Automated Corn Quality Measurement Kit

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Project No. 42

Contents

1 Introduction

This project is an interdisciplinary research collaboration between the 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).

1.1 Statement of Purpose

The project involves the implementation of Information and Communication Technology to address the problem of food loss, vital for developing countries such as India and Brazil, due to inadequate grain storage and quality monitoring methods. With the proper resources, smallholder farmers in developing countries would be able to analytically show the quality their product, reducing loss and giving farmers the ability to adjust the price of the product based on its quality.

1.2 Objectives

A portable Grain Measurement Quality (GMQ) Kit will be developed to automatically collect and transmit testing data on corn quality. The only similar type of test kits are for rice and are manually conducted with handwritten documentation of the results. This test kit shall contain electronic sensor systems and methods equipped with data recording capabilities for measuring grain quality. It will also include documented specifications for conducting the tests that are easy to follow for farmers in developing countries. The kit will enable field testing and automated transmission of the result data to a local university for tracking and analysis, making for a more efficient and reliable system.

The kit will be in the form of a portable battery powered handheld device approximately the size of a quart cup. The device will have a display as well as three selection button. In addition it will have an SD card slot to store the result data and a GSM module to wirelessly transmit the results to an on-line portal. The quality measurement device will measure three distinct values related to the quality of the corn: equilibrium moisture content, density and impurities.

The equilibrium moisture content is critical in determining if the corn has been dried and sored properly. If not within the acceptable range, the corn becomes highly susceptible to mold growth as well as insect damage. To measure the equilibrium moisture content, the temperature and humidity of an insulated sample will be taken. The final value will be calculated using the Hailwood-Horrobin equation.

The density shows how much damage the corn has sustained from mold and insects. If the corn does not meet a certain density it is not of proper substance and is significantly less valuable. The density of the corn will be calculated by filling a one quart cup full of corn and taking it's weight. This is also known as the test weight.

The purity of the corn is also large factor in determining corn quality. Chipped or broken kernels are more susceptible to mold as well as dirt ans other small particles indicates a degradation in the quality of the corn. Two sieve, a 12-64Th's and a 8-64Th's, will be used to separate the sample. On top will sit the intact kernels, in the middle broken or chipped pieces of the kernels and on the bottom any other matter within the sample. Once sieved, the weight of each layer will be taken.

All of the IO in the device will be handled by a micro-controller. It is also responsible for properly recording, storing and sending all of the result data from the three tests.

1.3 Benefits to the End User

- Provide a simple, reliable, cost-effective way to analytically measure the product
- Support increased revenue in correspondence with grain quality standards
- Increased efficiency due to automated and electronic methods of assessment
- Provide the means to store and display data to the user and send to local teams for feedback

1.4 Product Features

- Accurate measurements for the sample's equilibrium moisture content, density and impurity
- Automatically record and store data on the device
- Wirelessly transmit data using GSM
- Battery powered, rechargeable
- Durable and waterproof

2 Design

2.1 Block Diagram

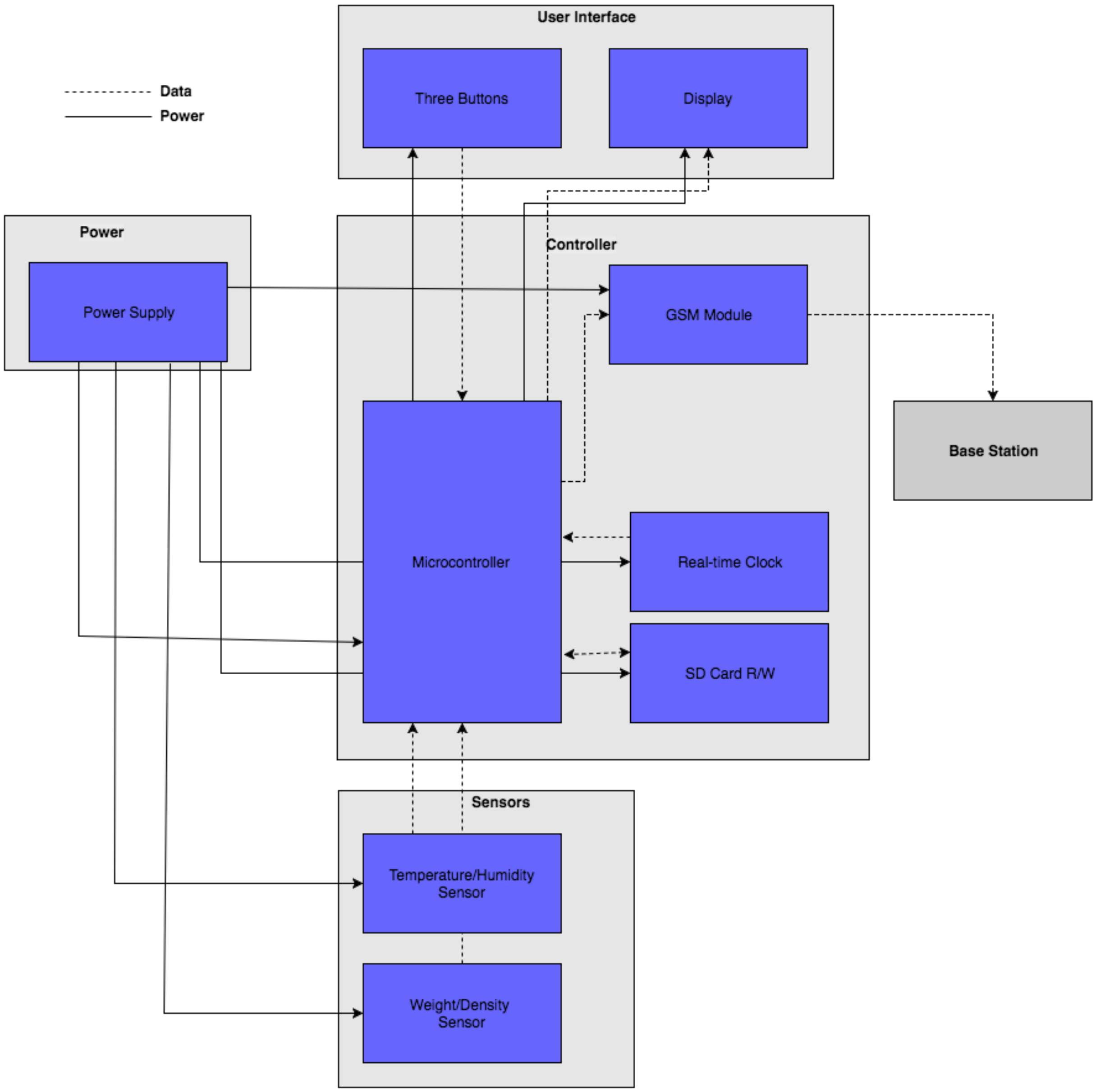

Figure 1: Overall block diagram for the project.

2.1.1 Battery Charging and Discharging

Input: $+5V$ power via usb
Output: $+3.7V$ for power supply
The rechargeable $+3.7V$ lithium ion battery will provide power to the device. The battery shall be able to be recharged using standard usb power $(+5V\ .5 - 1.5A)$. This is because the solar powered charging stations available only allow for charging via usb. The lithium ion battery will also have discharge and overcharge

protection to meet safety standards. The battery module will also include voltage regulation to safely power the other modules in the device.

2.1.2 Power Supply

Input: rechargeable $+3.7V$ lithium ion battery
Output: $+5V \pm 10\%$ to ATmega1280 microcontroller
——— $+4V \pm 10\%$ to SIM800L GSM module
——— $+5V \pm 10\%$ to display module
——— $+5V \pm 10\%$ to RTC module
——— $+5V \pm 10\%$ to SD card module
——— $+5V \pm 10\%$ force sensing module
——— $+5V \pm 10\%$ to temperature and humidity sensing module
The device is powered by a $+3.7V$ lithium ion battery, but different modules require higher voltages and can draw different max currents. To accommodate the differences the power supply module will utilize voltage regulation to pull the voltage up to the appropriate levels and safely power the other modules in the device. The power requirements for all modules are shown in the table below.

Module	Voltage/Current Requirement
ATmega2560 Microcontroller	$+5V$ Max Current Draw $50mA$
SIM800L GSM Module	$+4V$ Max Current Draw $2A$
SSD1306 Display	$+5V$ Max Current Draw $25mA$
DS3231SN RTC Module	$+5V$ Max Current Draw $840nA$
DHT22 Temp and Humidity Sensor	$+5V$ Max Current Draw $2.5mA$
SD Card Module	$+5V$ Max Current Draw $150mA$

Table 1: Power requirements for all modules.

2.1.3 User Input

Input: $+5V$ from the power supply
Output: three digital lines to microcontroller
Three selection buttons as well as an on/off switch will be assessable to the user. The buttons will allow the user to navigate the user interface, start tests and set initial configuration parameters. The buttons will be connected to the microcontroller via the digital IO (DIO) pins with proper debounce circuitry. The on/off switch will cut power to the microcontroller and the GSM module. This requires that the microcontroller keep track of persistent variables across boot cycles by storing the information on the SD card.

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 when the button is pressed it will discharge bring DIO to ground. The values of R($10k\Omega$) and C($100nF$) were chosen to provide .001 sec of debouncing time for the button. Finally, a $1k\Omega$ resistor is placed between the button and the 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.

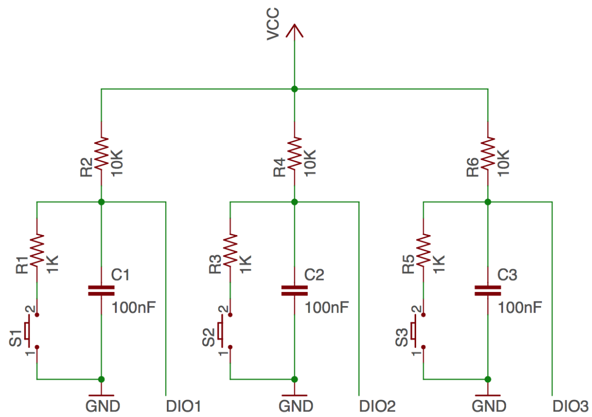

Figure 2: Three Button Debounce Schematic

More information on the on/off switch can be found in the power supply section.

2.1.4 Display

Input: $+5V$ from the power supply
——— SPI DIO from the microcontroller
Output: graphical images and text on the display
The display will be a monochrome 1.3" 128x64 graphic display capable of printing ASCII characters as well as some basic images. The text and images will help the farmer conduct the tests as well as read the results.

The SSD1306 monochrome display will communicate 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 pin out for the display module. DATA, CLK, D/C, RST and CS will be directly connected to DIO pins on the microcontroller for use with SPI.

Pin	Function
1	DATA - Data line
2	CLK - Clock
3	D/C - Data/Command
4	RST - Reset
5	CS - Chip Select
6	NA
7	Vin - $+5V$ VCC
8	GND - Ground

Table 2: Pin out for the display module.

More information on the display can be found in the data sheet[1].

2.1.5 Microcontroller

Input: $+5V$ from the power supply
——— state from user input
——— UART from gsm module
——— I2C from real time clock
——— SPI from the sd card
——— data from temperature and humidity sensor
——— analog value from load sensor
Output: SPI to display
———— UART commands to gsm module
———— I2C to real time clock
———— SPI to sd card
———— data to temperature and humidity sensor
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.

The ATmega2560 was chosen due to it's relatively large 256 kBytes of on board flash memory and exceeding the needed 24 IO pins. The large on board flash memory is critical in buffer the display as well as supporting the sd card module.

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

Four indication LEDs will be tied to four different DIO pins on the microcontroller. They will provide a basic indication of the status of the microcontroller. More information can be found in the software flow charts.

The ATmega2560 will be powered by a regulated $+5V$ supplied by the power supply. The power supply will also set the reset pin on the ATmega. The interfaces for all of the different modules can be seen in the block diagram below.

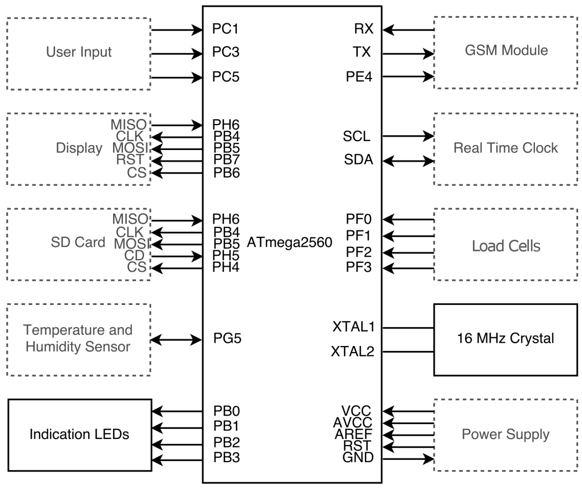

Figure 3: ATmega2560 interfaces to other components

A six pin header, not shown in the figure above, will also be placed on the pcb to allow for reprogramming of the microcontroller. The header will be directly connected to pins PB1, PB2, PB3, RESET, $+5V$ and GND.

A schematic for the microcontroller can be found in the schematics of overall system section.

2.1.6 GSM Module

Input: $+4V$ from the power supply
——— UART data from the microcontroller
Output: GSM messages to web portal
———— UART data to the microcontroller
The GSM module is responsible for sending the test results to the web portal. Currently the web portal expects test results to arrive in the from of a text message. The device will support this, but will also have the ability to send data via HTTP POSTs. This will allow for larger packets of data to be sent once the portal supports the method. All test results will be accessible by researchers, merchants and farmers through the web portal.

The device will use the SIM800L GSM module because of it's small package and low cost. The pin out for the module can be seen in the figure below.

Pin	Function
1	VCC - Power +4V
2	RST - Reset
3	TXD - serial send
4	RXD - serial receive
4	GND - Ground

Table 3: Pin out for the SIM800L GSM module.

The SIM800L requires $+4V$ and can draw up to $2A$ during communication. The power supply module...

The SIM800L has an internal UART and will communicate with the microcontroller serially over its RXD/TXD pins. The DIO pins on our microcontroller output $+5V$ while the UART on the SIM800L expects $+2.8V$.

In order to bring a $+5V$ input to a $+2.8V$ output, a transistor is used as shown below.

An op-amp (LM4558N) is used to amplify $+2.8V$ to $+5V$ as shown below.

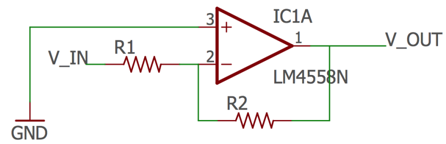

Figure 4: Op-amp configuration

For an op-amp,

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

Therefore,

$$V_- = V_+ = V_{IN}$$

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

$$\frac{0 - V_-}{R_1} = \frac{V_- - V_{OUT}}{R_2}$$

$$-R_2 V_{IN} = R_1 V_{IN} - R_1 V_{OUT}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2 + R_1}{R_1} = \frac{R_2}{R_1} + 1$$

In order to amplify a $+2.8V$ input to a $+5V$ output, $\frac{V_{OUT}}{V_{IN}} = 1.786$, so resistances can be chosen to be $R_1 = 350\Omega$ and $R_2 = 275\Omega$.

To prevent unwanted deviations in the voltage across VCC and GND a $100\mu F$ bypass capacitor will be added as recommend my the SIM800L data sheet[2]. The complet e schematic for the GSM module can be seen in the overall schmatic.

2.1.7 Real Time Clock

Input: $+5V$ from the power supply
——— I2C clock from microcontroller
——— I2C data from microcontroller
Output: I2C data to microcontroller

The real time clock will be used to provide a the current to the microcontroller. It does this by keeping tack of the time and having it's own coin cell battery so that it's always running. All test result will include the farmer's unique identifier as well as a time stamp provided by this module.

The device will use the DS3231SN I2C-Integrated RTC/TCXO/Crystal from Maximum Integrated[3]. The DS3231SN communicates using the I2C protocol (SCL and SDA pins) which is supported by our ATmega microcontroller. A bypass capacitor will be placed across VCC and GND as well as pull up resistors on the SCL and SDA lines. A +3v coin cell battery is attached to pin 14 and ground on the DS3231SN as specified in the data sheet[3]. The complete schematic for the real time clock module can be seen in the figure below.

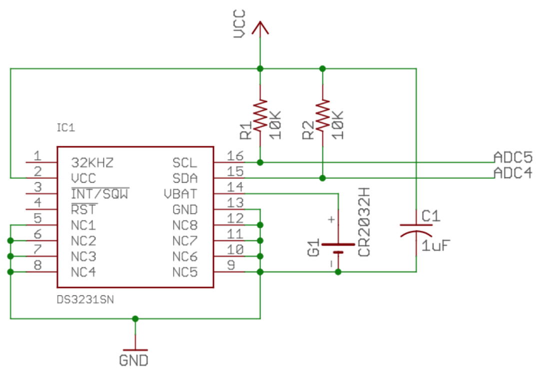

Figure 5: Schematic for Temperature and Humidity Sensing Module

2.1.8 SD Card Reader / Writer

Input: $+5V$ from the power supply
——— $+5V$ CLK signal from microcontroller
——— $+5V$ data in from microcontroller
——— $+5V$ chip select from microcontroller
Output: $+5V$ data out to microcontroller
The SD card will store 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. As the SD card has a finite amount of storage only the most resent results will be stored.

The device will use the

Pin	Function
1	CS - Chip Select
2	CD - Chip Detect
3	DI - Data In
4	DO - Data Out
5	CLK - Clock
6	GND
7	VCC - $+3V$
8	VCC - $+5V$

Table 4: Pin out for the DHT22.

2.1.9 Temperature and Humidity Sensing

Input: $+5V$ from power supply
——— single wire data from microcontroller
Output: single wire data to microcontroller
The DHT22 digital temperature and humidity sensor will be fixed within the insulated quart cup filled a sample of corn. A lid will be placed on the cup and the microcontroller will then wait a minute for the sample to stabilize before instructing the sensor to take a measurement. The sensor will take a measurement and communicate the results with the microcontroller. Below is the pin out for the DHT22.

Pin	Function
1	VDD - Power +5V
2	Data - Signal
3	GND
4	GND

Table 5: Pin out for the DHT22.

A $100nF$ bypass capacitor will be 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 will be placed between Data and VDD. The pull up resistor will prevent 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.

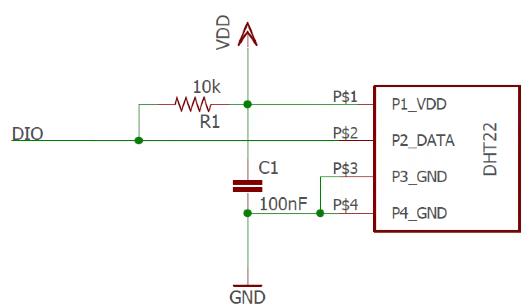

Figure 6: Schematic for Temperature and Humidity Sensing Module

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.

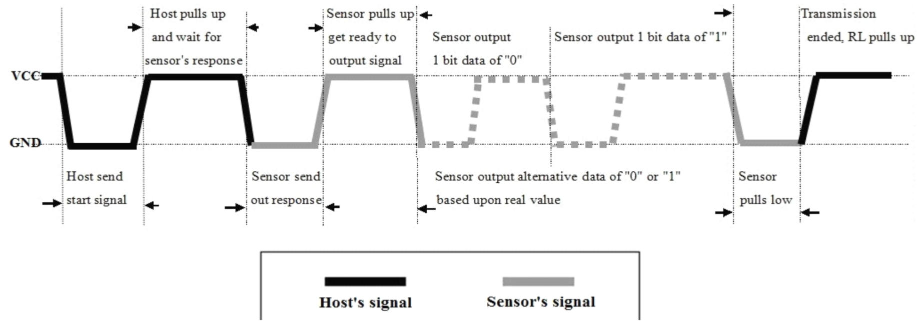

Figure 7: DHT22 single-bus communication protocol. [4]

2.1.10 Weight Measurement

Input: $+5V$ from power supply
Output: Four Analog values to microcontroller
In order to measure the weight of the sample, as well as material from the different sieved samples, a load cell will be used. It will be placed at the bottom of the freely moving insulated quart cup. The microcontroller will then read the weight via one of its analog to digital converters.

% Moisture in Corn	Test weight (lbs) of corn needed to equal one bushel
14	55.02
15	55.67
15.5	56.00
16	56.33
17	57.01
18	57.71

Table 6: Test weight (lbs) of corn needed to equal one bushel of No. 2 Yellow corn.[5]

We will be taking several weights on the corn sample: test weight of a quart cup of corn, the top level of sieve stack (whole kernels), middle level (fragments of kernels) and bottom level (other matter). In order to provide accurate data our for sensitive resistor needs to meet the accuracy standard for each of the measurements.

According to Integrated Crop Management[5] the typical weight of No. 2 Yellow corn is 55-57 pounds per bushel. This is also illustrated in the above table showing the relation between test weight and moisture content. Also mentioned within the article is that test weights can range from 45 to over 60 pounds per bushel.

$$\frac{56lbs/bu}{32quarts/bu} * 4.448N/lbs = 7.784N/quart$$

$$\frac{45lbs/bu}{32quarts/bu} * 4.448N/lbs = 6.255N/quart$$

$$\frac{60lbs/bu}{32quarts/bu} * 4.448N/lbs = 8.340N/quart$$

Given the above calculations the force sensor will need to measure within the range of 6.255N - 8.340N with an accuracy of at least .5% or ±4.75grams.

The total weight of the corn, broken kernels, and dirt is expected to be 700-900g, while the weight of the broken kernels and dirt is expected to be 3-10% of the total weight. Thus, strain gauge load cells of 100g and 1kg capacities will be used. Strain gauges are used to measure the change in resistance caused by an applied force, such that the force causes minute distortions of the wires of the gauge. Because such resistance changes are so small, an amplification circuit is necessary. A Wheatstone bridge is used such that the output voltage is measured and can be used to calculate the applied force.

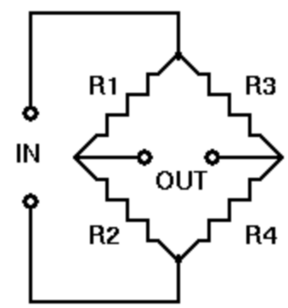

Figure 8: Wheatstone bridge amplifier for load sensor

Where the output voltage of the Wheatstone bridge is Vf= 2.5+G*k*F, where G is the gauge factor, k is the sensitivity, and and F is the applied force. The Detailed schematic can be seen in the overall schematic.

Calibration of the system is made such that there is a linear relationship between the applied force and the measured voltage. For example, a known weight of 300g will be applied to the 1kg model and the potentiometer turned until an output voltage of 3V is reached. Varying known weights (0g through 1kg at 150g intervals) are then applied and the output voltage measured to create data points. The line of best fit represent Vf=V0+G*W, where V0 is the output at zero load, G is the circuit sensitivity (slope), and W is the load weight.

2.2 Schematics of Overall System

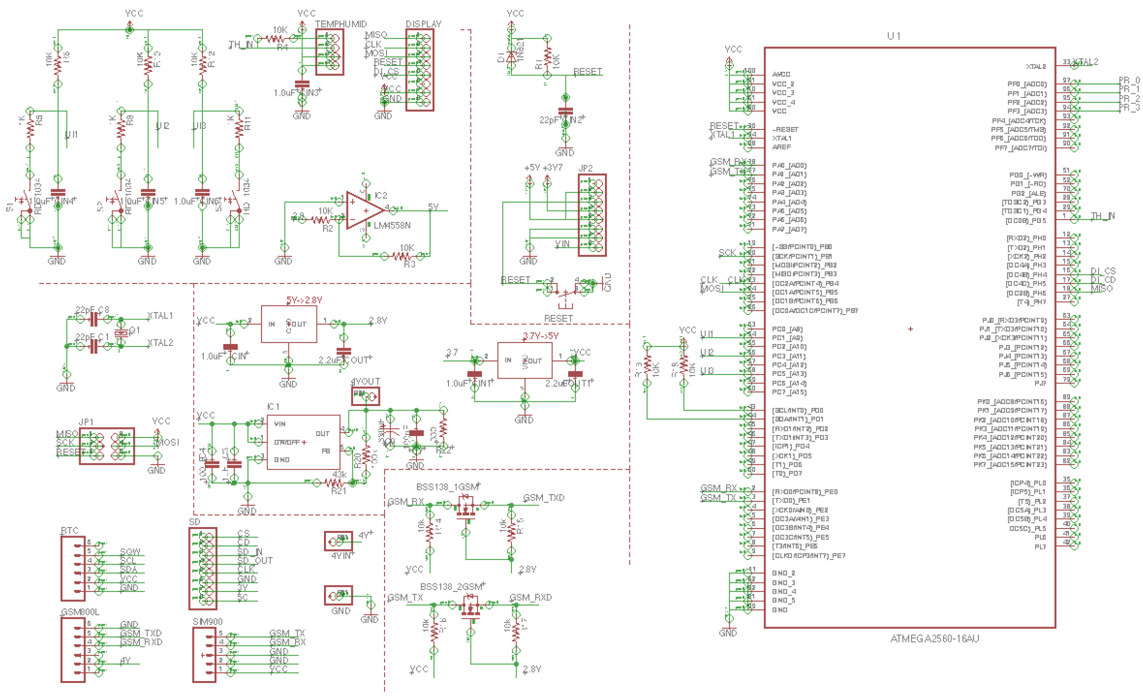

Figure 9: Overall Schematic for our Project.

2.3 Software Flowchart

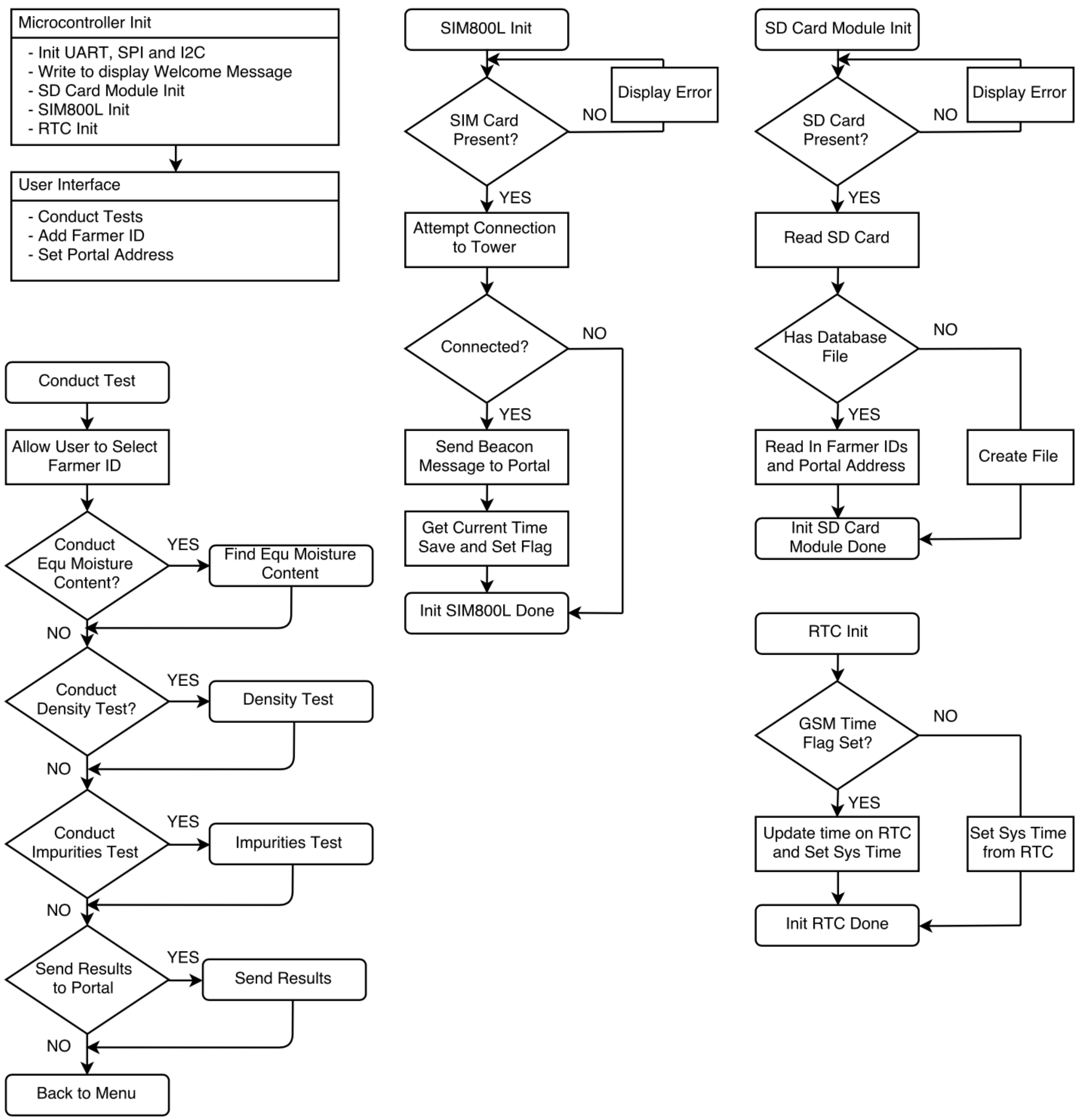

Figure 10: Full Device Flow Chart

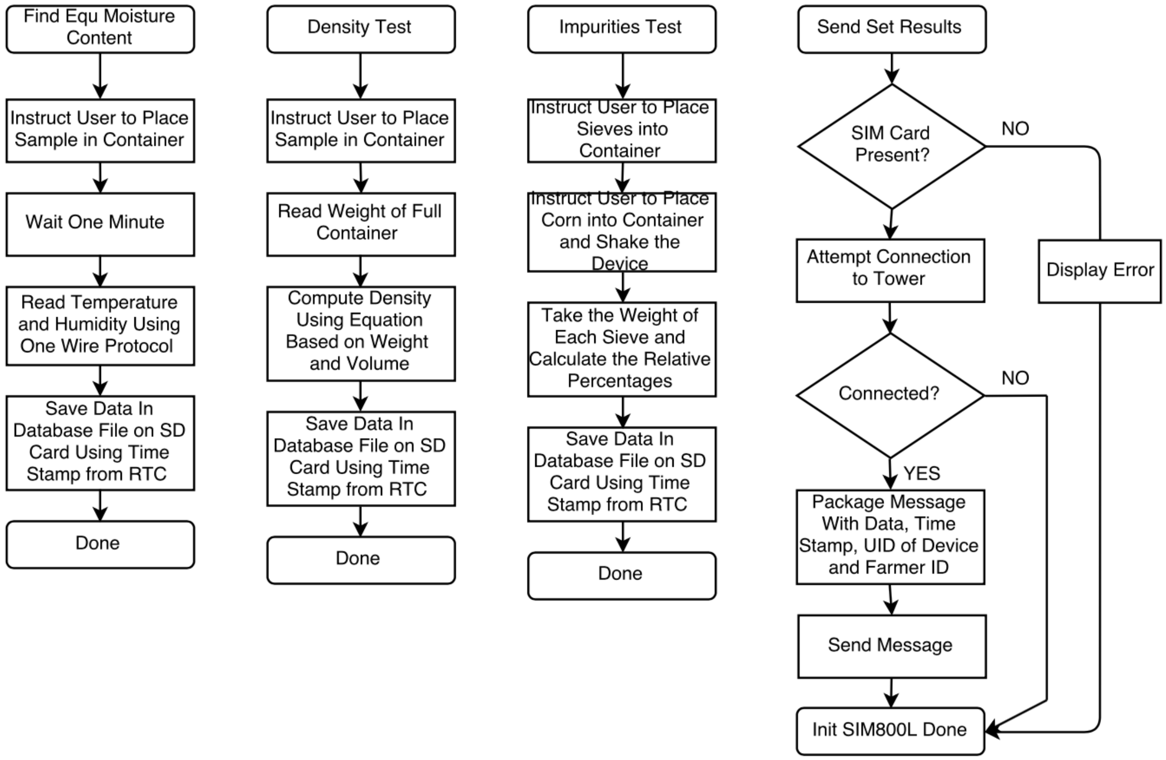

Figure 11: Detailed Sub-modules for Full Device Flow Chart

2.4 Simulations and Calculations

Calculation: Load sensor

Our force sensitive resistor (FSR) is explained. The way that it worked, was that when the resistance of the FSR decreased, the total resistance of the FSR and the pulldown resistor decreased. This causes the current flowing through both resistors to increase which in turn causes the voltage across the fixed 10K resistor, as well as the node connected to pin PC0 on the microcontroller, to increase.

The formula can be seen in the equation below which is based on the voltage divider rule:

$VPC0 = VCC(RR + FSR)$

Where VCC is the supply voltage of the circuit (5V), R is the 10K Ohm pull down resistor, and FSR is the Force Sensitive Resistor, where resistance is a function of force (newtons), given by: $FSR = 7.138 * pressure - .0765$ Example calculation for FSR resistance and output voltage with an input of 10N of force shown below: $FSR = 7.138 * (10N) - .07651k$ $VPC0 = 5V(10k10k + 1k)4.55V$

Note: we chose a 10k pull down resistor due to its wide availability and resistance value close to the range of values that the FSR will be between.

Simulation: Moisture Content

The plot below is from experimental data gathered from [2]. It relates the corn moisture and weight of corn needed to create a bushel of corn. This data is helpful as moisture varies with temperature and humidity, the number of corn kernels to create one bushel (a unit of selling) increases with moisture. Since we will be calculating moisture from our humidity and temperature sensors, and the end goal for our product is so that farmers get adequate prices for their corn, we decided to add the below plot.

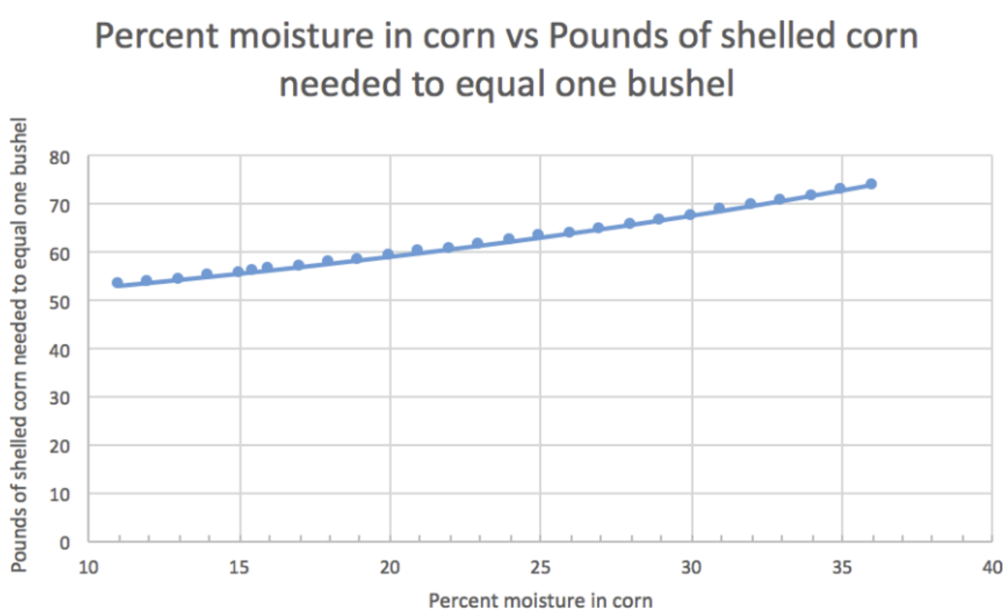

Figure 12: Plot from corn data

From the graph it is shown that with increasing percent coin moisture, the pounds of corn required to sell one bushel increase dramatically. Farmers may be undervaluing or overvaluing their corn if their percent moisture of corn is different from expected.

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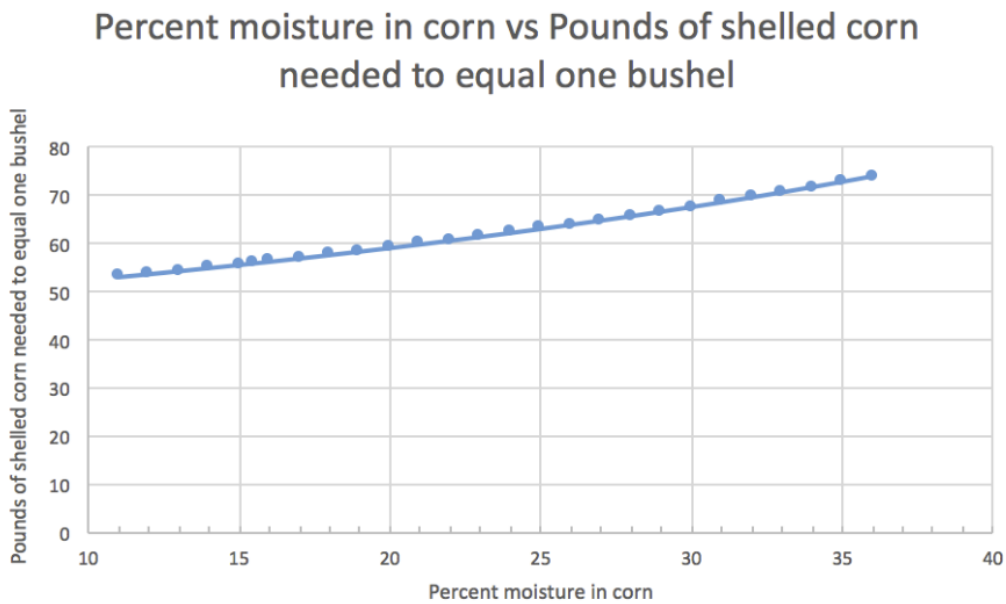

Figure 13: Plot from corn data

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3 Design Verification

3.1 Requirements and Verification

Table 7: System Requirements and Verifications

Requirement	Verification	Point Value
Lithium Ion Battery 1. Battery shall store $3000mAh$ with a tolerance of $-300mAh$. 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 lithium ion battery charger. (b) Attach a 3Ω load (c) Measure the current and voltage a 5 minute intervals (d) Stop test when the battery's voltage is less than $3.2V$ (e) Find the area under the IV curve generated by the test and ensure it is at least $2700mAh$. 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 $+3.7V$	10 points

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Table 7 – continued from previous page

Requirement	Verification	Point Value
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 diffrent modules (b) Ensure that the battery can supply enough current to suport the loads	10 points
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.	2 points

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Table 7 – continued from previous page

Requirement	Verification	Point Value
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	1 points
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	5 points
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	3 points

Continued on next page

Table 7 – continued from previous page

Requirement	Verification	Point Value
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	3 points
Temperature Measurment 1. Shall measure instantaneous temperature between 30 and 86 degrees C 2. Shall measure temperature within .5 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	3 points

Continued on next page

Table 7 – continued from previous page

<table>
<tr><th>Requirement</th><th>Verification</th><th>Point Value</th></tr>
<tr><td>Humidity Measurment
1. Shall measure relative percent humidity between 50 and 85
2. Shall measure humidity within .5% of actual relative percent humidity</td><td>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</td><td>3 points</td></tr>
</table>

Continued on next page

Table 7 – continued from previous page

Requirement	Verification	Point Value
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 (c) Ensure that the weight measured by the device is $\pm 4.75g$ 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 (c) Ensure that the weight measured by the device is $\pm .1g$ 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 (c) Ensure that the weight measured by the device is $\pm .01g$	5 points
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 $+4.8V$ - $+5V$	**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	1 points

Continued on next page

Table 7 – continued from previous page

<table>
<tr><th>Requirement</th><th>Verification</th><th>Point Value</th></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 $+4.8V$ - $+5V$</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 $4.8V$ - $5V$</td><td>1 points</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>1 points</td></tr>
<tr><td>Controller: SPI
1. Shall have an output clock rate greater than 100 kHz</td><td>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</td><td>2 points</td></tr>
</table>

3.2 Tolerance Analysis

Critical Component: Impurity Measurement System

Acceptable Tolerance: Current is limited to $1mA/cm^2$ of applied force, or $31.54mA$ for the surface of the used pressure sensor. To meet this tolerance, a measuring resistance must be chosen. This measuring resistance is connected to ground, with the positive terminal of an op-amp connected between Rm and the FSR and the negative terminal connect to the op-amp output. Thus, Rm limits current and controls the voltage sensitivity according to $VOUT = (V+)/[1 + RFSR/RM]$.

Test Procedure: Replicate the circuit shown in the FSR integration guide and use a digital multimeter to measure the current flowing into the FSR.

Presentation of Results: Results will be reported in the form of a table of data with annotations.

Critical Component: Load Sensor

Accuracy of load cells:

RO For 100g: 0.7mV/V 1kg: 1.5mV/V

resolution = [resolution of device reading the voltage]/[rated output*DC excitation voltage]

DC excitation voltage is 5V

Res of 100g is 0.029g Res of 1000g is 0.133g - assuming the resolution of the device is 1mV

3.3 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 attached to this document.

3.4 Ethical Issues

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.

4 Cost and Schedule

4.1 Cost Analysis

4.1.1 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
CR1220 Battery Holder	1	MPD	Digi-Key	$0.88	$0.88
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
Load Cell Weighing Sensor	1	VPG Transducers	Xcell	$8.49	$8.49
Total					$125.45

Table 8: Cost of parts

4.1.2 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 9: Cost of Labor

4.2 Schedule

Focus	Date	Member(s)
Prepare Mock-Up	9/19	Joan Brown
Finalize required measurements for corn quality	9/19	Kevin Villanueva
Finalized choice for weight measurment	9/26	Kevin Villanueva
Chose appropriate GSM module	9/26	Adam long
Create driving circuitry for GSM module	10/02	Adam long
Design circuitry for RTC	10/02	Adam Long
Determine requirements for temp and humidity sensing	10/02	Adam Long
Create circuitry for temp and humidity sensor	10/02	Kevin Villanueva
Chose a display and user input buttons	10/02	Joan Brown
Select microcontroller	10/02	Adam Long
Finalize full system design	10/07	All
Order parts for the design	10/07	Joan Brown
Create CAD model for housing and sieves	10/07	Kevin Villanueva
Write software for basic GSM comunication	10/07	Adam Long
Design PCB	10/14	Kevin Villanueva
Write software for communication with temp/humidity sensor	10/14	Adam Long
Write and test load sensor software	10/14	Joan Brown
Test GSM communication software	10/14	Adam and Joan
PCB Take 2	10/21	Kevin Villanueva
Write software for Displaying the user interface	10/21	Adam Long
Test the temp/humidity sensing	10/21	Joan Brown
Write and integrate software for RTC and SD Card reader /writer	10/26	Adam Long
Integrate physical buttons and test UI	10/26	Joan Brown
Finalize PCB Design	10/26	Kevin Villanueva
Order PCB	10/26	Kevin Villanueva
Finalize CAD drawing of enclosure	11/04	Kevin Villanueva
3D Print Enclosure	11/04	Joan Brown
Integrate all software and components	11/04	Adam and Joan
Test all components of the device	11/10	All
Walk through R&V	11/10	All
Prepare Mock Demo	11/17	Kevin Villanueva
Start Final Paper	11/17	Adam and Joan
Integrate system in enclosure and finalize demo	11/25	Kevin Villanueva
Finalize Demo	11/25	Adam Long
Continue Paper	11/25	Joan Brown
Finalize Mock Presentation	11/30	Kevin Villanueva
Continue Final Paper	11/30	Adam Long
Finalize Presentation	12/04	All
Finalize Paper	12/06	All

Table 10: Schedule for project

References

[1] "128 x 64 Dot Matrix OLED/PLED Segment/Common Driver with Controller," Datasheet, SOLOMON SYSTECH, 2008. [Online]. Available: https://cdn-shop.adafruit.com/datasheets/SSD1306.pdf

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Safe Practice for Lead Acid and Lithium Batteries

Document Prepared By: Spring 2016 Course Staff
ECE 445: Senior Design Project Laboratory
Last Revised: April 13, 2016

I. Introduction

Hello senior designers! If you are reading this document, you are probably planning on designing a project using some form of battery! Batteries are a great way to store energy for later use in portable devices or backup systems. One often overlooked problem with batteries is that they are dangerous. Additionally, different batteries are dangerous for different reasons. In this document, we will challenge students to justify why they need a battery, introduce dangers inherent to all batteries, explain the dangers that are unique to two common types of batteries (lead-acid batteries and lithium batteries), present some suggestions for charging batteries, and end with a discussion of the ECE 445 procedures for minimizing the risks of projects involving batteries.

II. Do You Need a Battery?

Due to the danger, the course staff would like to stress that students should ***avoid batteries if at all possible and use the very nice voltage supplies that are provided at every single lab bench***.

III. Dangers Inherent to all Batteries

To prevent runaway current, your batteries must always be stored in a secure location with the terminals covered by insulating material to ensure that there is absolutely no way that a short circuit can present itself. Both of these battery chemistries are capable of delivering unbelievably high currents ($>$5000A) and will overheat and possibly ignite (lead acid via ignition of evaporating hydrogen and lithium via decomposing cathode and eventual exposure to oxygen) if they become too hot. Additionally, proper ventilation should be allowed such that any gas can dissipate itself. If your circuit requires a battery, you must be able to demonstrate that your circuit will not have any conditions where a failure results in a short circuit.

IV. Unique Dangers of Lead Acid, SLA, Gel Mat, etc. Batteries

Lead acid batteries are the same types of batteries in your car. They are very high capacity and capable of outputting tremendous amounts of current at a reasonably low voltage. As the name implies, they are full of lead (bad) and acid (also bad). What's worse, the acid inside of a non-SLA or non-Gel Mat battery is in a liquid form and these batteries have valves to allow vapors to evaporate from the battery, meaning they pose a severe risk of spewing acid everywhere (VERY bad). For these reasons, if your project involves a lead-acid battery of any type, you will be *REQUIRED* to find the Material Safety Data Sheet (MSDS) and data sheet for your battery before you can acquire the battery and you must keep this documentation with you at all times in the laboratory. If possible, it is advised that students purchase a battery with protection against chemical spills (SLA is typically the most effective for student projects relating safety and cost) in order to minimize the risk of chemical leakage occurring.

V. Unique Dangers of Lithium-Ion, Lithium Iron Phosphate, etc. Batteries

Lithium batteries are the type of batteries found in your mobile phones and laptops. They are generally smaller and lighter than comparable capacity lead acid batteries, but they are also *substantially more flammable*. Unlike the lead acid battery where cell damage typically translates to reduced capacity, cell damage in a lithium battery translates to *a particularly nasty chemical fire*. Lithium Iron Phosphate batteries tend to be somewhat more fire resistant on account of different cathode material; however, they are still extremely flammable. For this reason, if you elect to use a lithium battery in any capacity, you will be required to complete additional fire safety and fire extinguisher training before proceeding with the course. Additionally, you will be required to incorporate some circuit to prevent your battery cell voltage from decaying below 3.0 $\frac{V}{cell}$ (2.5 $\frac{V}{cell}$ for $LiFePO_4$) or exceeding 4.2 $\frac{V}{cell}$ (3.65 $\frac{V}{cell}$ for $LiFePO_4$). Any charge or discharge tests must be performed while the battery is inside of one of the specially design lithium safety bags and any protection or charging circuits must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard. These procedures are in place in order to protect you, others, and the brand new ECEB from being reduced to a smoldering pile of ashes. ***IF YOUR BATTERY BEGINS TO SWELL, FEEL HOT OR MAKE FUNNY NOISES: disconnect the battery IMMEDIATELY and place it in a battery bag FAR AWAY FROM FLAMMABLE STUFF. You should then report the issue to your TA and a power-centric TA IMMEDIATELY either in person or via a phone CALL to dispose of the battery as soon as possible.***

Swollen Battery = Time Bomb

There are several ways to damage a lithium cell. They include:

- Over charge
- Over discharge
- Over current (charge or discharge)
- Excessive heat
- Internal or external short circuit
- Mechanical abuse

Always check the battery specifications before purchasing or using them!
To minimize the risk associated with lithium batteries, the following precautions should be followed:

- Written work instructions and checklists should be generated for testing procedures
- Remove jewelry that may accidentally short circuit the terminals
- All dented batteries should be disposed of immediately (Contact your TA AND Casey Smith (217)-300-3722; cjsmith0@illinois.edu))
- Cover all metal work surfaces with insulating material
- Batteries should be transported in non-conductive carrying trays
- Always ensure the the open circuit voltage is within the acceptable range for your battery

VI. Charging Lead-Acid Chemistry Batteries

Charging a lead-acid battery is a non-trivial task. The course staff strongly suggest that if you must build a charger, you use some kind of integrated circuit (IC) solution. Additionally, you must familiarize yourself with the battery's charge characteristic and maximum charging current. Lead-acid batteries are inherently safer than lithium chemistry batteries. While an overcharge or overdischarge will cause extreme damage to your battery, the damage will be limited to internal calcification of the plates, reducing your capacity to a fraction of what it originally was. For this reason, ***the course staff strongly suggests that you use a lead-acid type battery if your project requires a battery and is not weight or size sensitive***.

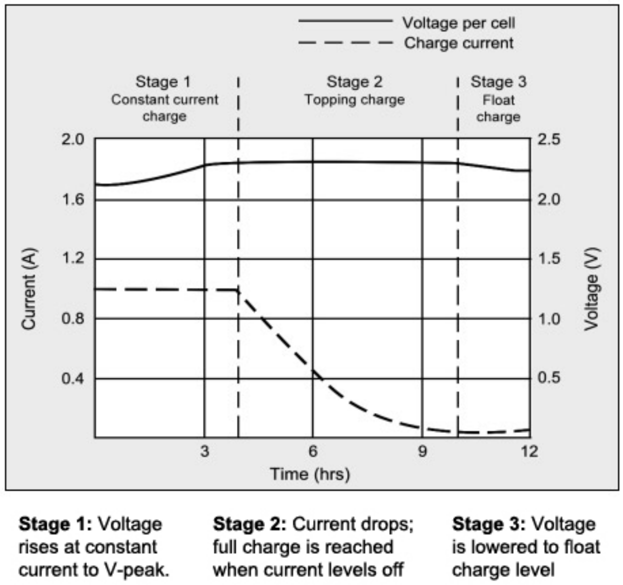

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

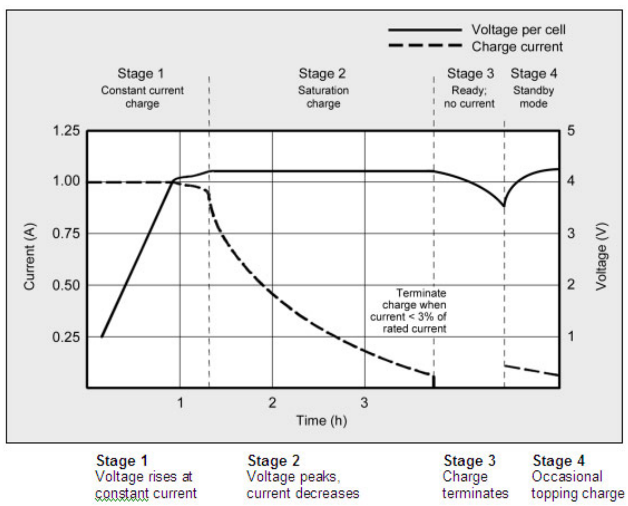

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

VII. Charging Lithium Batteries

Charging a lithium battery is also a non-trivial task. The course staff continue to strongly suggest that if you must build a charger, you use some kind of IC solution. You must also familiarize yourself with the charge characteristic and maximum charge current. *Any circuitry you design that involves a lithium battery must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard.* As an addition, it is important to note that batteries, which we can model as ideal voltage sources, charge with ideal current sources. Having an ideal current source and voltage source in parallel with the load is fine! Problems arise if we instead have two voltage sources in parallel. Any mismatch in the voltage will break KVL, which leads to a sudden rush of current from one source to the other in order to try and balance the voltages. This is a very unstable and hazardous methodology, therefore we always charge our batteries with current driving sources.

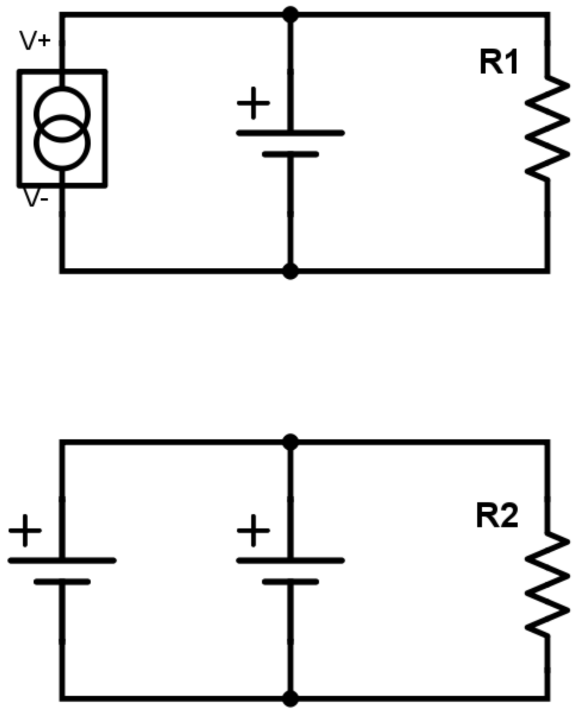

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

VIII. Charging Suggestions and Testing Requirements

If possible, we strongly suggest purchasing and incorporating a fully featured charging suite if your project requires batteries. Those must meet rigorous safety standards in order to be sold in the USA. If this is not possible for any reason (your project is cost sensitive because it is for the developing world, you are using solar panels to charge a battery, etc.), we strongly suggest using an integrated circuit solution. As a last resort, you may attempt to design your own charging circuit. Regardless of the route you choose to take, due to the inherent danger of charging these batteries, everything must be approved by your TA and one of the power-centric TAs before you even bring your design to the breadboard. Once your charging design has been approved, its functionality must be validated to your TA in a demonstration before the battery is connected to the system. Initial testing of the charging circuit with the battery connected should be done in the senior design lab with a TA present and proper protective and emergency equipment easily accessible.

TABLE I: A Short Table of Suggested Charging ICs. (Google is Your Friend)

Chemistry	**Suggestions**
1S-2S Lithium	MAX1551/5, LM317 (see datasheet)
3S+ Lithium	LT1505, LT1512, LM317 (see datasheet)
Lead Acid	LM317 (see datasheet), LTC4020, LT3652

IX. ECE 445 Procedures

1) Justify to the course staff that your project requires a battery.
2) Determine the appropriate chemistry for your project. Spill-resistant lead acid is vastly preferred.
3) Obtain safety documents:
   a) If you are using a lead-acid battery: obtain the MSDS and battery data sheet.
   b) If you are using a lithium battery: obtain additional fire safety and fire extinguisher training
4) In this order:
   a) If your project allows for it: search for a commercially available charger.
   b) Search for ICs that will perform the entire charge algorithm for you.
   c) AS A LAST RESORT: Design your own charging circuit.
5) Simulate your circuit in SPICE, even if you plan to use a charging IC.
6) Have your TA and a power-centric TA review and approve your design.
7) Build your design on a breadboard and validate functionality to your TA before attaching a battery.
8) If using a lithium battery, place it in one of the lithium battery bags whenever charging or discharging the battery.
9) To be done only in the senior design lab with a TA present and with protective and emergency equipment easily accessible: connect a battery to your circuit.
10) If your circuit behaves correctly, congratulations! You are done. If not, close is NOT close enough and you will have to return to Step 4.

If a problem occurs in your circuit:

1) Shut off power
2) Locate problem before power is restored
3) If circuit breaker is tripped, report to ece-eshop-repairs@illinois.edu to reset
4) If help is needed, contact Casey Smith ((217)-300-3722; cjsmith0@illinois.edu) or the electronics shop for assistance
5) If the situation is an emergency, **call 911**

A. Emergency Procedures

- If a lead acid battery spills: use the Battery Acid Spill Kit located in the back of the lab to clean the spill. Contact Casey Smith and your TA immediately.
- If a lithium battery explodes, **call 911** and evacuate the area.
- If a lithium battery ignites, **call 911** and extinguish it with either of the fire extinguishers located in the lab. They are both rated to extinguish electrical fires and should be at your bench whenever you are actively working with your batteries. Contact Casey Smith and your TA immediately.
- If a lithium battery swells, feels hot to the touch, or makes funny noises but does not ignite, keep the battery in the bag and contact Casey Smith and your TA immediately. The battery cannot be left unattended until it has been properly disposed of.

By signing below, you acknowledge that you have read this document and agree to follow the ECE 445 Course Staff's guidance regarding high capacity batteries and will complete all necessary safety training and adhere to the guidelines set forth in this document as well as additional guidelines as the course staff deems necessary.

JOAN BROWN 10/5/16

Print Name Date

10/5/16

Signature Date

TABLE II: History of Revision

Revision	**Date**	**Authors**	**Log**
A	3/19/2016	Lenz	Creation
B	3/28/2016	O'Kane	Additonal Information, General Revision
C	3/29/2016	SP16 Staff	Collaborative Revisions
D	4/7/2016	Salz	General Revision