Wireless Sensing System for Intelligent Concrete Curing Proposal

Spring 2012 ECE 480

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In collaboration with:

Executive Summary:
We are a Senior Design team of four electrical engineering students working through Michigan State University’s ECE 480 course under the direction of Professor Michael Shanblatt. The purpose of our project is to complete the design, fabrication, testing, and demonstration of a Texas Instrument-based wireless sensing system for immersion in concrete structures\(^1\). In order to facilitate our completion of this task, guidance is available from Michigan State University’s Associate Professor Jian Ren, and Texas Instruments’ Analog Applications Engineer Pete Semig. Advice from Matt Lauer, of the TI MAVRK Team, will help to guide us in MAVRK implementation.
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Chapter 1: Introduction and Background

1.1 Introduction

The curing process for concrete construction is equally important, if not more important, than the process of pouring the concrete itself. Properly cured concrete can have significantly superior properties compared to concrete that is improperly settled. Sufficiency cured concrete will exhibit greater durability, wear resistance, and gain strength faster. Cured concrete will also have better sustainability to deicers and freeze/thaw damage. Environmental factors have a large contributing influence on whether or not concrete settles properly. Of these variable conditions, temperature and moisture tend to have the largest effect on the overall outcome on the finished concrete product.

The process of curing can be vague at best. Pourers are usually forced to give an educated estimate of when their pour will be solidified. Although the structure may feel structurally sound on the outside, it is a guessing game when trying to determine the rigidity of the concrete within. In some cases, it is impossible to decide if a structure is properly cured until it is too late. This uncertainty can result in the structure ultimately failing. The ambiguity of curing presents a serious risk economically, as well as the potential for a disaster in terms of physical safety. This topic is being targeted as our area of interest.

Previous attempts have been made at creating a solution to this problem. Texas Instruments (TI) is looking to improve on the idea even further in order to eliminate proposed shortcomings in existing designs. TI has taken interest in designing a system that would wirelessly relay data consisting of two crucial parameters, temperature and moisture, in order to inform a customer when a concrete product has fully matured. This an opportunity to solve a persistent problem using much the technology that is already available at TI and this challenge is also being recognized as a chance to showcase some of their newest components. The entire process will be run on and controlled by TI’s latest MAVRK and uMAVRK modules. The technical aspects of how this will be accomplished will be covered in further detail later in this document. Texas Instruments has generously decided to allow our team to access some of the world’s best technology in order to design a wireless sensing system for intelligent concrete curing.

Our senior design team, Design Team 2, consists of four electrical engineering MSU seniors; Chai Yong Lim, Kevin Gladstone, Jonathan Sangregario, and Yanqing Li. We work side by side on a daily basis to tackle this immense design task. Serving as our communication relay with TI and as our product sponsor; Analog Applications Engineer Pete Semig, along with Matt Lauer of the TI MAVRK Team will provide us with the guidance, tools, and resources in conjunction with MSU associate professor; Jian Ren, to succeed in making this concept a functioning reality. The following materials function as our documentation for the process that will take us from the foundation of raw ideas to a final working product.
1.2 Background

The need for a solution to our targeted problem has been paid plenty of attention over the past 15 years. Currently there are limited companies, such as Engius, who developed IntelliRock systems that have released similar sensing units with varying amenities. The fundamental operation of these devices requires one to drill holes (5’’ by 1’’ diameter) in the hardened concrete in numerous areas. Next, their sensors must be placed in the drilled holes. The sensors are then physically connected to a unit that receives information based on the temperature and moisture of the internal concrete. The gathered information about the desired parameters is then displayed on a central unit. This data is then utilized to calculate whether or not the concrete is properly cured. Long installation time and ease of access are two major problems with these current modules\[3\].

The first problem presented is the amount of time and work required in the drilling process and probe placement. A large portion of this time could be eliminated if the units could be immersed in the concrete before the pouring even begins. Gathering data from the sensors individually at each of the test locations also contributes to the tediousness of the overall procedure. The sensors in current commercial devices are connected via wires to the central unit. This drawback constrains the product user to testing only a single small area of the concrete at a time. If a wireless connection could be utilized instead, the user could ultimately gather data from multiple sensors at once from a remote location.

There are several products that have successfully accomplished a few of our specifications individually. CAS Dataloggers is a company that specializes in manufacturing various data acquisition systems. While they do not currently produce a logging system that incorporates both moisture and temperature, they do offer them as separate entities. Their other relevant systems include wireless data loggers and a concrete maturity logger. This maturity logger precisely calculates concrete maturity by monitoring temperature change over a period of time. This particular product is very appealing in the construction industry but comes with a very high cost and lacking the ability to monitor moisture. This data logging system, along with the IntelliRock products do not offer the desired mobility and all-in-one nature our wireless sensing system aims to provide[3].

These complications have inspired our team to seek alternative options for a more efficient solution. Most available wireless sensing systems come considerably higher cost than wired systems. Texas Instruments has provided the opportunity to taking a new approach to the situation with their development of a mobile transmitting system which allows for a more feasible cost. When completed, it is believed that this product has a great potential of generating strong revenue[3]. In the previous Fall semester, another MSU ECE 480 senior design team, “Design Team 5”, fabricated the circuitry for a sensor module to be used in the wireless sensing system. This circuitry would provide the necessary signals and power supplies to our sensors which will be capable of measuring the temperature and moisture of a test environment. Due to time constraints, Design Team 5 did not finish circuitry debugging, sensor implementation, and the software programming to make the sensing system complete. These issues restricted the team from gathering and displaying proper data information. Our overall goal is to take the working portions of their previous design and add the necessary components to meet the requested design specifications with a functioning prototype as our final product.
Chapter 2: Objectives

2.1 Deliverables

Texas Instruments has requested a functional demonstration prototype of a concrete curing sensor system and its accompanying software. The entire device must also be able to be submerged in concrete. The system will incorporate TI’s µMAVRK module which, when buried, will wirelessly transmit gathered data to the MAVRK prototyping platform. The results will then be read and displayed by a computer. The completed prototype will be tested in a blend of materials which resembles concrete. Time constraints will not allow for testing with actual concrete. A successful solution must survive the test environment and accurately transmit the temperature and moisture level of the concrete simulated material. Finally, the data will then be displayed on a computer in a user friendly manner. The user will then be able to determine the status of the concrete based on the display output.

2.2 Specifications

- **Accurate measurement of both temperature and moisture.**
  - Analysis of this data will be left to other parties.
- **Battery life of no less than three weeks.**
  - The system will not be removable from the concrete and must have power until the concrete is cured.
- **Robust enclosure.**
  - Sensors must be exposed in order to collect data from concrete while other internal electronics are kept safe.
- **Software must display data collected by the sensor system in an easily interpreted fashion.**
  - The system shall be designed to accommodate a wide range of users for both large and small scale build projects.
- **Prototype will be built on a printed circuit board using industry standard Gerber files.**
- **Size of the prototype does not need to be minimized.**
  - Ease of construction and testing will be important for a successful demonstration piece.
  - Size Constraints can be considered in further prototyping
- **Testing set-up must simulate concrete conditions.**
  - As previously mentioned, the device will not be able to be tested in actual concrete due to time constraints.
  - In order to validate our testing, our chamber must simulate the conditions of concrete as accurately as possible given our available tools and time.
### 2.3 House of Quality

![House of Quality Diagram](image)

**Figure 1**: House of Quality Diagram
2.4 Risk Analysis

- **Proposed test conditions may not coincide with actual conditions in concrete.**
  - Battery life cannot be fully tested due to the limited project timeframe. Since a full discharge could take weeks, we will have to simulate the expected battery life.
  - Signal reception through concrete will be difficult to test due to inaccuracies in the simulated concrete mixture.

- **Robustness of system enclosure.**
  - Substantial damage to the system may occur if the enclosure fails during a whole-system test.

- **Software implementation is a primary design concern.**
  - Texas Instrument’s MAVRK platform is currently unreleased to the public. The system may not function as intended, or lack of documentation and teaching resources may make the software implementation challenging to meet the time constraints of the semester. To help alleviate these risks, we will utilize Matt Lauer of the MAVRK team for support.
Chapter 3: Design and Diagrams

3.1 FAST Diagram

Six Sigma is a systematically driven approach that companies employ daily to ultimately reduce the possibility of error from manufacturing to service. In every aspect of a business, there exists a derived model to produce the most efficient product possible. One of the foundational methods in Six Sigma is a fast diagram. This diagram is a visual representation that identifies the needs and objectives our customer desires in a product. Our team will take these needs into great consideration while attempting to effectively produce a fully functional prototype. The structure of the diagram begins with a primary task followed by a basic function. This main function then stems into secondary functions. By asking “How” in a rightward direction and “Why” in a leftward direction, a relevant flow will present itself informing us that the necessary criterion is in place. Figure 2, shows the diagram we created in the beginning of the semester that provided a reference to help keep us on the correct path towards meeting our customer’s needs.
3.2 Functional Block Diagrams

Our ultimate goal is to design a sensor module that will connect to the μMAVRK via the μEVM connector. The sensor module will gather moisture and temperature characteristics of the surrounding medium and then relay varying analog voltage levels to the μMAVRK unit. The μMAVRK will the perform analog to digital conversion of the data and transmit it to the MAVRK through a wireless communication. For our application, the MAVRK will send the received data to a personal computer, via USB cable. Finally, a graphic user interface (GUI), derived from DT2, can display the real time temperature and moisture values to the user for curing analysis – see Figure 3.

Figure 3: Functional System Block Diagram

The sensor module consists of a temperature sensor; a resistive temperature detector (RTD), and a moisture sensor known as the Vegetronix VG400. The resistance of the temperature sensor will be changed depending on the temperature of the surrounding environment. To utilize the RTD we will implement a Wheatstone bridge to convert a changing of resistance to a corresponding varying voltage. The output voltage of the moisture sensor will be proportional to the moisture level in the surrounding medium. The temperature and moisture signal will then be amplified and buffered by the gain amplifier and then fed into the analog to digital converter on the uMAVRK daughterboard. The above block diagram (Figure 4) illustrates this process.

Figure 4: Sensor Module Block Diagram
3.3 Existing Design and Alterations

Design Team 5 made significant headway in the design of the system during the Fall Semester of 2011. We will move forward with many of the analog design decisions inherited from the previous team. In general, most of our modifications will involve increasing component package size as an attempt to ease construction of our prototype.

3.3.a Fall 2011 Temperature Sensing Circuit

![Fall 2011 Temperature Sensing Circuit Image]

Figure 5: Fall 2011 Temperature Sensing Circuit

Modifications to the 2011 Temperature Sensing Circuit

Temperature reading is achieved using a resistive temperature device as a part of a Wheatstone bridge. The Wheatstone bridge will be improved by removing the switch, U3. In order to maintain long battery life, a current-limiting resistor will be put in its place. R7 will also be adjusted to improve battery life. The amplification and buffering of the temperature signal will not be changed. The output RC filters will be removed if they are found to be unnecessary.
3.3.b Fall 2011 3.3V Rail

Figure 6: Fall 2011 3.3V Rail

Modifications to the 2011 3.3V Rail

The 3.3V rail will likely remain unchanged.

3.3.c Fall 2011 Humidity Sensing Circuit

Figure 7: Fall 2011 Humidity Sensing Circuit

Modifications to the 2011 Humidity Sensing Circuit

The humidity sensor used by Design Team 5 will be replaced with a Vegetronix VG400 moisture sensor because the 2011 Design Team 5’s testing for humidity resulted in readings of 100% relative humidity from small quantities of moisture and will not meet the design criteria of the system. The VG400 outputs a clean zero to three volt signal and will only need to pass through a buffer op-amp. By using a sensor powered by a 3.3V rail, the circuitry for the 5V rail implemented by Design Team 5 can be eliminated. Power for the moisture sensor will then be provided from the above 3.3V rail (see 2.3.b).
3.4 Testing Procedure

The RTD voltage output will be compared to the reading of a proven thermometer in order to map a voltage versus temperature chart for a suitable range of values one might expect to encounter while curing concrete. In the event the 3 volt range of the ADC is not being fully utilized, the amplification of the Wheatstone bridge will be increased.

The Vegetronix moisture sensor will undergo a similar procedure. A known volume of sand will have water added to it in steps to map the output voltage to a percentage of moisture in the mixture. Vegetronix has stated that the VG400 has a known grounding issue when used in an enclosed area, such as the fixture which will be used to demonstrate our system. The suggested alternative, the VG400, does not have the low power consumption needed for our project. Assuming the readings within our chosen test fixture are consistent, generating our own voltage to moisture curve should allow us to gather accurate readings for the sake of demonstration. In actual concrete deployment the large pouring area would mean the grounding issue would not be a problem.

Our final demonstration fixture will be a container filled with sand that totally envelops the system. Heat will be provided by a heating lamp or hot plate. We will display our temperature register appropriately fluctuating as heat is added to the test container. We will also validate our moisture sensor by adding water to the sand inside the test container. As we add more and more water, our GUI will display the moisture level increasing fittingly.

Chapter 4: Project Management Plan

4.1 Team Tasks

In order to complete the project effectively in a limited 15 weeks’ time, each team member has assigned a technical task based on their experiences, interests and strengths. Beside technical tasks, each member has their own individual role in the team.

Non-technical role/Technical Task Description

Kevin Gladstone – Presentation Preparation / PCB layout design, hardware troubleshooting, developing voltage/moisture curve for sensor output.

Yanqing Li – Webmaster / Circuit schematic design, hardware troubleshooting, test fixture design.

Chaiyong Lim – Manager / μMAVRK Programming: μMAVRK-sensor board interaction and data transmission to MAVRK.

4.2 Resources and Facilities

Throughout the duration of this project, our team will have access to the Engineering Building 2221 lab. Contained within the lab is all the testing equipment necessary to complete the project. In addition, the sponsor Texas Instruments will provide a MAVRK development board and any analog IC’s the team deems necessary. The MAVRK boards we will use are a relatively new technology and as a result, there are limited resources related to the programming and use of these devices. One such resource is an online community - TI’s MAVRK E2E support forum. We will utilize this source of guidance as well as the repository of software development tools and demos TI has provided on their MAVRK Wikipedia page. The software packages available to us will be described in further detail in the following section.

4.2.a Software Resources

Composer Studio

Code Composer Studio™ (CCStudio) is an integrated development environment (IDE) for Texas Instruments’ embedded processor families. CCStudio comprises a suite of tools used to develop and debug embedded applications. It includes compilers for each of TI's device families, a source code editor, project build environment, debugger, profiler, simulators, real-time operating system and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before and add functionality to their application thanks to sophisticated productivity tools.

In our design, we will program the MSP430 microcontroller on either uMAVRK daughterboard or MAVRK Motherboard to conduct analog to digital conversion, RF wireless communication, and power management.

MAVRK Qt GUI SDK

Software available for user interface design includes Qt GUI Software Development Kit (SDK) and the MinGW C++ libraries. The Qt software is an open source development kit that provides the functionality to create GUI Desktop applications for Windows and LINUX operating systems. MinGW is an open source collection of C++ libraries with a version of the GNU Toolchain including compiler, linker and associated utilities.

The user interface on PC will be programmed using Qt GUI Software Development Kit to display the real time temperature and moisture value of concrete. We will develop our GUI in a manner that is user friendly so that a variety of users can efficiently analyze the data our device is gathering.
4.2 Budget

The estimated cost for this project is showed at below, the MAVRK platform and all of the analog IC’s will be provided by Texas Instrument. Most of the budget will be on PCB fabrication and sensors. The total estimated cost for this project is within $500 dollar limit.

<table>
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<th>Component</th>
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### 4.3 Project Timeline

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<th>Finish</th>
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Figure 8: Project Timeline
4.4 Gantt Chart
Chapter 5: References

5.1 Resources

[1] Project Summary
http://www.egr.msu.edu/classes/ece480/capstone/ProjectSummariesSp12.htm

[2] Concrete Curing

[3] Previous Years Project
http://www.egr.msu.edu/classes/ece480/capstone/fall11/group05/docs/Deliverables/FINALPRO
POSAL.pdf


5.2 Images and Tables

Cover Page
TI Logo
MSU Engineering Logo
http://profile.ak.fbcdn.net/hprofile-ak-snc4/41571_140956305934885_5091_n.jpg

p.6
Gantt Chart Template
http://www.schrodingersghost.com/?p=399

p.10
Design Team 2’s Schematic
See Appendix A

p.11
Design Team 2’s Schematic
See Appendix A
Appendix A

Figure 10: Fall 2011 Design Team 5 Circuitry