical layout of the buttons for the user input and the display. See User Interface of Appendix for a mapping of the prompts given to the user.

2.1.4 Real Time Clock

The real time clock, or RTC, is used to provide the current time to the user. The time is initialized by the user upon the first power on and can later be manually changed if needed. The RTC then keeps track of the time even when the device is powered off through a coin cell battery specific to the RTC. Any test results sent include the farmer's unique identification number as well as a time stamp provided by this module.

A DS3231SN I2C-Integrated RTC/TCXO/Crystal from Maximum Integrated[2] is used for the RTC. The DS3231SN communicates to the microcontroller using I2C protocol (SCL and SDA pins). A bypass capacitor is placed across VCC and GND as well as pull up resistors included on the SCL and SDA lines. The +3V coin cell battery is attached to pin 14 and ground on the DS3231SN as specified in the data sheet[2]. The complete schematic for the RTC is shown below.

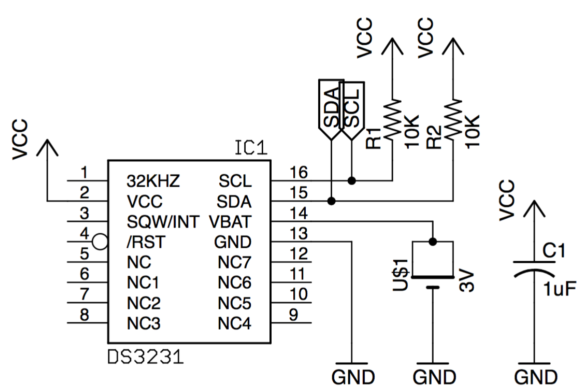

Figure 8: RTC Schematic

2.1.5 GSM Module

The GSM module is responsible for sending the test results to the Farmer's web portal in the form of text messages, although the device itself also supports sending data via HTTP POSTs. Larger packets of data can be sent if the portal can support the latter. All test results are accessible by researchers, merchants, and farmers through the portal.

The SIM800L GSM is used for its small package and low cost. It has an internal UART and communicates with the microcontroller serially through its RXD/TXD pins. Note that communication between the SIM Card and GSM Module requires a matching circuit to promote low loss between receiver and transmitter, thus a diode isolation circuit is used. A schematic for the module is shown below.

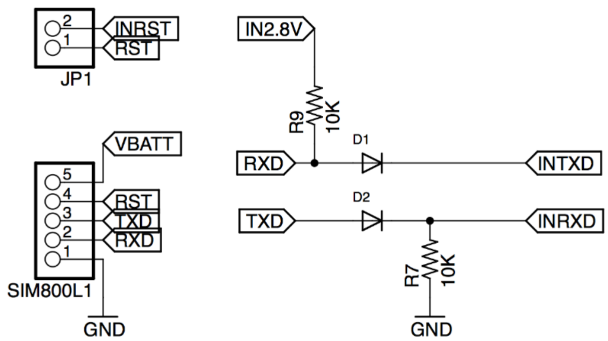

Figure 9: SIM800L Schematic

To prevent unwanted deviations in the voltage across VCC and GND, a $100\mu F$ bypass capacitor is added as recommend my the SIM800L data sheet[3].

The complete schematic for the GSM module can be seen in the overall project schematic. Refer to Enclosure and PCB of the Appendix to see photos of the physical placement of the module. Note its location for ease of access for changing or replacing the SIM card.

2.1.6 SD Card Reader / Writer

The SD card stores the most recent test results as well as any other information that needs to be persistent between boot cycles of the microcontroller. Data results are stored in the event that a GSM signal is not attainable and the data can't be sent out. Note that as the SD card has a finite amount of storage, only the most resent results will be stored.

The following is a schematic of the connections for the pinout of the module, where inputs from the microcontroller are the clock (CLK), data in (DI), chip select (CS), and the output to the microcontroller is data out (DO):

Refer to Enclosure and PCB of the Appendix to see photos of the physical placement of the module. Note its location for ease of access for changing or replacing the SD card.

2.1.7 Battery Charging and Power Supply

The battery charging and discharging unit involves a rechargeable $3.7V$ Lithium-ion battery which powers the device. The battery can be recharged via standard USB power (5.5V, 0.5 – 1.5A) and includes voltage regulation to power all modules in the device. The unit satisfies protection and safety standards outlined by ECE 445 course staff. Below is the schematic for the battery charging unit.

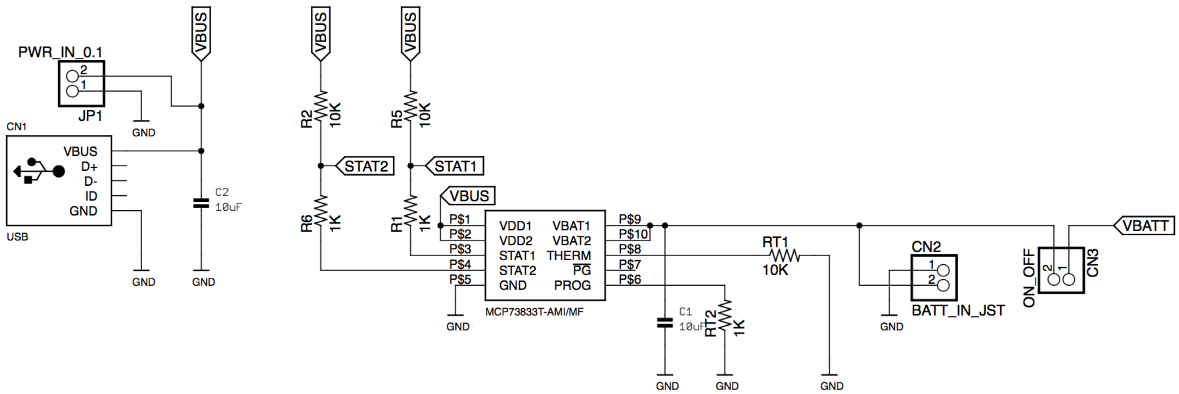

Figure 10: Battery Charging Unit Schematic

An on/off switch cuts power to the microcontroller and the GSM module. Note that this requires that the microcontroller keep track of persistent variables across boot cycles by storing the information on the SD card.

All modules require a 3.3V power supply, noting that the GSM module additionally requires voltages equal to the Li-ion battery and 2.8V. Voltage regulators of sufficient output current ranges are used to obtain 3.3 and 2.8V levels from the battery. Refer to Battery Charging and Power Supply of Design Verification for calculations ensuring proper current ranges.

Below is the schematic for the power supply unit.

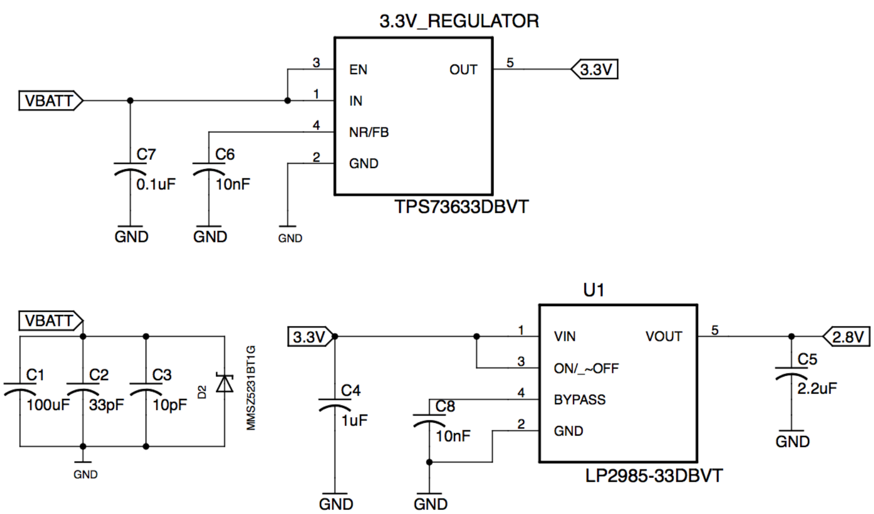

Figure 11: Power Supply Unit Schematic

Refer to Enclosure and PCB of the Appendix for photos of the physical setup of the Li-ion battery and related components.

2.1.8 Temperature and Relative Humidity Sensing

The DHT22 is digital temperature and relative humidity sensor that is fixed within the insulated weighing container. The user will follow on-screen directions for initiating the test and will wait approximately one minute for stabilization prior to the measurement being taken. Results are used to determine equivalent moisture according to the Hailwood-Horrobin equation shown in Hailwood-Horrobin of the Appendix.

The DHT22 communicates using a single-bus communication protocol. The microcontroller will begin by sending the start signal and once the DHT22 receives the signal it will change from standby-status to running-status. The DHT22 will then respond by sending a 40-bit data packet that reflects the relative humidity and temperature. Once the data has been received, the DHT22 will change back to standby-status until it receives another start signal from the microcontroller. A timing diagram for this communication can bee seen in the figure below.

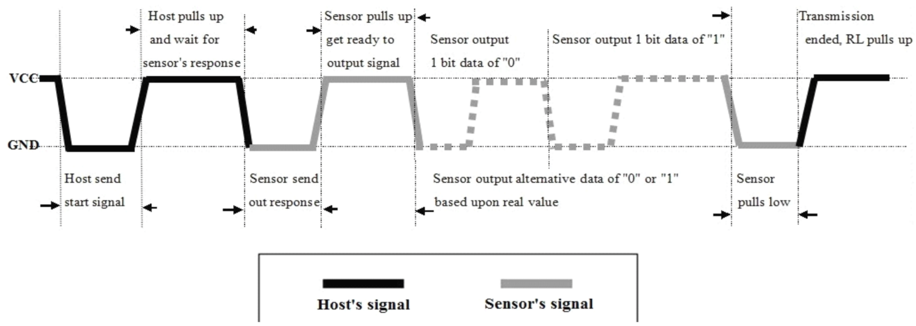

Figure 12: DHT22 single-bus communication protocol. [4]

The DHT22 utilizes a thermistor for measuring ambient temperature, such that when the temperature rises, resistance decreases. A capacitive relative humidity sensor is used for measuring relative humidity, such that a water vapor-sensitive dielectric is located between two electrodes, and whose capacitance rises as water vapor content in the near surrounds does.[?]

A $100nF$ bypass capacitor is placed between VDD and ground. When the DHT22 is powered, the capacitor will charge to capacity and if there is a change in the voltage between VDD and ground it will discharge in an attempt to bring the voltage back to the of charge of the capacitor. This will provide basic smoothing to make any change in voltage less pronounced.

A $10k\Omega$ resistor is placed between Data and VDD. The pull up resistor prevents the data pin from being in an undefined state and follows the specifications set out for communication.

The following is the schematic for the DHT22 with DIO connecting to the digital input/output on the microcontroller.

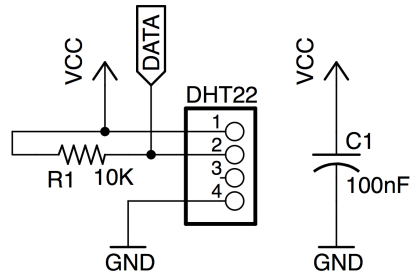

Figure 13: Temperature and Relative Humidity Schematic

2.1.9 Weight Measurement

The weight measurement module is used for both impurity concentration and density calculations, discussed in Weight Measurement of Design Verification. In order to measure the weight of the sample as well as material from the different portions of the sieved sample, a force sensitive resistor (FSR) is used. It is laminated underneath a plastic platform that the weighing container is placed on for each measurement to be taken. The microcontroller reads the weight via one of its analog to digital converters upon command.

In order to determine impurity abundance, the user first pours the full sample into the weight measuring container and follows the on-screen instructions. The user will then pour the sample into the 8/64" sieve (pan underneath) and manually shake 15 times, separating the whole kernels and large plant material from the rest of the sample. Another weight measurement is taken, and the process is repeated for the 12/64" sieve, leaving the user with direct measurements of the full sample, broken kernel, and dirt/small particle masses. The following equations can be used to determine the concentration in terms of a percentage of the full sample. The mass of the weighing container is taken into consideration when programming the microconrtoller. See discussion on the FSR in Weight Measurement of Design Verification.

The FSR functions such that its resistance decreases non-linearly as the mass of the weight on the active area of the FSR increases. The chance in resistance is very small however, so the following amplification circuit is used with the corresponding gain equation listed where the FSR voltage is measured[5]. Details of deciding the value of R_M are listed in Weight Measurement of Design Verification. See Op-amp Analysis of the Appendix for obtaining the output voltage equation.

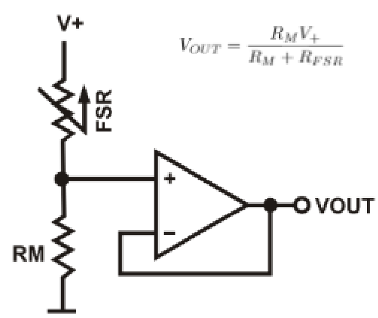

Figure 14: FSR Amplification Circuit[6]

For determining which amplification circuit to use for each sieved portion, the following circuit is used. It utilizes an analog MUX whose inputs correspond digitally to the buttons pushed via the microcontroller, and whose voltage output is sent to the microcontroller to be analyzed to determine the force applied in terms of the sample's weight.

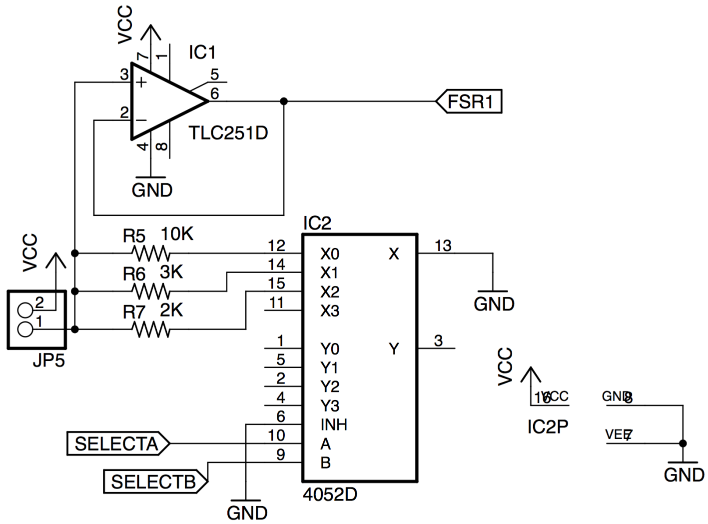

Figure 15: Weight Measurement System Schematic

If the user selects button 0, the path with R_{M1} (denoted by R5) would be connected, if the user selected button 1 , the path with R_{M2} (denoted by R6) would be connected, and if the user selected button 2, the path with R_{M3} (denoted by R7) would be connected.

Methods of determining an unknown sample's mass placed on the FSR is discussed in Weight Measurement of Design Verification.

3 Design Verification

See Requirements and Verifications of the Appendix of each module for explicit tables and confirmations.

3.1 Microcontroller

Through setting the DIO pins of the ATmega to ground or 3.3V and observing the microcontroller's response to voltages within 0 to +0.2V and +3.1 to +3.3V (respectively), it was observed that a logical low and logical high were read for all trials within those ranges, satisfying the requirement for the digital input of the microcontroller. Similarly, by setting all pins to logical low or high and using a multimeter to read the voltages, it was observed that they satisfied the requirement of being within range of 0 to +0.2V and +3.1 to +3.3V, respectively, thus satisfying the digital output design requirements.

To ensure that the analog inputs were being properly quantized, we swept the input of the ADC on the microcontroller from 0V to +3.3V while observing the output via serial monitor. The result was a digital value ranging from 0 to 1023 just as expected.

To verify that the SPI communication protocol was functioning correctly, we attached an oscilloscope to the clock (SCK), data out (MISO) and data in (MOSI) lines on our SPI bus for the project. The clock was measured at 16MHz, well above the required 100kHz. The data for both in and out were clearly being generated in time with the clock pulse.

3.2 User Input

Through viewing live data from an oscilloscope, it was proved over 100 trials that the button does in fact output a logical low to the microcontroller in every trial, thus surpassing the 95 percent requirement of the module.

By attempting to press multiple buttons at a time, it was observed that only one was recognized by the microcontroller.

3.3 Display

By beginning a timer and pressing the next and back buttons navigating the user interface over 50 trials, a total time of 15.7 seconds had passed. Following

$$\frac{time_{total}}{num_{trials}} = time_{1button}$$

where $time_{total}$ is 15.7 seconds and num_{trials} is 50, $time_{1button}$ is .314 seconds. This satisfies the requirement of one second or less of load time.

By giving the device to 10 random users, we found that there was a 100 percent success rate in following the on-display instructions, satisfying the minimum requirement of 80 percent.

3.4 Real Time Clock

The coin cell battery must have a life of at least one year. To test this, the current drawn on the coin cell battery was measured while the RTC was running. The following eqution is used:

$$\frac{rating_{mAh}}{currnet_{draw}} = life$$

where $rating_{mAh}$ is $38mAh$ and the current draw is 0.84μA. Therefore, the life of the battery is 5.16 years, exceeding the requirement.

3.5 GSM Module

To test the functionality of the GSM module, 100 text messages were sent by the device to a known number (a member of the group). Exactly 100 of these messages were received correctly, satisfying the requirement of at least 90 percent success rate.

3.6 Device Storage (SD Card)

According to

$$characters_{perentry} * bytes_{percharacter} * entries = storage_{max}$$

where $characters_{perentry}$ is roughly 50 characters, $bytes_{percharacter}$ is 4 bytes and $entries$ is 10000, there is a 2GB capacity for storage, far exceeding the requirement of the ability to store the most recent $10,000$ test results, granted that our storage device is rated at 4GB.

3.7 Battery Charging and Power Supply

Voltage values from TPS73633DBVT linear regulator outputted a nominal voltage of 3.3V when probed.

Voltage values from LP2985-33DBVT linear regulator outputted a nominal voltage of 2.8V when probed.

The following table is used to ensure that the voltage regulators chosen can supply the necessary currents to the modules it powers.

Module	Max Current Drawn
ATmega2560 Microcontroller	$50mA$
SIM800L GSM	$2A$
SSD1306 Display	$25mA$
DS3231SN Real-time Clock	$840nA$
DHT22 Temp and Humidity Sensor	$2.5mA$
FSR Weight Measurement	$14.52mA$[5]

Table 1: Current Requirements of Modules

Nominal current draw (without SIM800L) is rated at 92.5mA, which is well below the maximum output current of 500mA of either linear regulator. During peak consumption (when transmitting) current draw raises to 2.09A, which is supported since the current being drawn for the SIM800L is taken directly from the battery which supports 2A.

3.8 Temperature and Relative Humidity Sensing

The DHT22 results are consistent with the sample of grain being in a sealed bag in a slightly warmer environment (higher T and h than room temperature in an 'average' room). However, no ground truth was able to be established due to a lack of access to a device that measures temperature and humidity with a known accuracy. An IR thermometer of 1 degree Celsius accuracy was intended to be used, but was not obtained. Therefore, this requirement was not met, nor was the extremes (measuring between 30 and 86 degrees Celsius) for the lack of a controlled environment. No humidity measuring device was available for the group to use as well.

3.9 Weight Measurement

A brief discussion on relevant equations to the module are included prior to the testing results.

The following are the impurity concentration and density measurements referred to in Weight Measurement of Design.

$$\frac{mass_{broken}}{mass_{full}} * 100 = \ percent\ broken\ kernels$$

$$\frac{mass_{dirt}}{mass_{full}} * 100 = \ percent\ dirt\ and\ small\ particles$$

$$\frac{mass_{full} - mass_{broken} - mass_{dirt}}{mass_{full}} * 100 = \ percent\ whole\ kernels$$

A non-direct method of measuring the mass of the whole kernels due to a tossed design idea of sieves sitting within one another that would all be shaken simultaneously, and weight measurements taken after each sieve level is removed.

The following equation is used to determine density, where volume is the volume of the weighing container (in this project's case, approximately 71 square inches.

$$\frac{mass_{full}}{volume} = \ density$$

Referring back to the following image depicting the amplification circuit used for the FSR,

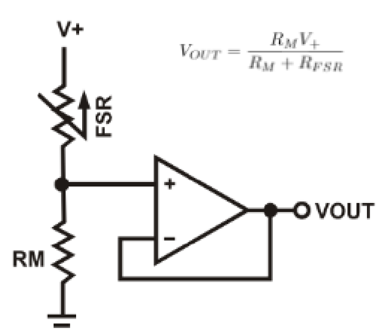

Figure 16: FSR Amplification Circuit[6]

Exact values of R_M are selected based the desired sensitivity range of input masses.

Desired accuracies of 0.1g for the full sample, 0.1g accuracy for the medium particles, and 0.01g accuracy for small particles must be considered in determining how to obtain weight measurements. The proper accuracy calculations according to the central limit theorem[7] and a 5 percent accuracy of the FSR are as follows, such that the denominator in each corresponds to the needed accuracy:

With a total sample weight expected to be 2000g,

$$\frac{(0.05(2000g))^2}{0.1} = 100000$$

$$\frac{(0.05(0.10)(2000g))^2}{0.1} = 1000$$

$$\frac{(0.05(0.10)(2000g))^2}{0.1} = 10000$$

samples need to be taken for the whole sample, medium, and small particles respectively. The 0.10 factor is included to represent an expected maximum of 10 percent of the total weight coming from medium and small particles, each.

Through testing, the following graph of FSR Voltage vs Mass was obtained. The process follows averaging $10,000$ samples (R_M=2kilo-ohms) of a known weight on the FSR, recording that data point, and doing the same for multiple weight samples. The resulting polynomial equation can be used to approximate what an unknown sample mass is based on the FSR voltage, or linear approximations can be made with conditional statements in the code for programming the microcontroller. The mass can then be used in the previously discussed impurity concentration or density equations. The FSR became permanently damaged due to unknown causes (likely a connection issue between the connectors, tail, or active area) caused our group to be unable to further investigate and solidify this module, thus not satisfying the design requirements for this module.

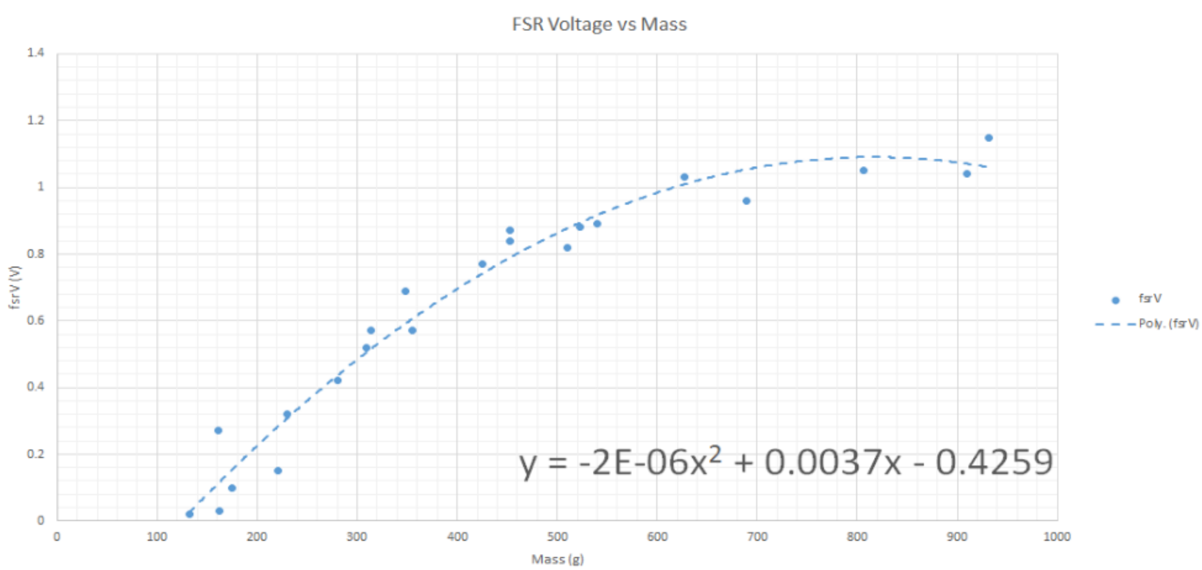

Figure 17: FSR Voltage vs Mass and Equation

In order to verify the design, we would be comparing their supposed weight by the model to the exact weight measured on a scale of 0.01g accuracy purchased by the group. Changes to R_M, the number of samples averaged, the number of data points included in determining the polynomial expression, or using linear approximations and splitting the graph into multiple sections are all approaches that could be used to fine tune the system.

4 Cost

4.0.1 Parts

Description	Quantity	Manufacturer	Vendor	Cost/unit	Actual Cost
SIM800L on PCB	1	SIMCom	Amazon	$11.99	$11.99
Ting GSM SIM card	1	Ting Wireless	Amazon	$9.00	$9.00
DS3231S RTC	1	Maxim Integrated	Digi-Key	$9.61	$9.61
CR1220 Battery	1	Energizer	Amazon	$2.89	$2.89
Monochrome 1.3" 128x64 graphic display	1	Solomon Systech	adafruit	$19.95	$19.95
ATMEGA2560-16AU-ND	1	Atmel	Digi-Key	$16.55	$16.55
16 MHz Crystal	1	Interquip Electronics	adafruit	$0.75	$0.75
MicroSD card module	1	adafruit	adafruit	$7.50	$7.50
4GB Blank SD Card	1	SanDisk	Amazon	$7.95	$7.95
DHT22	1	Aosong	adafruit	$9.95	$9.95
Lithium Ion Battery 3.7V 4400mAh	1	PKCELL	adafruit	$19.95	$19.95
FSR Weighing Sensor	1	VPG Transducers	Xcell	$7.49	$7.49
PCB	1	OSHPark	OSHPark	$10.00	$10.00
Total					$123.63

Table 2: Cost of parts

4.0.2 Labor

Name	Hourly Rate	Hours	Total	Total x 2.5
Adam Long	$30	300	$9000	$22500
Joan Brown	$30	300	$9000	$22500
Kevin Villanueva	$30	300	$9000	$22500
Total				$67,500

Table 3: Cost of Labor

5 Conclusion

5.1 Accomplishments

There were successes of varying degree in all modules with the exception of weight measurement. User input, display, RTC, GSM, SD Card, battery charging, and power supply satisfied all of the requirements of design. Major accomplishments also include orienting large modules accordingly in the PCB enclosure so that the device is compact, with parts that may need to be removed or exchanged accessible to the user. See Enclosure and PCB of the Appendix to see photos of how everything is placed in the enclosure.

5.2 Uncertainties

Uncertainties lie in the temperature and humidity module, as no ground truths were able to be established in the project duration. Additionally, how the sensor would be inserted in the weighing container such that it would not become damaged by small particles was undetermined.

The graph obtained is by testing the FSR as seen in its Design verification is likely inaccurate, as not many data points were taken (although there was a large number of samples averaged). Refer to future work for more on the weight measurement module.

5.3 Ethical Considerations

Our project follows IEEE codes of ethics as following:
1. To accept responsibility in making decisions consistent with the safety, health, and welfare
of the public, and to disclose promptly factors that might endanger the public or the environment.
3. To be honest and realistic in stating claims or estimates based on available data.
5. To improve the understanding of technology; its appropriate application, and potential consequences.
6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.
7. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others.
9. To avoid injuring others, their property, reputation, or employment by false or malicious action.
10. To assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

5.4 Future Work and Recommendations

Future work on the project includes:
-An encompassing kit enclosure (brief-case style): a waterproof, durable case was ordered, but the width was not sufficient to fit the sieves used (Pelican 1520 case, 14" diameter sieves). We recommend purchasing a case with foam that can be cut so that parts can be inset and the weighing container can be placed on a weight sensor with relatively good repeatability.
-Investigating using strain gauge load cells: this was a part of the original design of the kit, but was later disregarded for its complexity in design and power drawn. Wheatstone bridges [8] would be required, as well as a physical implementation that would ensure that the entirety of the weight is distributed only the desired load cells since different load cells of different weight capacities would be needed for the project.

-Combining the findings and results of the project with other projects within Beckman Institute and the College of ACES, specifically, the Farmer's web portal project, the quality measurement device mounted in the grain storage containers, and the edge-detecting image processing program that would allow for an automated method of detecting unwanted materials, mold, etc. Contact Mr. John Hart at jmhart3@illinois.edu for more information.
-Investigating implementation of different FSRs, specifically of different sized active areas. However, we recommend due to the likely inherent inaccuracies, to rather implement load cells.
-If an FSR is used, purchase multiple and be very careful that no portion of the FSR become damaged by bending, heat, etc. Do not solder the tail of the FSR.[5]

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[8] S. Al-Mutlaq, "Getting Started With Load Cells," Accessed Aug. 2016. [Online]. Available: https://learn.sparkfun.com/tutorials/getting-started-with-load-cells

[9] "Equilibrium Moisture Content," Web Article, Wikipedia, Accessed Oct. 2016. [Online]. Available: https://en.wikipedia.org/wiki/Equilibrium_moisture_content

Appendix A Requirements and Verification

Table 4: System Requirements and Verifications

Requirement	Verification	Satisfied? Y or N
Lithium Ion Battery 1. Battery shall allow the device to function for 8 hours on a signal charge. 2. Battery shall be unable to discharge if device is powered off. 3. Safely charge the batter using micro usb according to the safety guidelines	**Lithium Ion Battery** 1. Verification for item 1: (a) Fully charge the battery using a standard battery charger. (b) Power on the device and conduct a test every 15 min. (c) Time how long it takes for battery's voltage to drop 10% of capacity. 2. Verification for item 2: (a) Fully charge the battery using a standard lithium ion battery charger. (b) Reattach the battery to the powered off device (c) Let sit for 48 hours (d) Ensure battery has not discharged beyond typical self-discharge 3. Verification for item 3: (a) Safely discharge the battery (b) Plug the battery into the device and allow it to charge (c) Measure the voltage on the batter and ensure it has charged safely to $+3.7V$	Y
Power Supply 1. Shall supply the required voltages to the corresponding modules 2. Shall support the max current draws of the different modules	**Power Supply** 1. Verification for item 1: (a) Power on the power supply (b) Measure voltage VCC and GND of each module (c) Ensure that each module has the a voltage within their safe operating range 2. Verification for item 2: (a) Add all of the max current values of the different modules (b) Ensure that the battery can supply enough current to suport the loads	Y

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Table 4 – continued from previous page

Requirement	Verification	Satisfied? Y or N
User Interface 1. Button press must output logical low to microcontroller 95% of the time 2. Only one button input can shall be processed at a time	**User Interface** 1. Verification for item 1: (a) Attach a multimeter to ground and the output of the button being tested. (b) Press the button 100 times counting the number of times that the button misses the voltage threshold for a logical state specified by the microcontroller (c) Ensure that the event happened less than 5 times 2. Verification for item 2: (a) Insure the buttons are all attached to the microcontroller. (b) Have the microcontroller output an indication when a button is pushed (c) While pushing multiple buttons ensure that the microcontroller is only recognising one input.	Y
Display 1. Display must respond to valid button input within 1 second of press 2. UI must accurately display actions to instruct the user on how to properly measure grain samples, $> 80\%$ success rate	**Display** 1. Verification for item 1: (a) Power on the device (b) Start a timer and press the next and back buttons when the display fully responds 50 times (c) Divide the time elapsed by amount of button pushes and ensure less than 1 sec of load time 2. Verification for item 2: (a) Give the device to group of subjects (b) Ensure 4/5 of the group were able to successfully use the device	Y

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Table 4 – continued from previous page

Requirement	Verification	Satisfied? Y or N
GSM Messaging 1. Device must be able to send results via text with a delivery rate grater than 90%	**GSM Messaging** 1. Verification for item 1: (a) Power on the device (b) Conduct 100 tests with the device and send the results to a known number (c) Ensure that over 90 texts were received with the test message result data	Y
Real Time Clock 1. Shall have a separate coin cell battery with life over one year 2. Shall provide accurate time stamp with 3 seconds of the current time 24 hours after the device has been powered off.	**Real Time Clock** 1. Verification for item 1: (a) Power on the device (b) Measure the current draw on the coin cell battery attached to the RTC while it is running. (c) Divide the mAh rating of the battery by the current draw on the battery (d) Ensure that the run time exceeds one year 2. Verification for item 2: (a) Power on the device (b) Ensure the time is set to the current time (c) Power off the device and let sit for 24 hours (d) Power on the device and ensure the device time is within 3 seconds of the current time	Y
Device Storage 1. Shall have the capacity to store the 10,000 most recent test results	**Device Storage** 1. Verification for item 1: (a) Calculate the size of an individual test result that will be created in software (b) Multiply by 10,000 and ensure that there is enough capacity to store the results	Y

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Table 4 – continued from previous page

Requirement	Verification	Satisfied? Y or N
Temperature Measurment 1. Shall measure instantaneous temperature between 30 and 86 degrees C 2. Shall measure temperature within 1 degrees C of actual temperature	**Temperature Measurment** 1. Verification for item 1: (a) Use an accurate thermometer and a cooler to create a 30 degrees C environment (b) Ensure the sensor is capable of reading the tempature (c) Use an accurate thermometer and a heater to create a 86 degrees C environment (d) Ensure the sensor is capable of reading the tempature 2. Verification for item 2: (a) Use an accurate thermometer to take the temperature (b) Take the temperature using device sensor (c) Increase the temperature by 5 degrees C validating with accurate thermometer (d) Repeat 5 times ensuring that readings don't differ by more then .5 degrees C	N

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Satisfied? Y or N
Humidity Measurment 1. Shall measure relative percent humidity between 50 and 85 2. Shall measure humidity within .5% of actual relative percent humidity	**Humidity Measurment** 1. Verification for item 1: (a) Use an accurate humidity reader and create an environment that has a relative humidity of 50% (b) Ensure the sensor is capable of reading the humidity (c) Use an accurate humidity reader and create an environment that has a relative humidity of 85% (d) Ensure the sensor is capable of reading the humidity 2. Verification for item 2: (a) Use an accurate humidity reader to take the relative humidity (b) Take the relative humidity using device sensor (c) Increase the humidity by 5% validating with accurate humidity reader (d) Repeat 5 times ensuring that readings don't differ by more then .5 degrees C	N

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Table 4 – continued from previous page

Requirement	Verification	Satisfied? Y or N
Weight Measurement 1. Shall measure the a quart cup of corn, typically between $640g - 850g$, with accuracy of $\pm 4.75g$ 2. Shall measure sieved out broken kernels, typically 6% to 12% of the sample, with accuracy of $\pm .1g$ 3. Shall measure sieved dirt and other matter, typically 1% to 5% of the sample, with accuracy of $\pm .01g$	**Weight Measurement** 1. Verification for item 1: (a) Measure the test weight of a quart cup of corn using industry standard scale (b) Measure the test weight of the corn using the device with specified amplification (averaged of 20 data points) (c) Ensure that the weight measured by the device is within $\pm 4.75g$ 2. Verification for item 2: (a) Sieve out a sample of broken kernels and measure the weight of approximately 6% of the original sample (b) Measure the weight of the broken kernels using the device with specified amplification (averaged of 20 data points) (c) Ensure that the weight measured by the device is within $\pm .1g$ 3. Verification for item 3: (a) Sieve out a sample of dirt and other matter and measure the weight of approximately 1% of the original sample (b) Measure the weight of the broken kernels using the device of specified amplification (averaged of 20 data points) (c) Ensure that the weight measured by the device is within $\pm .01g$	N

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Table 4 – continued from previous page

<table>
<tr><th>Requirement</th><th>Verification</th><th>Satisfied?
Y or N</th></tr>
<tr><td>Controller: Digital Input
1. Shall read a logical low with voltage within the range $0V$ - $+.2V$
2. Shall read a logical high with voltage within the range $+3.1V$ - $+3.3V$</td><td>Controller: Digital Input
1. Verification for item 1:
(a) Power on the device and set all pins as inputs and serially print their values
(b) Using a power supply set the DIO pins to ground and ensure that the controller outputs logical low
2. Verification for item 2:
(a) Power on the device and set all pins as inputs and serially print their values
(b) Using a power supply set the DIO pins to $+5V$ and ensure that the controller outputs logical high</td><td>Y</td></tr>
<tr><td>Controller: Digital Output
1. Shall output a logical low with voltage within the range $0V$ - $+.2V$
2. Shall output a logical high with voltage within the range $+3.1V$ - $+3.3V$</td><td>Controller: Digital Output
1. Verification for item 1:
(a) Power on the device and set all pins to logical low
(b) Using a multimeter ensure that all of the pins have a voltage within the range $0V$ - $.2V$
2. Verification for item 2:
(a) Power on the device and set all pins to logical high
(b) Using a multimeter ensure that all of the pins have a voltage within the range $3.1V$ - $3.3V$</td><td>Y</td></tr>
<tr><td>Controller: Analog Input
1. Properly quantize analog inputs to 0-1023</td><td>Controller: Analog Input
1. Verification for item 1:
(a) Power on the device, upload a program to set all pis to inputs and print their values.
(b) Slowly sweep input voltage and check for proper quantization</td><td>Y</td></tr>
</table>

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Requirement	Verification	Satisfied? Y or N
Controller: SPI 1. Shall have an output clock rate greater than 100 kHz	**Controller SPI** 1. Verification for item 1: (a) Power on the device and set output clock to 100kHz (b) Using an oscilloscope measure the pulse width and calculate the clock rate (c) Ensure greater than 100kHz	Y

Appendix B Enclosure and PCB

The following are images of the PCB enclosure, display, user input buttons, PCB, orientation of all units or modules connected to PCB, etc.

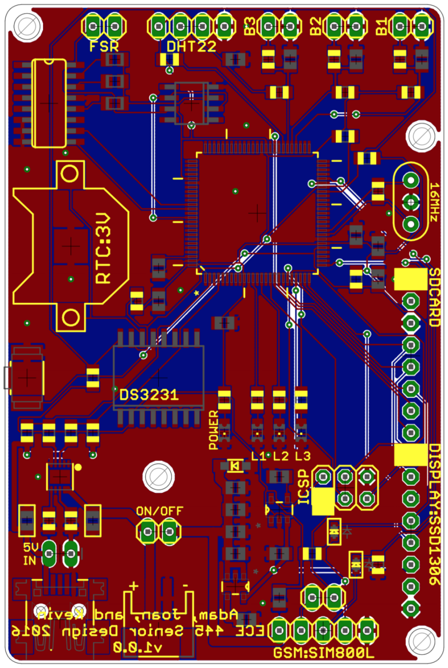

Figure 18: PCB Design

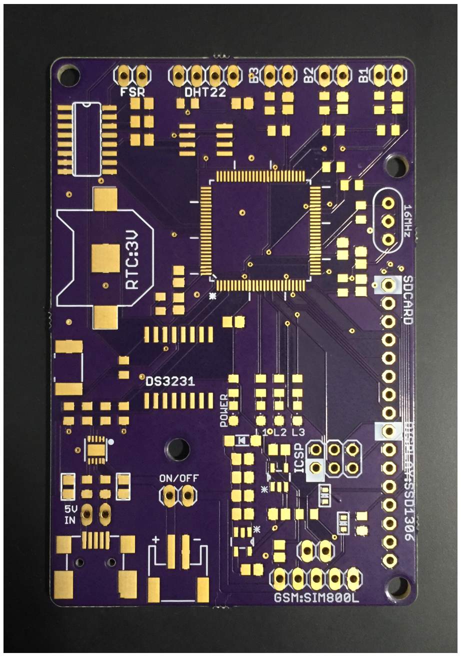

Figure 19: Top View of blank PCB

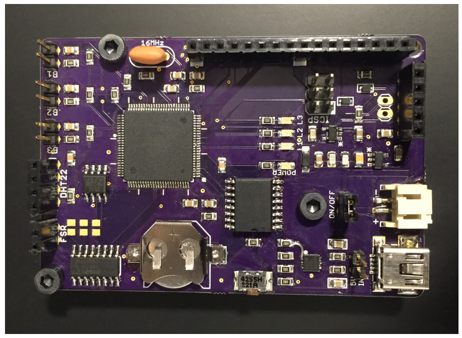

Figure 20: Top View of PCB

Figure 21: Aerial View of PCB Enclosure Lid: Display and Buttons

Appendix C Software Flowchart

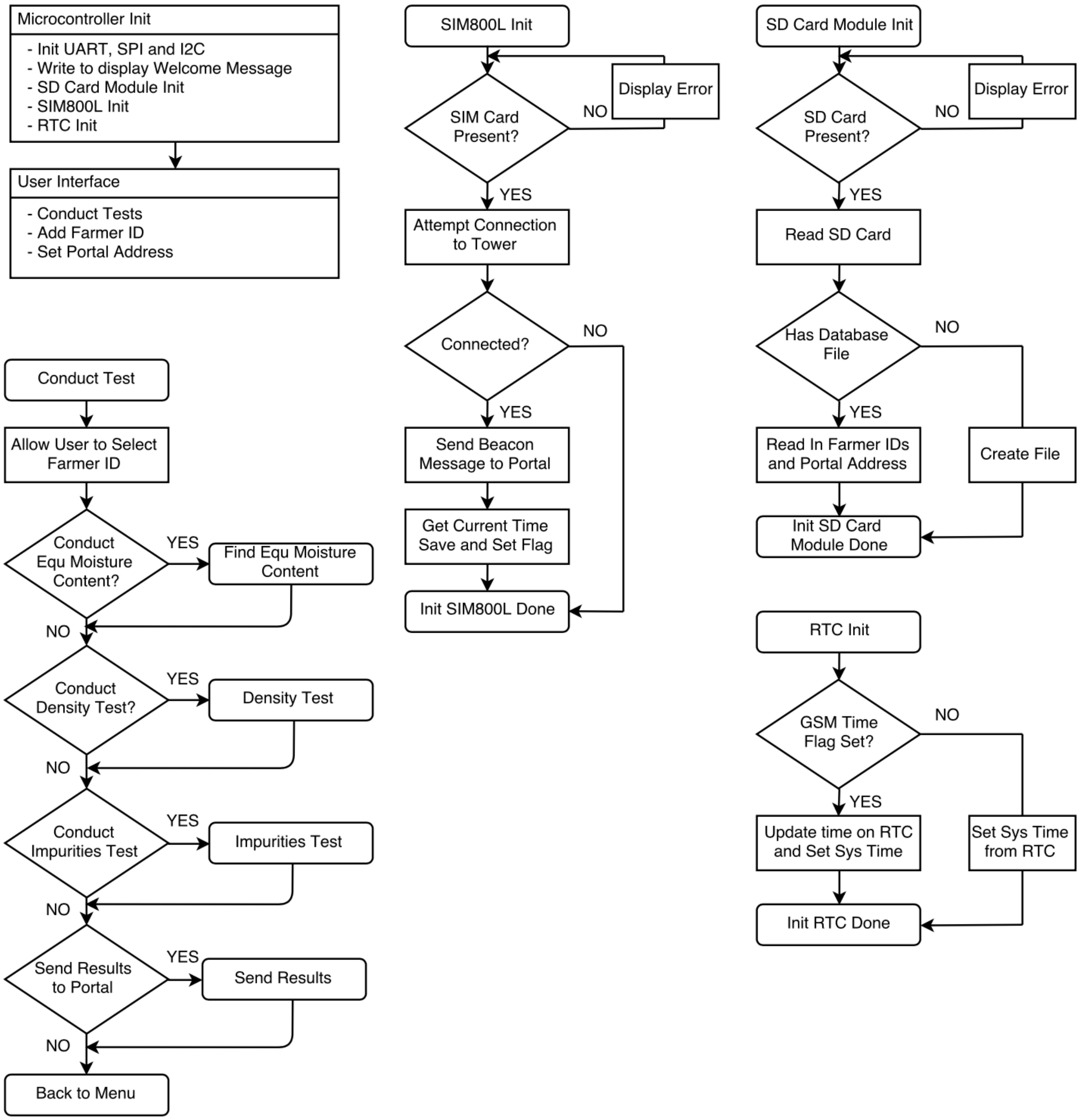

Figure 22: Full Device Flow Chart

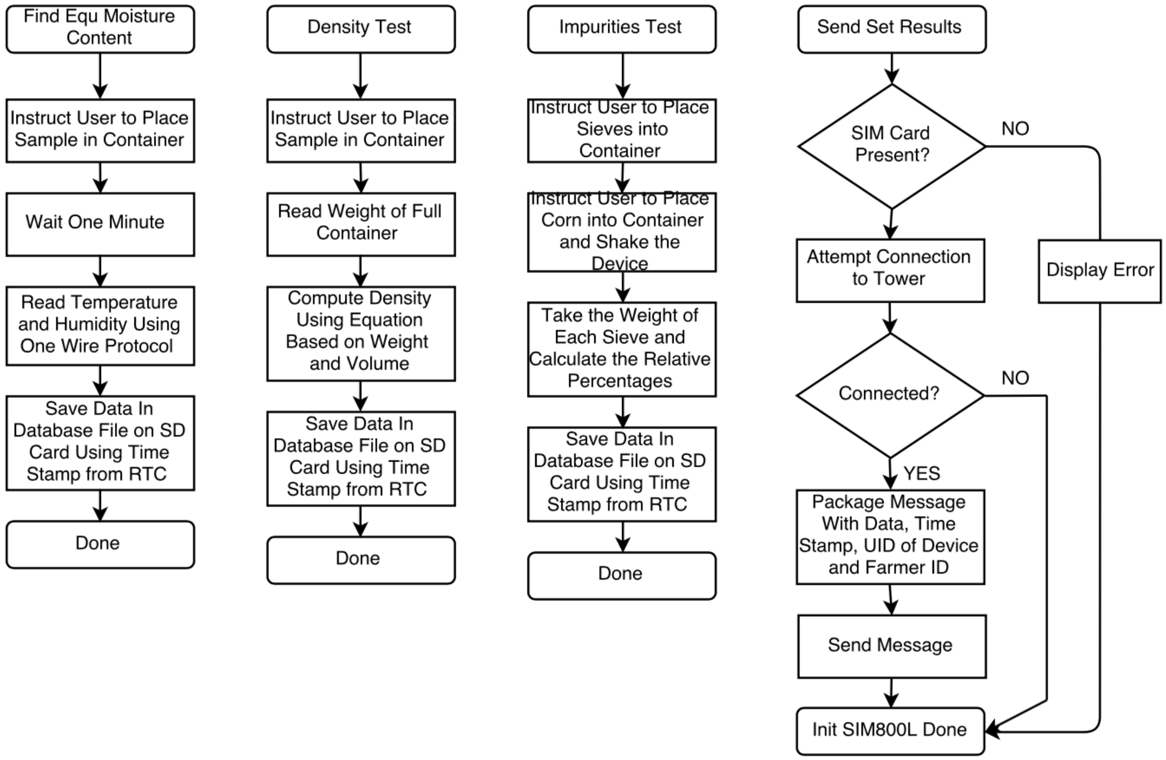

Figure 23: Detailed Sub-modules for Full Device Flow Chart

Appendix D Calculations

D.1 Hailwood-Horrobin Equation

The results of the temperature and relative humidity measurements taken are used to determine equivalent moisture according to the Hailwood-Horrobin equation[9] shown below.

$$M_{EQ} = \frac{1800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1+K_1Kh+K_1K_2K^2h^2}\right]$$

$$W = 330 + 0.452 * 10^{-4}T - 8.44 * 10^{-7}T^2$$

$$K_2 = 1.09 + 2.84 * 10^{-2}T - 9.04 * 10^{-5}T^2$$

$$K_1 = 6.34 + 7.75 * 10^{-4}T - 9.35 * 10^{-5}T^2$$

$$K = 0.791 + 4.63 * 10^{-4}T - 8.44 * 10^{-7}T^2$$

Figure 24: Hailwood-Horrobin equation for Equivalent Moisture

D.2 Op-amp Analysis

Referring back to the following image depicting the amplification circuit used for the FSR,

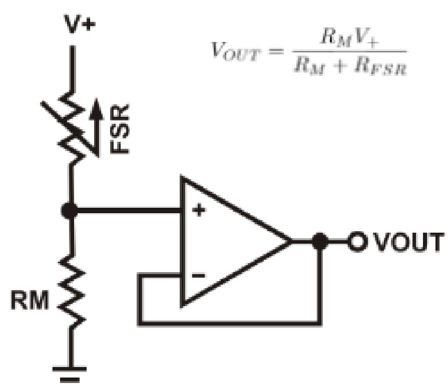

Figure 25: FSR Amplification Circuit[5]

The following is the process for determining the output voltage. For an op-amp,

$$i_- = i_+ = 0 \; and \; V_- = V+$$

Therefore,

$$V_- = V_+ = V_+$$

Using KVL for the positive terminal of the op-amp,

$$\frac{V_+ - V_{OUT}}{R_{FSR}} = \frac{V_{OUT} - V_{GND}}{R_M}$$

$$V_{OUT}(R_{FSR} + R_M) = R_M V_+$$

The output voltage of the FSR, denoted by VOUT in the above circuit, used is

$$V_{OUT} = \frac{R_M V_+}{R_M + R_{FSR}}$$

Where the gain is

$$\frac{R_M}{R_M + R_{FSR}}$$

such that V_+ is 3.3V.

Appendix E Safety

The end product will be in an entirely closed case, with most electrical components (aside from the user interface and sensors) being insulated from the end user. That being said, there arent any major electrical and mechanical safety concerns with our end project, granted each module of the project isnt damaged.

Concerning minor safety considerations: Sieves in the weight/impurity module may scratch end user when placing in corn sample Frayed wires from any sensor may induce electrical shock if not properly handled Case closing may pinch fingers of end user.

Concerning project team safety: there are several electrical components that will need to be soldered on the PCB. This brings up the chance of injury from heat/burning that can occur from improper use of a soldering iron. Frayed electrical components may induce electric shock when testing the end product. Placing sharp mechanical enclosing in the end product may subject the team to minor cuts and injury.

The above being said, there is a very low chance of injury for both end user and project team with minor injury being possible, but still unlikely.

Additional safety information on the lithium ion battery can be found on the ECE 445 website.