MEMS Soil Monitor

PROJECT PLAN

Team #5

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Table of Contents

List of Figures

List of Definitions

CCEE: Construction, Civil and Environmental Engineering

ECpE: Electrical and Computer Engineering

DAQ: Data Acquisition System

MEMS: Micro-Electrical-Mechanical Systems

1 Introductory Material

1.1 Acknowledgement

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

1.2 Problem 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 Operating 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 Intended Uses (two paragraph +)

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 Other 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 Proposed Approach and Statement of Work

2.1 Objective of the Task

The objective of the project is to provide researchers the hardware and software tools to be able to reliably collect soil data with an instrument which is cheaper to scale for large experiments than available off the shelf tools. Researchers are always looking for less expensive, more reliable tools, and the goal is to assist them in creating a tool that will work for their specific use.

2.2 Functional Requirements

Requirements
Four Independent Sensor Channels
SD card data logging
Resistance Measurement Range 209-210 ohms
Capacitance Measurement Range 1-2 pF
Cable length max 3ft
CSV output
One month battery life in average climate
Minimum temperature resolution of 1 deg. C
Minimum capacitance measurement of 15fF
15 minute sample period

Figure 1: List of Functional Requirements

The requirements were provided by the Client. The requirements are not listed in any specific order, although some requirements are more important than others, such as battery life, resistance measurement, CSV output. As the project continues, requirements may be added, removed or changed.

2.3 Constraints Considerations

Feasibility of all functional requirements will be determined in the project prototyping phase. For all requirements which cannot be reasonably met on the prototype, the team will discuss with the customer the following solutions:

- Change requirement
- Remove requirement
- If dependent on other requirements, relax conflicting requirement

2.4 Previous Work And Literature

Micro-electro-mechanical (MEMS) sensors are devices that can detect and measure different parameters of interest by a combination of mechanical and electrical phenomena. For example, temperature, pressure (strain), moisture, etc. are all able to be measured by MEMS sensors. MEMS sensors take advantage of the material properties they are made of by generating a signal (resistance, voltage, capacitance, etc.), and this signal can be measured and used to get the desired parameter to be measured if one knows how the signal is proportionally related to the parameter. MEMS sensors are commercially available and can be used in many different applications. One specific application is structural health monitoring of civil engineering projects according to a two-volume report titled *Development of a Wireless MEMS Multifunction Sensor System and Field Demonstration of Embedded Sensors for Monitoring Concrete Pavements* written by Ceylan et al.

In the report by Ceylan et al., structural health monitoring (SHM) is an important application for MEMS sensors to be utilized in. MEMS sensors can be embedded in concrete in different civil engineering projects such as bridges and highways to monitor properties of the pavement. Important properties to measure include strain, temperature, and moisture content of the concrete in these structures. By monitoring these important properties, the appropriate governing body could perform preventative maintenance of roads and bridges to appropriate locations before major damage to the pavement structures shut them down for an extended amount of time. According to Hugo and Epps Martin, traditional SHM methods have not utilized MEMS sensors but rather “full-scale test tracks instrumented with a large number of sensors such as strain gages, pressure cells, displacement gauges, subgrade moisture sensors, etc.” (qtd. in Ceylan).

A specific goal mentioned in the report by Ceylan et al. was to field-test and evaluate commercial MEMS sensors and wireless sensors based on radio frequency identification technology (RFID). This was done on a small section of US 30 highway near Ames, IA, being repaved in May 2013. Sensors were installed within the roadway before it was repaved to measure moisture, temperature, and strain of the pavement. Data was obtained from these sensors over the course of about a year from May 2014, 2013, until April 1, 2014. Data was collected a couple of months before opening to traffic, during the summer months, and the winter months. Reliability of the sensors to last for an extended amount of time was a major concern considering the harsh environment of the concrete and climate of Iowa. Of the 27 total sensors installed at the beginning of the project, only 5 total sensors remained on the last day of evaluation in April. Speaking with one of the researchers and authors of the report, Shuo Yang, he emphasized the importance of sensors needing to be reliable in harsh environmental conditions. He also said that the time of installation, per-unit cost of sensors (some in the order of hundreds of dollars), and the cost of data loggers (also in the order of hundreds of dollars) were drawbacks.

The customer has used commercially available data acquisition systems in the past. None of the tested products have been viable for the customer’s application. Below is a brief list of the specific issues with several of the systems previously tested:

- ECH2O Datalogger: Public pricing not available
  - 5 channels (sensors not included)
  - 1-3 year battery life depending on sample rate
  - +/- 1 degrees celsius
  - +/- 3% moisture content

- Sensiorion EK-H4: $388
  - 4 channels of temp and humidity sensors
  - +/- 3% relative humidity
  - +/- 0.4 degrees celsius

2.5 Proposed Design

The core of the system we are designing will be an Arduino Uno. It will log our resistance and capacitance measurements and store them in a .csv file format. There are more than enough analog input pins on the Arduino UNO to take all of our measurements. The challenging part of this project will be measuring resistance and capacitance with a high enough resolution.

The output of the temperature sensor will only vary by a few ohms over a wide temperature range. This makes it very challenging to accurately measure temperature. One way we could accurately measure the resistance is by using a wheatstone bridge. The initial prototype will use several methods of measuring paired with averaging. The most accurate measurement method will be chosen for the final product.

The output of the moisture sensor will only vary by a few picofarads over a wide moisture range. This will also be very challenging to measure. One potential solution for measuring capacitance is setting up an RC circuit using a known resistor value and the moisture sensor as the capacitor. If you apply a voltage to the circuit, you can measure the time it takes the voltage across the capacitor to go high. Using this time, we can calculate the capacitance using the relationship 0.632 * rise time = resistance * capacitance.

It is expected that the hardware limitations of the Arduino will not allow the full requirements to be met, but will show that with a higher resolution ADC, higher tolerance voltage reference, and good analog design practices the full requirements can be met.

2.6 Technology Considerations

This project involves embedded hardware design and is limited to the performance of commercially available microcontrollers, ADCs, and other electrical components. It has been identified by the team that the resolution required for the project is at the edge of what is possible using readily available hardware.

Furthermore, the development phase of the project will be completed using an Arduino development board which will likely not be able to achieve the required resolution for all requirements. The team will determine as early as possible if requirements are reasonably achievable early in the project and negotiate changes with the customer as needed.

2.7 Safety Considerations

Device will be deployed along roadways and left in remote areas for long durations. Although no safety requirements have been imposed by the customer, the team intends the final product to be low-profile but highly visible as to not be a safety concern to vehicles or equipment when deployed in the field.

2.8 Task Approach

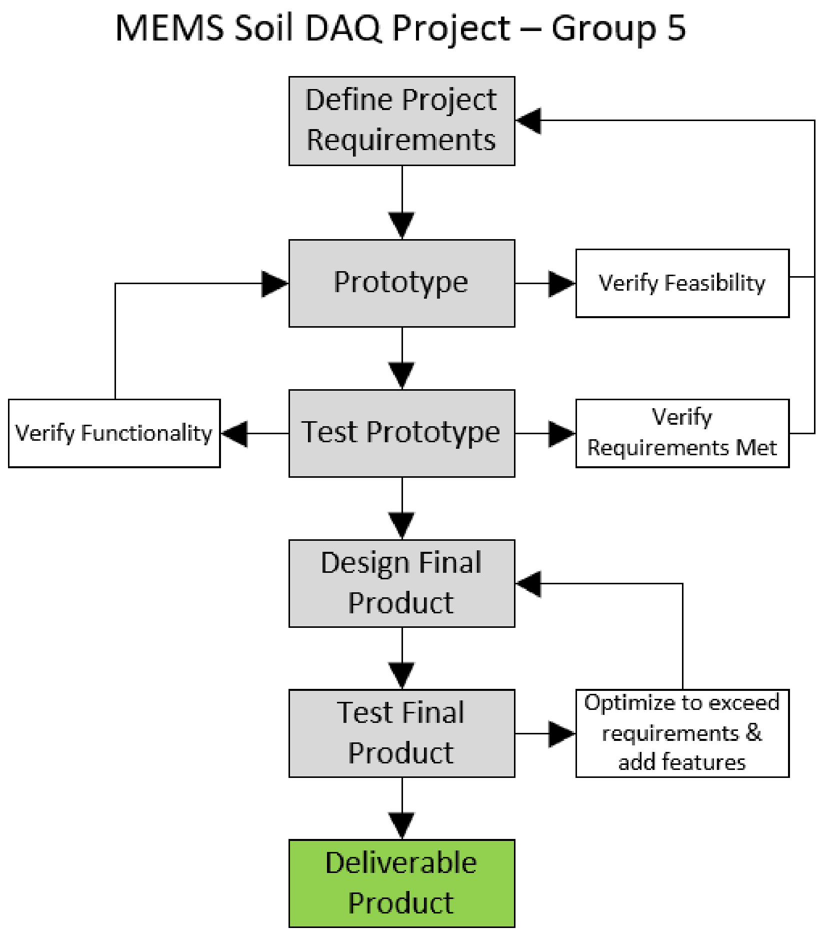

Figure 2: Project Task Approach

2.9 Possible Risks And Risk Management

The team has identified the following aspects of the project as the most prone to add project risk:

- Required resistance resolution of 1 ohm across all temp and environmental conditions
- Required capacitance resolution of 100fF across all temp and environmental conditions

In order to manage this risk, the team will establish early on if the performance the customer requested is feasible. Particularly the capacitance resolution is of concern due to the parasitic capacitance of the long sensor leads. It is likely that calibration will have to occur in order to minimize the effects of parasitics. The customer is aware of this risk and understands that the resolution requested is outside the ability of common off the shelf data acquisition equipment.

2.10 Project Proposed Milestones and Evaluation Criteria

The following are major project milestones and associated criteria for completion:

1. Complete requirements
    a. All information needed from customer acquired to fully understand application and what a successful final product looks like
2. Functional Prototype
    a. Prototype fulfills basic functionality of final project in lab environment
3. Prototype Testing
    a. All requirements met or shown to be feasible
4. Final Design
    a. All requirements met in lab environment
5. Deliverable Product
    a. All requirements met and tested across range of intended applications and in the worst conditions required

2.11 Project Tracking Procedures

Team members track all technical progress on the project using a shared Google Drive and a standard template from which weekly reports are generated and delivered to the customer.

2.12 Expected Results and Validation

High level testing will include testing by the team, and at later stages by the customer, to verify that operation of the product is intuitive. The final product should be easily operated with the reference of a user manual provided by the designers. A successful product will not only meet all functional requirements but will not require any additional expertise outside of the rHigh level testing will include testing by the team, and at later stages by the customer, to verify that operation of the product is intuitive. The final product should be easily operated with the reference of a user manual provided by the designers. A successful product will not only meet all functional requirements but will not require any additional expertise outside of the researchers application of the product. The described usability will be validated by the customer and any non-intuitive steps simplified or addressed thoroughly in the provided user manual.

2.13 Test Plan

Each phase of the project will test in a different manner to verify performance and reliability is acceptable.

Project Phase	***Testing Requirement***
Prototype	Lab testing only using discrete resistors and capacitors as replacement for actual sensors. Verify all requirements achievable and reasonable.
First Revision	Meet and/or exceed all functional requirements in a lab setting and mild conditions of final application.
Deliverable Product	Meet and/or exceed all functional requirements in the worst conditions the device will encounter. Minimum 1 month test.

Figure 3: Test Plan Table

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

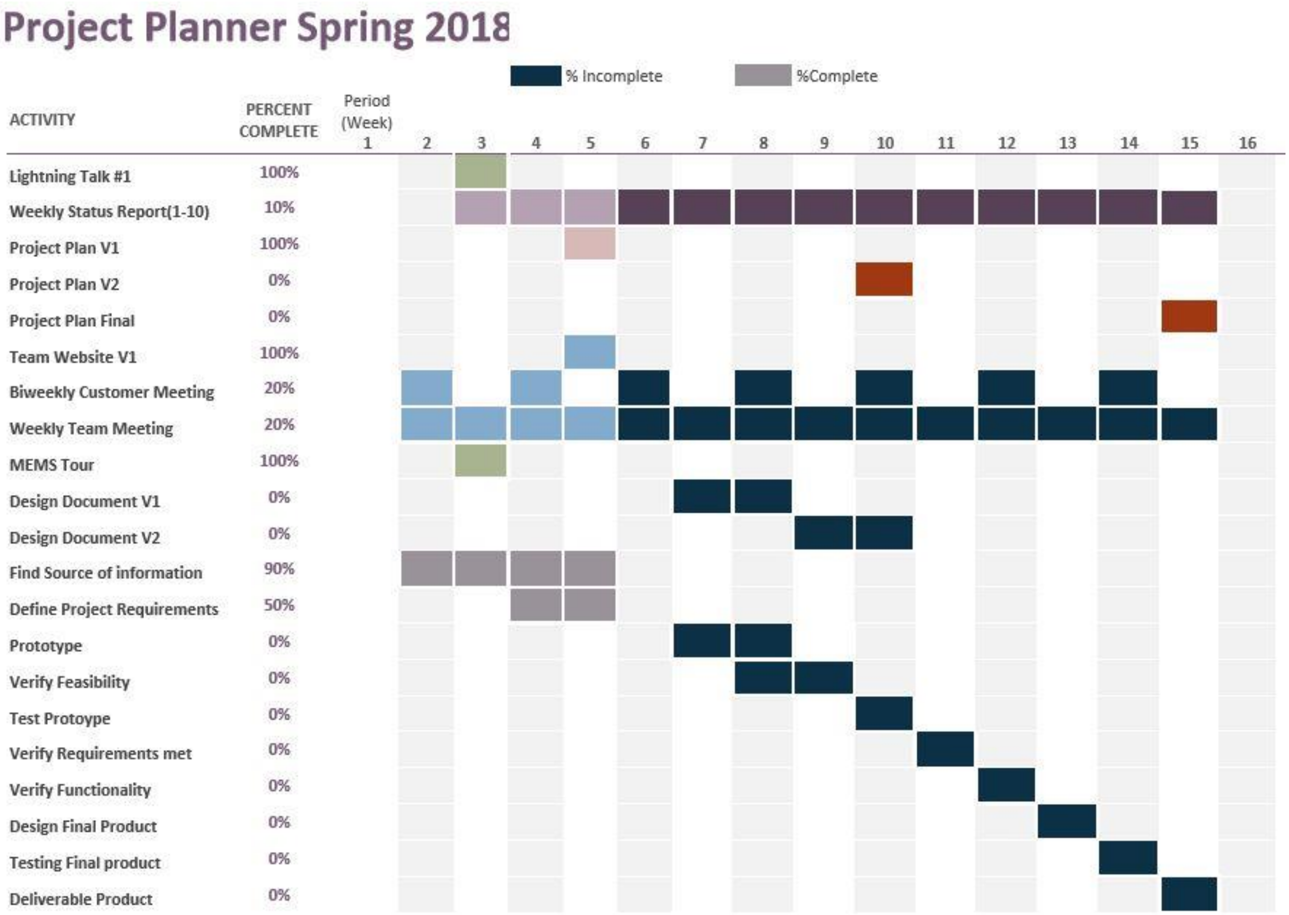

Figure 4: Project Timeline

3.2 Feasibility Assessment

The feasibility of this project is very high. There are numerous factors that affect feasibility of this project including time and schedule, cost, complexity, and resources. We have summarized each criterion below in Table W and why the criterion can be met.

Feasibility Criterion	Brief Description
Time and Schedule	We are given two semesters in the senior design curriculum to formulate a project plan and design plan to carry out to completion. This

	should allow plenty of time to develop a working prototype and solution.
Cost	We have been given a tentative discretionary budget of $500. The estimated cost of a prototype is no more than $100 so fulfilling this criterion should not be an issue.
Complexity	The complexity of the project is a broad category that encompasses the constraints and specifications our end-product is supposed to meet. With our skillsets and engineering knowledge, we believe we can satisfy the constraints and specifications of the project.
Resources	These include any material objects we need to make a functional prototype of the project. There are various labs at Iowa State that can be utilized to gain access to necessary testing equipment, software, etc. Anything we don't have access to can be purchased through ETG.

Figure 5: Feasibility Assessment Table

3.3 Personnel Effort Requirements

Our team is composed of five electrical engineering students at Iowa State University. We all have similar and complementing skillsets that we will use to complete project tasks. These tasks are summarized in Table X on page (insert page number) with the total number of hours needed to do each task exceptionally well. Please note that the hours listed in the table are for both semesters we students are in the senior design curriculum at Iowa State University. The estimated times were assuming two 14-week semesters of work with about 10 hours of availability each week for each student to work on the project. This means 1400 discretionary hours would be available. However, we students have other time commitments and won't always have the same availability each week, so we cut that estimate in half to try and account for other time commitments.

Personnel Hours Estimate	
Item	**Amount (hrs)**
Design and Simulation	50.00
Prototyping and Testing	150.00
PCB Design (Schematic and Layout)	100.00
PCB Fabrication*	N/A
Soldering and Other Assembly	200.00
Overhead	200.00
Total	700.00
*Note: PCB Fabrication will be done by a third party vendor.	

Figure 6: Personnel Hours Estimation

3.4 Resource Requirements

To reach our end goal of creating a 4-channel data acquisition system prototype, we will need to buy necessary hardware we don't already have available. Table Y below shows various hardware items we anticipate using on this project. Full schematics of circuit designs are not currently available at this moment of writing, so quantity estimates were made along with an approximate average per unit price to get an approximate idea of the total cost of hardware. We anticipate a prototype for our data acquisition system to cost around $100.00 although this could change depending on various factors such as actual quantities of components used, size of the PCB, tolerance of components, etc. This approximate cost of a prototype is well below the tentative $500 discretionary budget constraint.

Hardware Expenses Estimate			
Item	**Qty**	**Average Unit Price ($)**	**Cost**
Arduino Microcontroller	1	30.00	30
Components			
Resistors	50	0.25	12.5
Capacitors	25	0.02	0.5
Op-Amps	6	0.50	3
Diodes	5	0.10	0.5
PCB	1	50.00	50
Total			**$96.50**

Figure 7: Estimated Financial Costs

This project will require software as well to design, simulate, and program our data acquisition system. We do not foresee any software costs since we already have access to appropriate software in computer labs on campus or can download any necessary software on our personal computers for free.

3.5 Financial Requirements

The financial requirements are pending. The resources for this project will come from the Senior Design budget first. If needed, the CCEE department will allow for funding throughout the project.

4 Closure Materials

4.1 Conclusion

Structural health monitoring of civil construction projects is an important application area to help maintain and improve the life-cycle of civil infrastructure projects. The complexity of monitoring any pavement structure is apparent with the specific small section of repaved roadway on US 30 near Ames presenting challenges to researchers in May of 2013. Commercial sensors used on the project were unreliable overall with a high rate of failure within about 1 year of the sensors being installed. In addition, the cost of implementing the sensors and their corresponding data acquisition systems (data loggers) was high.

The end goal of this project is to develop a DAQ system that can interface with MEMS sensors developed by the ECpE department at Iowa State. This data acquisition system needs to meet various constraints including high resolution measurement of resistance and capacitance to measure temperature and moisture content of soil respectively and withstand harsh environmental conditions underground in Iowa's climate.

Our project team has started work on this project by defining requirements and scope of the project. These requirements are ideal requirements for the final product but are subject to change if testing indicates a constraint is not realistic. We have developed a flow process to reach our goal of designing and building a DAQ system. This includes defining requirements of the project, prototyping a solution, testing the prototype and refining, designing a final product, and testing and refining the final product.

The anticipated solution will be a system using embedded hardware and Arduino software. Specifically, an Arduino Uno's analog pins will be utilized to interpret an input signal provided by the MEMS sensors and any necessary measurement circuitry. Programming can be done in Arduino's integrated development environment, which is straightforward and intuitive to use. There is a sufficient number of analog pins on the Arduino Uno to meet the four independent measurement channels requirement. An SD card can be used as a memory unit to store the data on-chip and a researcher can then obtain the data by connection a computer to the module that will be near the surface.

4.2 References

Work Cited

Ceylan, Halil; Yavas, Seval; Dong, Liang; Jiao, Yueyi; Yang, Shuo; Kim, Sunghwan; Gopalakrishnan, Kasthurirangan; and Taylor, Peter, "Development of a Wireless MEMS Multifunction Sensor System and Field Demonstration of Embedded Sensors for Monitoring Concrete Pavements, Volume I" (2016). InTrans Project Reports. 219. http://lib.dr.iastate.edu/intrans_reports/219

4.3 APPENDICES

If you have any large graphs, tables, or similar that does not directly pertain to the problem but helps support it, include that here. You may also include your Gantt chart over here.

– Any additional information that would be helpful to the evaluation of the project plan or should be a part of the project record shall be included in the form of appendices

– Examples of project documentation that might be included are property plat layouts or microprocessor specification sheets germane to the proposed project.