WIRELESS EMBEDDED ROADWAY HEALTH MONITORING

Design Document
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0 List of Abbreviations and Acronyms

CAD: Computer Aided Design
EM: Electromagnetic

FCC: Federal Communications Commission
FIFO: First-In First-Out
I2C: Inter-Integrated Circuit
LCD: Liquid Crystal Display
PCB: Printed Circuit Board
RF: Radio Frequency
RTC: Real Time Clock
SD: Secure Digital
SPI: Serial Peripheral Interface
USB: Universal Serial Bus
HUB: Center of the Network (HUB)

1 Executive Summary

Structural health monitoring systems will evaluate the real-time safety of the roadway at a very low cost without an inspector. It can detect problems such as cracks much sooner than manual inspection, which is necessary to support a reliable and sustainable transportation infrastructure system.

2 Purpose

In phase I of the project, the previous team finished the circuit design for the sensor which can be embedded into concrete to measure the temperature and humidity. The sensor can communicate wirelessly with a HUB which will be a microcomputer such as a Raspberry Pi. In phase II, we need to achieve the same goal and improve the circuit design from phase I. The new board must be 1”x1”x1” and use less power than phase I, and the team will build an Android application for communicating with the HUB.

3 System Requirements

The new system designed by this project as well as the improvements to the existing system will be expected to meet the following criteria:

1. Sensor devices can communicate among themselves and the HUB.
2. The HUB needs to store all data until extraction via Android app.
3. The maximum distance between the HUB and smartphone is approximately 100 meters.
4. The enclosure should be 50% smaller than phase I, which is also water/shock resistant and can handle pressures induced by the solidification of concrete and overhead traffic.
5. Handles temperature ranges from -20̊ F to 140̊ F.(-28.9°C to 60°C).

6. The size of battery must be smaller than phase I. The size should be less than 2”x2”.
7. The battery life of each unit will last a minimum of one year.
8. Must be able to transmit and receive data between nodes through concrete.
9. Must encompass full automation of data aggregation, transmission, & receiving.
10. The smartphone must store all data logs and do some basic analysis transferring from bit strings into the readable values in correct unit of humidity and temperature.
11. Log files must include date, time, nodes used, temperature and humidity reading data about the samples.

4 Functional Requirements

4.1 Communications

The communication system uses a wireless RF system designed to work through reinforced concrete. The two main specifications that the communications system must follow is that firstly, it must be powerful enough to communicate between nodes through the concrete and secondly, it needs to consume as little power as possible to prevent the shortening of the node lifespan. The communication network consists of an antenna, a microcontroller, and a transceiver this document covers later.

4.1.1 Antennae

The antenna used for communication is an enclosed whip antenna operating at 433MHz. The antenna meets the requirements of having sufficient reception in concrete, durability and low cost.

4.2 Microcontroller

System Requirements: The microcontroller unit is composed of a low-power microcontroller with a built-in real time clock and RF transceiver. The microcontroller communicates with a sensor and flash memory chip across an SPI bus.

Functional Requirements: The microcontroller will also periodically generate local temperature and humidity readings via an external sensor. When the HUB requests the microcontroller's sensor data - which it stores in the flash memory chip on the circuit - the microcontroller will transmit all of its data to the HUB, and upon confirming the data was sent and is not corrupt with a checksum, the data will be erased from the flash chip. The microcontroller will also help pass data on its way to the HUB to and from other units.

Non-functional Requirements: Once deployed, the owner cannot manually reset or modify the microcontroller, meaning system failure is unrecoverable. Device failure will result in data loss and affects the overall lifespan of the network. Therefore, the focus is on making the device have high reliability. The primary solutions are fault-tolerant software to recover from system-faults, and performing energy-efficient optimizations to system and network functions in order to expand lifetime. During design, we may also change the system's hardware, so the software must be extensible, to allow hardware swapping.

4.3 Sensor Temperature/Humidity

System Requirements: The microcontroller will interface with a Sensirion **?(SHT10)?** temperature and humidity sensor to make the required measurements.

Functional Requirements: The sensor must take measurements in such a way as to minimize power consumption and not interfere with other peripherals on the bus.

Non-functional Requirements: Because the sensor does not use a standard serial communication protocol, a hardware solution for communication with the device will not be available. This requires disabling all interrupts on the microcontroller, which could interfere with incoming transmission if the size of the data received is larger than the FIFO available on the transceiver. Performing measurements as fast as possible as well as having global interrupts disabled only when needed will minimize the chance of data loss.

4.4 Power

For the device to be wireless, it must be powered by an internal battery. The battery chosen will use Lithium Primary Coil battery technology, due to Lithium being able to function at temperatures ranging from -40 to 140 degrees Fahrenheit. The battery must also be able to last at least one half year before needing changing (recharging for future implementations).

4.5 HUB

System Requirements: The HUB (raspberry pi or something similar) will sit at the side of the road and receive data transmitted from the closest nodes in the network as well as initialize the network at first setup. The HUB will be controlled by the implementation of an android app.

Functional Requirements: On start-up, the HUB will send out a signal to the nearest nodes of the network to perform the initial setup. After that, the HUB will wait indefinitely until data is transmitted to it or a user initiates a data extraction from the android app.

Non-functional Requirements: The HUB will be a road-side unit and not embedded into the concrete of the highway, therefore, the power and means of communication will be implemented with a solar panel to charge a battery and an antenna listening for transmissions from the network.

4.5.1 Antennae

The HUB will use an RF transceiver communicating at the same frequency used within the network. Due to more flexibility in powering the HUB, the HUB will either have a transceiver with a higher output power or range extender to ensure signals sent by the HUB can reach the first level of the network.

4.5.2 Memory

The HUB must log the data on its hard disk in an organized fashion. Access to data will be via an Android application. After data retrieval and checking whether the data in not corrupt, the data will be destroyed from the HUB.

4.6 Android Application

The HUB must transfer its data to the user's smartphone with the help of an Android application. The user will enter the app, find and connect to the HUB via Bluetooth, and press a button to extract the HUB's data. This will open a web socket between the HUB and smart phone, and transfer all of the HUB's constituents' data wirelessly. Once the transfer is complete, the data will be destroyed from the HUB and the socket will be closed.

5 Testing

As has been stated previously, the second most important objective for our circuit is that it use power efficiently. We will test our node for its power consumption, as well as the efficiency of the sensor network and our sensor's ability to withstand the concrete environment.
As for the communication part, since the air and concrete environment is almost the same as the previous team and they have finished lots of research for this part and got the reliable results, we are able to build up our communication part based on their research results.

5.1 Power

For testing the power consumption of a node the current draw, average lifespan of the battery under normal operation, and efficiency of the charging system will all be measured. This will allow for calculations of node and battery lifespan.

5.1.1 Battery Life and Health

To test the battery, measurements will be taken of remaining battery life after 24 hours of operation. This will give the expected battery life and whether or not the size of the battery being used should be increased. In addition, measurements will be taken to see how exposing the battery to the two extremes in temperature ranging from -20° F to 140° F affects the lifespan of the battery.

5.1.2 Current Draw

Current draw will be measured over an average cycle for the node and then will be multiplied by the amount of cycles the node would experience in a day. This will determine the amount of mAh used per day by the node.

5.2 Sensor Network

The sensor network needs to be optimized for power efficiency and data reliability. This is accomplished by limiting transmission time and with table-drive routing. Limiting transmission time with a schedule introduces problems with schedule de-synchronization and difficulties in schedule construction. Additionally table-driven routing does not adapt well to node failures.

Sensor network testing will be performed during later stages of project development. In order to test the network, the devices should first be placed in similar conditions as the concrete tests. Each test should run through a series of configurations ranging from a dense network with low node depth to a sparse network with high-node depth. The testes themselves will measure the quality of non-overlapping schedules with node neighbors and the quantity of packets that are lost. Finally, re-tests of schedule quality and packet quantity will be performed when the devices are randomly deactivated.

5.3 Data Retrieval

The sensor in the device must also be verified for accuracy. It must be exposed to the elements so that it can survive pouring while providing accurate temperature and humidity readings. The accuracy can be tested by placing it in a controlled environment and measuring the accuracy across different ranges of humidity and temperature. Finally, verification that the sensor can survive concrete pouring will be needed. The best way to perform this test is by subjecting it to high temperature and acidity levels, similar to those present in the curing process of concrete.

6 Detail Description

This section will lay out the main specifications set forth for the project by the team and advisers. It will include sections on I/O specifications, interface specifications, hardware and software specifications, simulations, implementation issues, and testing.

6.1 I/O Specification

The base station will serve as the only point of I/O for the user. Output of the system will be the network continuously generating data and transmitting it to the base station. There will be no continuous user input into the system, and the only time input to the system is needed is when the user wants to change network parameters such as sampling frequency.

6.2 Interface Specification

The Android application will be the only User Interface in this project, and will consist of one activity. The main activity will have a button which will search for Bluetooth devices, and display a list of devices. Clicking on one of the list items will connect to that device (hub). Once the device is connected to the base station, the user will either press a button which will migrate all of the hub's data to the smartphone and delete the data from the hub, or enter a frequency in an EditText box for the hub to send to the nodes as the sampling frequency.

6.3 Hardware Specification

The hardware being used is a CC1310 system-on-chip from Texas Instruments. The chip houses an ARM Cortex M3 CPU, RTC, and RF transceiver, as well as 128KB of flash memory and 20KB of RAM. The sensor will take measurements of the temperature and the humidity. The antenna for charging will be a patch antenna designed to operate at a frequency of 300 MHz.The system will also have a coin battery.

6.4 Software Specification

The software for the MCU will be developed in C using Texas Instruments Code Composer Studio. The Android application will be written in Android (Java) in Google's Android Studio IDE. All software will be optimized for lowest possible power consumption on battery-powered devices to maximize lifetime. Software will be robust to allow the network to survive should one or more nodes stop function.

6.5 Simulation/Modeling

PCB design, hardware schematics, and antenna schematics will be created and tested to ensure that the hardware will work as intended. Designs will be made using CAD software.

6.6 Implementation Issues & Challenges

One main challenge of implementation for the nodes is survivability during the concrete pouring and curing. During the concrete pouring, there will be high temperatures and pressures as well as strong vibrations which can cause stress to the PCB and node housing.

Signal attenuation in the concrete is another challenge that the system will be required to overcome. The signal loss increases drastically in concrete compared to air, which may cause the system to transmit data repeatedly until success. This will cause the battery to drain faster than desired.

6.7 Testing, Procedures, & Specs

Multiple nodes must be able to talk between one another. To test this, multiple nodes will be implemented into a simulated network. One node will record measurements and send data to multiple nodes one at a time to verify that only the intended target receives the data.

The node container will be exposed to setting concrete to test if the enclosed electronics will survive the curing process. To ensure this, the enclosure must be water/shock resistant and can handle the pressures introduced by the solidification of concrete.

The nodes must be able to work between temperatures ranging from -20° F to 140° F. One node will be exposed to extreme temperatures and will be tested to see if the node maintains normal operation.

Average current draw of the node will be measured and can be used to calculate expected battery life. The battery life of each unit will be calculated through an excel spreadsheet to verify that it will last a minimum of 1 year.

The nodes will be embedded in concrete roadways. To verify that the communications will work, nodes will be placed in concrete chambers and tested to verify data can be transmitted between them.

The nodes will collect and transmit data automatically. Nodes will be tested to ensure data is automatically collected and transmitted on a timely basis.

The network must be intelligent in that it will be able to reroute the entire network around nonfunctional nodes. A network will be created in free space, then a node(s) will be intentionally deactivated to see if the network can re-route around the lost nodes.

The base station must be able to record logs of all data that it receives. To confirm this, one sensor will send confirmation data to the base station, which will extract it to see if any data is lost or corrupted.

The log files that are transmitted must include date, time, node id, and sensor data. The transmitted data will be checked to make sure that all of the required information is present and correct.

7 Parts List

TBD

8 Results

As of now, little testing has been done as components are still being received and prepped for testing. All results and conclusions from part and system testing will be accurately recorded as to allow comparisons between the multiple parts and system designs under consideration. Formal documentation of results will be implement to allow easily readable and navigation of tests.

9 Conclusion

Future applications of this project will help to maintain concrete integrity and decrease the need for manual inspections of civil structures. Implementation of this network will help to make wireless sensor networks for monitoring structures more feasible to implement in production. Further refinement to the concrete mixture can be improved upon data collection during curing process. Economically, the use of wireless sensor networks is beneficial to owners of such structures in the sense that they can wait longer before having to replace a roadway.

10 References