MEMS Soil Moniter

DESIGN DOCUMENT

Team #5

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List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Table 1: Functional Requirements

Figure 1: Functional Prototype Requirements

Figure 2: Arduino Resistance Measurement

Figure 3: Adalogger Resistance Measurement

Figure 4: Resistance Measurement Prototype

CCEE: Construction, Civil and Environmental Engineering

ECpE: Electrical and Computer Engineering

DAQ: Data Acquisition System

MEMS: Micro-Electrical-Mechanical Systems

1 Introduction

1.1 Acknowledgement

This project is possible because of the time donated (directly and indirectly) by the students and professors involved.

1.2 Problem and Project Statement

The Civil, Construction and Environmental Engineering (CCEE) department at Iowa State wants to utilize MEMS sensors for soil monitoring underneath pavement. Currently, the CCEE department is using expensive, unreliable sensors for monitoring temperature and moisture content of soil underneath roadways. In addition, many of these sensors do not come with data acquisition modules. This leads to researchers spending hours in the field with their own measurement devices collecting data.

The CCEE department wants to utilize a MEMS sensor developed by the Electrical and Computer Engineering (ECpE) department at Iowa State. This sensor is inexpensive and precise, but does not come with a data acquisition system. This project will create a data acquisition system for the MEMS sensors designed by the ECpE department. The system will gather soil moisture and temperature throughout the course of a month, which will be interpreted by the CCEE researches in order to make decisions.

1.3 Operational Environment

The sensor and data acquisition module will be used outside in the harsh Iowa environment. The sensor will be underground and connected to the module through cables. The module will be at the surface to provide access to the SD card and the battery pack.

The sensor will need to have a low propensity to corrode since it will be in the ground for the entire life cycle. The data acquisition module must be able to last one month in an average climate; approximately one month in roughly 60 degrees Fahrenheit will be our "test climate."

1.4 Intended Users and Uses

The users of this product will be the researchers from CCEE who are monitoring the soil underneath roads or pavement. The researches will be gathering data such as temperature change and moisture content change and utilizing that data to make decisions for the Iowa Department of Transportation.

The product is intended to be used in the outdoors. It is to be used only for gathering temperature and moisture changes throughout the course of two to six weeks underneath pavement. This product could also be used to measure temperature or moisture of soil in other settings if needed.

1.5 Assumptions and Limitations

Assumptions

- There will be four independent channels for sensors
- The unit will have a minimum battery life of one month in average Iowa temperatures
- The unit will log data with an SD card
- The range of resistance measurements will be approximately 209-211 ohms
- Capacitance measurement will be in the range of 1-2 pF, with a resolution of 15 fF
- The cable connecting the sensor to the data acquisition module will be no longer than three feet
- 15 minute sampling period

Limitations

- Limitations (such as voltage input, max output, etc.) will be determined after we meet with the sensor developer.

1.6 Expected End Product and Deliverables

The end product will be a complete system that can measure resistance and capacitance via a MEMS sensor and store that information in 15 minute intervals for an entire month.

The MEMS sensor is provided to us by the CCEE department, and was developed by the ECpE department. This sensor is able to measure temperature and moisture content.

The output of the sensor will be collected by the team's data acquisition unit. The unit will store that information onto an SD card and be readily available by researchers when they need to access the data.

2. Specifications and Analysis

2.1 Proposed Design

The team has discussed with the customer and agreed upon the following requirements:

Requirement	Threshold
Independent Sensor Channels	Minimum 4
Operating Environment	-10 to 100 degrees Fahrenheit
Battery Life	1 month in fair temperature, 2 weeks minimum
Data Storage	Onboard SD card
Resistance measurement range	100-400 ohms
Resistance resolution	1 ohm
Capacitance measurement range	1 – 5 pF
Capacitance resolution	20fF
Max sensor cable length	3ft
Durability	Operate 1 month outdoors in all conditions
Sample rate	Nominal 1 sample / 15 mins
Data Format	CSV
Cost	No requirement

Table 1 Functional Requirements

To fulfil the above requirements, a prototype embedded hardware system has been developed which will meet all requirements in a lab environment. That is to say, the prototype is not required to meet any environmental or battery life requirements although the design is intended to show that the requirements are attainable with good mechanical design and better understanding of the battery requirements once the working prototype has been fully measured and characterized.

The functional prototype hardware will consist of the functional blocks shown in Table 1. A detailed description of each block is described below:

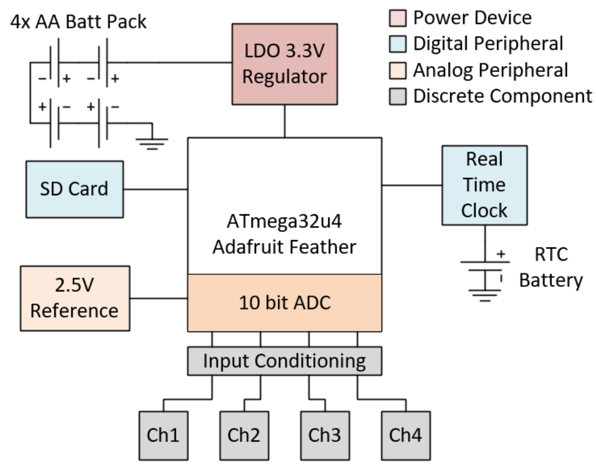

Figure 1 Functional Prototype Architecture

Power

The prototype will be powered by four AA cells in series for a total estimated capacity of 16.8Wh. This setup is not ideal given that a 3.3V LDO regulator is being used. At nominal battery voltage, regulation efficiency will be nearly 50%. This leaves great room for improvement on the final solution which can use a battery technology better suited to the application. The initial prototype requires an average of 20mA to operate the processor, real time clock, SD card, and ADC. Data acquisition of all four channels is estimated to take 10mS to complete. The microcontroller datasheet does not provide estimates of sleep current, so an estimated 100uA is used in the following calculation which includes regulator quiescent current, sleep current, and leakage. So with one sample every 15 minutes, the average draw is:

$$Average\ Draw = 100uA * \left(1 - \frac{4 * 10mS}{1hr}\right) + 20mA * \left(\frac{4 * 10mS}{1hr}\right) = \mathbf{100.2uA}$$

Clearly the battery life will be almost completely determined by the sleep current. In fact, increasing the time the processor runs from 10mS to 100mS on each sample only adds an additional 2uA average draw on the battery. Assuming a regulator efficiency of 50% and nominal battery capacity, the prototype should be able to attain a battery life of:

$$Optimal\ Battery\ Life = \frac{2.5Ah}{100.2uA} = 1039\ days\ of\ battery\ life$$

This assumes optimal software power reduction, negligible battery impedance and does not include any environmental effects. In real conditions, AA batteries are typically derated to as little as 25% of their nominal capacity. Even so, the above calculation shows that a one-month battery life across temperature is possible. The final product will also use a more efficient regulator which allows for a smaller battery.

Digital Peripherals

The functional prototype will make use of an Adafruit Feather shield which hosts a micro SD card slot as well as real time clock chip. The final product will implement these on the custom designed PCB but the Adafruit shield offers a convenient platform with which the team can obtain the same functionality in a larger, more expensive form factor. An 8 GB micro SD card will be onboard which will be able to store many months of data before being transferred to a PC. The real time clock will allow samples to be time stamped to do detailed analysis of collected data.

Analog Peripherals

An ATmega32u4 microcontroller has an onboard 10 bit ADC which will be used for the prototype. When paired with an external 0.1% 2.5V reference, resistor measurements with resolutions of less than 1 ohm are possible.

2.2 Design Analysis

As of writing, the design in Table 1 has been demonstrated on a breadboard with the exception of the following requirements:

1. Battery life requirements, no power reduction implemented
2. All environmental requirements, implemented on breadboard
3. Capacitance (moisture) measurement
4. No real time clock implemented

The prototype has been very successful in proving that the data collection and storage is feasible. Capacitance measurement is actively being worked on by the team and we are confident that we will be successful. In the event that ADC performance limits capacitance measurement the team has ordered an external 16 bit ADC which if needed can interface with the microcontroller and provide more resolution.

Each sensor channel will require some sort of conditioning to be measured by the ADC. Currently the prototype implements two temperature channels and two moisture channels. Temperature channels require a precision current source implemented with the reference and a high tolerance resistor. Moisture channels will require one high tolerance and high value resistor. The team is concerned that although precise measurements may be obtained in a lab environment, parasitic effects of sensor cables in moist soil will likely have detrimental effects on the moisture sensor. This will be examined closely once the functional prototype is fully assembled. In the event this is an issue, it's likely a small microcontroller will have to be placed near the sensor to eliminate parasitic effects. This microcontroller could also handle temperature measurements and digitally communicate the data to the microcontroller on the surface via a serial protocol such as I2C.

INSERT IMAGE OF PROTOTYPE

Additional characterization of the analog inputs will be required upon prototype assembly to fully understand the sensor resolution and how it may be affected by the environment of the application. Full characterization and calibration over temperature will alert the team to any accuracy issues over temperature. Should any temperature issues arise, we will either increase resolution such that the requirements are still met at extremes of temperature requirements or will negotiate with customer to relax accuracy requirements at extreme temperatures.

Proposed design strengths:

- Simple and scalable to larger/smaller applications
- Low power consumption
- Highly accurate temperature measurement

Design Weaknesses and unknowns:

- Moisture measurement performance
- Enclosure and weatherproofing
- Ability to attain low standby current draw

3 Testing and Implementation

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or a software library

Although the tooling is usually significantly different, the testing process is typically quite similar regardless of CprE, EE, or SE themed project:

1. Define the needed types of tests
2. Define the individual items to be tested
3. Define, design, and develop the actual test cases
4. Determine the anticipated test results for each test case 5. Perform the actual tests
6. Evaluate the actual test results
7. Make the necessary changes to the product being tested 8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you've determined.

3.1 Interface Specifications

There are plenty of software/hardware interfacing that must be done in order to test our project effectively. The largest issue is going to be verifying that our measurement methods are correct. As will be explained in the next section, we will be using LCR meters and Multimeters to verify that our testing methods are accurate.

Since we will be taking real-time measurements of resistance and capacitance, we need a way to visualize these readings. We have decided to store all of the data into a CSV file, then import it to a computer and view the data on excel. This will be the same interface used in our final project, but we will plot temperature and water content instead of resistance and capacitance.

We will be able to verify our project's temperature and resistance accuracy when we compare our plots completed on excel with the real temperature inside of the heat chamber. We will also compare our capacitance measurement accuracy a similar way.

3.2 Hardware and Software

Proper testing of our design prototype and solution will involve a variety of hardware and software. Most of the hardware is available through engineering labs in Coover Hall. We also have access to the necessary software as students at Iowa State through the workstations in the computer labs in Coover Hall. A humidity chamber could be used in the PCC lab in Town Engineering Building.

Hardware used for testing:

- Temperature Chamber
- Humidity Chamber
- Digital Multimeter
- Oscilloscope
- Power Supply
- Signal Generator
- LCR Meter

Software used for testing:

- Arduino IDE
- Excel
- National Instruments LabVIEW SignalExpress
- PSPICE (Multisim/Ultiboard)

Hardware Descriptions

INSERT IMAGE OF TEMPERATURE CHAMBER

The temperature chamber provides a controlled temperature environment to test electronic circuits and devices of concern under different temperature conditions. There are openings to the exterior world that can be insulated with a special foam and still provide enough room for cables to be connected to a multimeter.

INSERT IMAGE OF HUMIDITY CHAMBER

A humidity chamber will enable us to be able to characterize our capacitive moisture sensors by controlling the relative humidity of the environment they are in.

INSERT IMAGE OF MULTIMETER

The digital multimeter will be utilized to measure resistances, capacitances, voltages, and currents in our circuits. It will allow us to have a comparison for our data acquisition results and readings.

INSERT IMAGE OF OSCILLOSCOPE

An oscilloscope is a multifunction measurement tool that will allow us to monitor AC or DC signals and measure their frequency. This will allow us to confirm whether we are getting an expected output and can troubleshoot circuits in this way.

INSERT IMAGE OF POWER SUPPLY

Even though our project will not be connected to a portable DC power supply, it will be utilized in the lab to conveniently provide a desired voltage where we need to in our circuits.

INSERT IMAGE OF SIGNAL GENERATOR

A signal generator will be used to provide an excitation signal as an input to our circuits. We then will used the aforementioned oscilloscope to look at an output response and interpret data from the circuit.

INSERT IMAGE OF LCR METER

An LCR meter will be used to get very accurate readings of inductors and capacitors when we are testing our data acquisition system with known inductance and capacitance values.

Software Descriptions

INSERT ARDUINO PROGRAMMING ENVIRONMENT PICTURE

The Arduino IDE (Integrated Development Environment) is software that allows us to program and send a series of instructions to the Arduino board. Specifically, we are using an Arduino Feather Adalogger model that will be programmed via this programming environment.

INSERT GRAPH OR DATA FROM EXCEL

Excel is a very familiar datasheet program on the Windows operating system. We will be utilizing Excel to format data that will be collected and stored on an SD card.

INSERT NATIONAL INSTRUMENTS / LABVIEW / SIGNAL EXPRESS PICTURE

SignalExpress can be utilized to automate and take a series of electronics testbench measurements very quickly. The data can then be easily transferred to a datasheet software program like Excel.

INSERT MULTISIM ENVIRONMENT PICTURE

Multisim is a software package that contains other software that can be used to simulate a proposed circuit that has been drawn in a schematic view. In addition, Ultiboard is a software package within Multisim that can be used to design a PCB

3.3 FUNCTIONAL TESTING

Our system contains two different sub-systems that will need to be tested individually. Once we can confirm that our sub-systems are working, we can integrate them together into a top-level system. The sub-systems that need to be tested are as follows.

- Resistance Measurement Circuitry
- Capacitance Measurement Circuitry

Our resistance measurement circuitry is quite simple to test. We just measure a resistance value using our system, viewing the output in the Arduino IDE, and compare that to the resistance measured by a multimeter. If those two values match (within 1 ohm of resolution), then we can say that our resistance measurement circuit is acceptable. We can test our capacitance measurement circuitry the same way, except rather than verifying the results with a multimeter, we can use an LCR meter to obtain a more accurate result. If the two capacitance values match (within 20 fF of resolution), we can say that the capacitance measurement circuit is acceptable.

Once we have confirmed that our resistance (temperature) and capacitance (moisture) measurements are accurate, we can assemble our top-level system and verify that it is working. Our top level system consists of our data-logging unit hooked up to two temperature sensors and two moisture sensors. We need to confirm that it meets the requirements for accurately measuring temperature, measuring moisture content, and storing the data. These can be broken down into separate tests.

In order to confirm that our system can accurately measure temperature, we can use a temperature chamber available in the labs in Coover Hall. We must be able to accurately measure temperature between -10 and 100 degrees Fahrenheit. We can use the temperature chamber to sweep the temperature from -10 to 100 degrees Fahrenheit, then check the output of our datalogger to ensure our measurements are acceptable.

In order to confirm that our system can accurately measure moisture content, we can use a humidity chamber located in the PCC lab in Town Engineering Building. We can sweep the moisture content from 0 to 100%, then check the output of our datalogger to ensure our measurements are acceptable.

The data logger is the easiest part of our system to test. You can verify that it is operational by removing the SD card, plugging it into a computer, and checking to see if the temperature and moisture measurements were stored in a CSV file.

3.4 Non-Functional Testing

Our usability will be determined by allowing our advisor to test the project. The final project only needs to be simple and functional; there are no security needs necessary for our project.

3.5 Results

Our team has been testing the accuracy of the resistance and capacitance. The reason we are doing this is due to the requirements of MEMS sensor is to measure the temperature and moisture of the soil. Where resistor refers to the temperature sensor and capacitor refers to the moisture sensor. From now on, our team has successfully found a way to test on resistance accuracy.

Resistance test failure

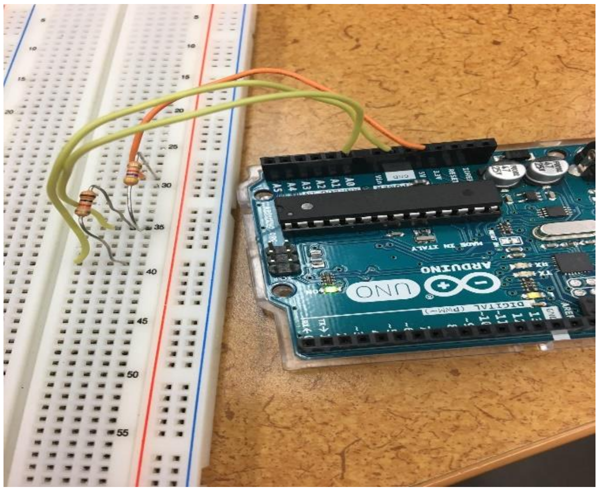

Figure 2: Arduino Resistance Measurement

We have tried the most basic circuit network to test the accuracy of the resistor using Arduino UNO. The resistor was measured to 4.63k Ω from a multimeter and Arduino was about 30 to 60 Ω off of the multimeter.

Output

```
R2: 4695.78
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4664.02
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4695.78
Vout: 0.70
R2: 4664.02
```

Resistance test success

Figure 2 below is the resistance measurement using Arduino IDE to view the output. Our team has successfully confirmed the resistance is accurate by using this method to measure.

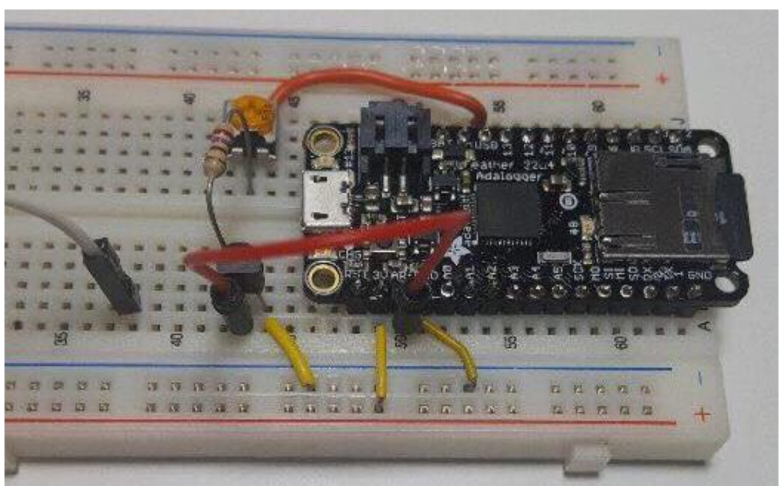

Figure 3: Adalogger Resistance Measurement

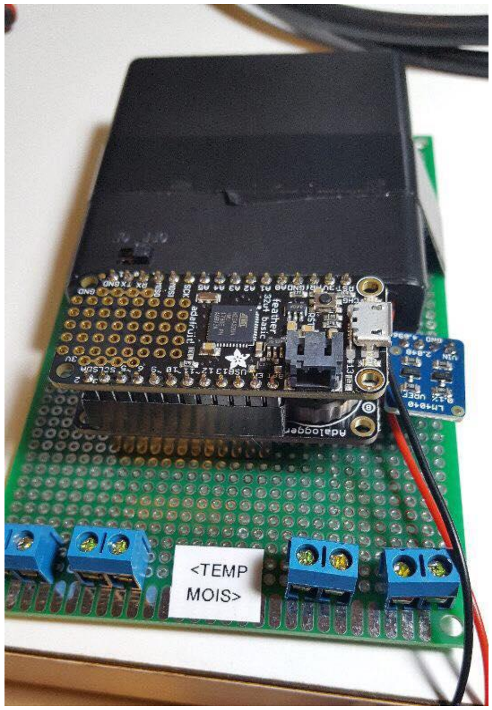

Figure 4: Resistance Measurement Prototype

Our team will start working on capacitance measurement and the sensor characterization. For capacitance measurement, we will use LRC meter to obtain a more accurate result instead of using a multimeter. Sensor characterization will be measured in Microelectronic Research Center

<u>Challenges</u>

- To make sure the sensor is well functioning at different temperature especially in lower temperature. From client's requirement, the sensor's battery can at least work for two weeks at low temperature.
- Measurement of capacitance (moisture).
- Method of cutting wafer to reduce the number of other sensors being destroyed.

4 Closing Material

4.1 Conclusion

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

Our team has a working prototype for resistance/temperature measurements, and we have commenced modeling and simulating a capacitance measurement circuit. Furthermore, we have followed leads on getting our sensors cut into distinct dies and will continue to pursue those leads.

We have split up into two groups – a group whose purpose is to continue developing our circuit measurement prototypes and a group that is working with professors to ensure we have functional sensors.

The end product will be a complete system that can measure resistance and capacitance via a MEMS sensor and store that information in 15 minute intervals for an entire month. The MEMS sensor is provided to us by the CCEE department, and was developed by the ECpE department. This sensor is able to measure temperature and moisture content.

The best plan of action will be to prototype the resistance and capacitance measurement circuits individually, then combine the two circuits into a complete unit. While one part of the team is working on that aspect, the other part of the team will be testing sensors and cutting them to make them usable and reliable. This should take the entire first semester, and the second semester will be refining and improving the accuracy of our prototype.

4.2 References

We have yet to reference any specific documents, this will fill up soon.

4.3 Appendices