WIRELESS EMBEDDED HEALTH MONITORING SYSTEMS

Design Document

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Table of Contents

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

1 EXECUTIVE SUMMARY

The goal for this project is to design, develop, and implement a working system, which monitors and collects data that road surveyors normally complete. These tasks include sensor data sampling of concrete, charging remote systems wirelessly, and transmitting data across multiple nodes to a collection box on the side of the road. In addition, this system must be able to survive in concrete with minimal time intervals for charging.

2 PURPOSE

Structural health monitoring systems evaluate structures for safety without requiring the presence of an inspector. This saves time, money, and possibly lives as structural degradation can be detected much sooner than manual inspection. Implementing such a system without wireless communication however becomes too difficult, fragile, and expensive to be feasible. A wireless sensor network make the system low cost, have quick installation times, and high system reliability.

3 SYSTEM REQUIREMENTS

The new systems designed by this project as well as the improvements to the existing systems will all be expected to meet the following criteria.

1. Sensor can communicate between multiple nodes.
2. The enclosure is water/shock resistant and can handle pressures induced by the solidification of concrete and overhead traffic.
3. Handles temperature ranges from -20°F to 140°F.
4. The battery life of each unit will last a minimum of one year.
5. Each charging of the battery will take a maximum of 12 hours.

6. Must be able to transmit and receive data between nodes through concrete.
7. Must encompass full automation of data aggregation, transmission, & receiving.
8. Must be able to detect and reroute around non-functional nodes.
9. The base station must store all data logs
10. Log files must include date, time, nodes used, and information about the samples.

4 FUNCTIONAL REQUIREMENTS

This section describes the functionality of each component in the project design. These components include communication, a microcontroller, sensors, a power system, and a base station. Communication is accomplished by radio frequency transmission through an antenna. The microcontroller acts as the brains of the system determining when the system is to turn on as well as when to sample, store, and transmit data. The data consists of temperature, humidity, and strain, which the sensors gather. Additionally, the system will require a power supply to run it. After creation, a base station will collect and store all node data from the entire network. On the following page is the system level diagram for the project.

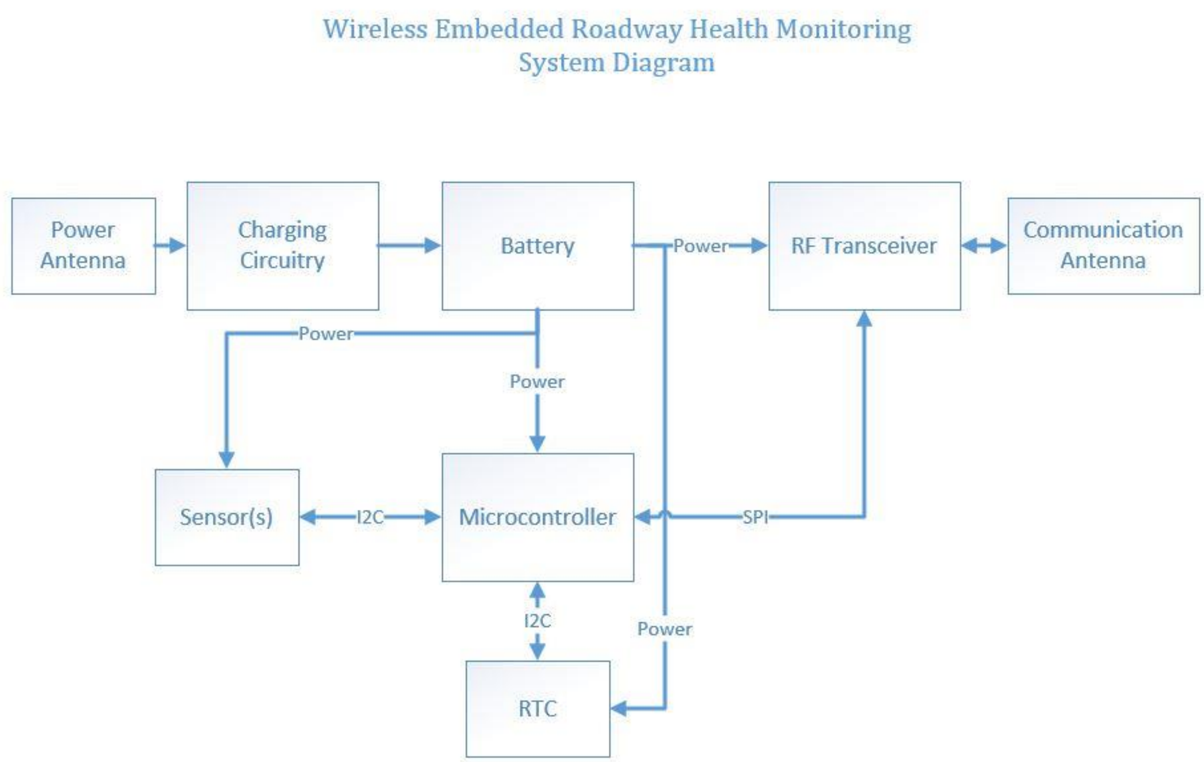

Figure 1: System Overview Diagram

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 ANTENNA

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 is composed of a low-power microcontroller augmented with a real-time clock. The microcontroller communicates with the real-time clock, a sensor, and transceiver across an SPI bus.

Functional Requirements: On start-up, the microcontroller will setup a communication schedule by communicating with nearby devices. The schedule provides a method to forward data to a base station. By following the schedule, the microcontroller will assist nearby devices in forwarding data, and will get a time-slot to forward its own data. The microcontroller will also periodically generate local temperature and humidity readings via and external sensor. When the microcontroller’s time-slot occurs, it will forward any data it has received or generated.

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 SHT71 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

The power source must charge the nodes wirelessly. This is due to the harsh conditions during the curing process and setup of concrete that causes a high failure rate of wired connections. For the device to be wireless, it must be powered by an internal battery.

4.4.1 BATTERY

The battery chosen will use Lithium Ion technology due to Lithium Ion being able to function at temperatures ranging from -20 to 140 degrees Fahrenheit. The battery must also be able to last at least one half year before needing recharging. Once a more accurate model of power consumption during data reading and communication is available, then the size of battery best suited for the project will be chosen.

4.4.2 CHARGING

The node will use a method of wireless charging for power. Wireless charging is necessary due to the harsh environments of concrete. The two types of wireless charging that are available are RF and EM. Because the nodes operate inside the roadways, the charging system must charge as efficiently as possible. Multiple test scenarios must be completed with both RF and EM charging systems due to the loss during transmission from the concrete slowing down the charging process.

4.4.2.1 RADIO FREQUENCY

According to Jiang [1], wirelessly charging systems in reinforced concrete is most efficient around 900MHz. The transmission loss is roughly -22dB for devices in dry concrete when using a dipole antenna. For a patch antenna, the transmission loss was roughly -22dB for similar situations. Refer to Figure 2 and Figure 3 for more information.

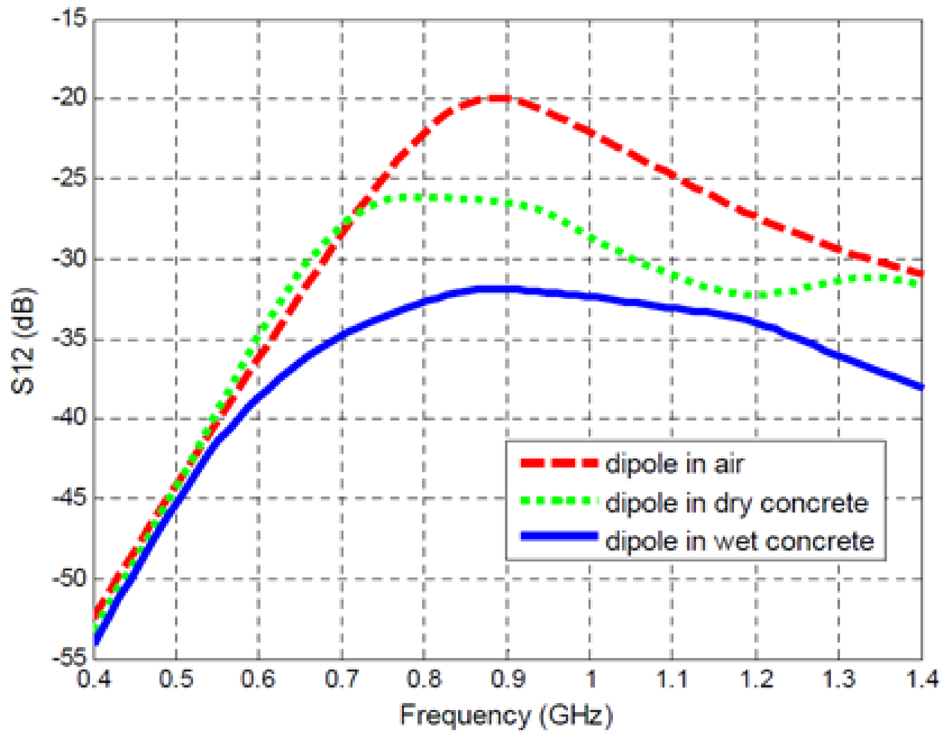

Figure 2: Dipole antenna S12 efficiency through concrete versus frequency, Jiang [1]

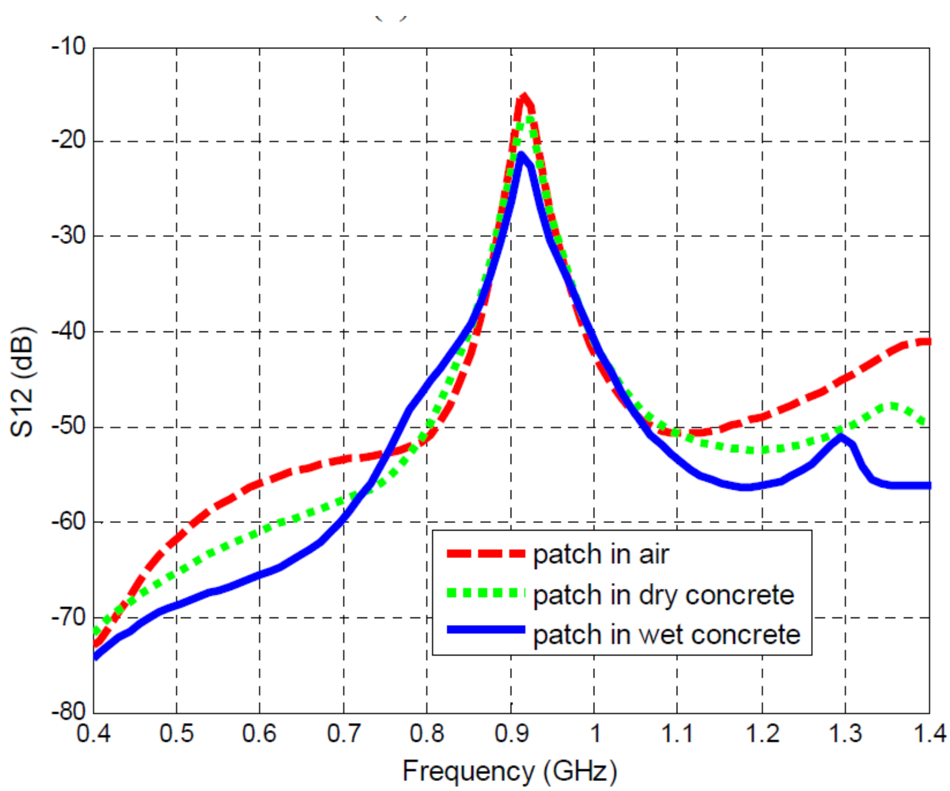

Figure 3: Patch antenna S12 efficiency through concrete versus frequency, Jiang [1]

4.4.2.2 ELECTROMAGNETIC

The second option for power transmission through concrete is via magnetic resonance coupling. A strongly coupled magnetic resonance method is utilized following the design discussed by Jonah [2]. Based on the paper, the wireless power transfer efficiency of 38.3% could be achieved at depths of up to 30cm and up to 62.6% at depths of 15cm between the transmitter and the receiver when the thickness of the slab of concrete is 10cm. The frequency will be 27.2 MHz since it is one of the available ISM band. The same frequency is also utilized in many RFID application.

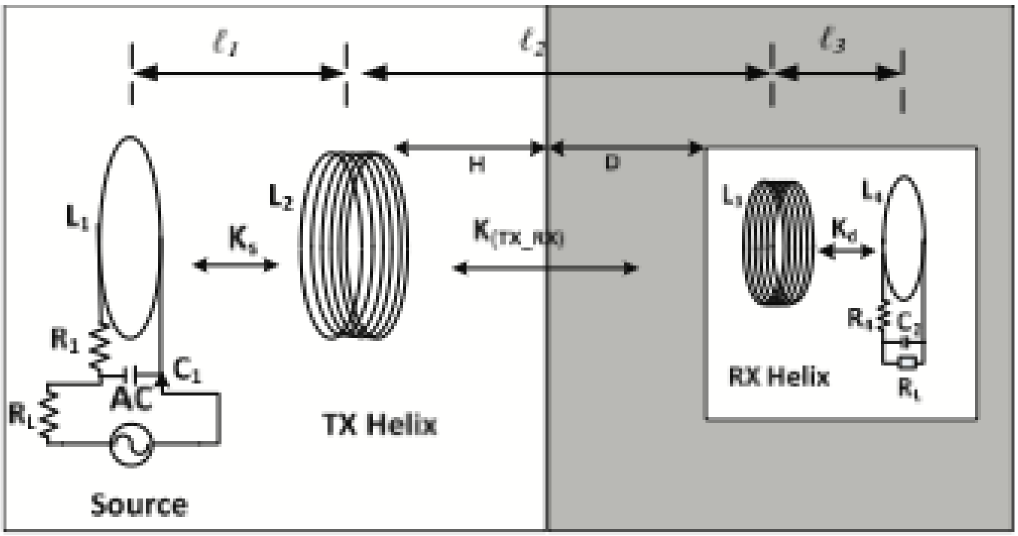

Figure 4: Strongly coupled magnetic resonance, Jonah [2]

4.5 BASE STATION

System Requirements: The base station 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 base station is considered a later stage of the project, so most of its design is still untouched.

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

Non-functional Requirements: The base station 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 ANTENNA

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

4.5.2 MEMORY

The base station must log the data in an organized fashion. It places the data on a removable storage device, which is easily accessible by the user. Access will be either through a USB port or from an SD card.

4.5.3 DATA EXTRACTION

The user will be able to temporarily disable the network from sending data, remove the storage device, and download the data to a personal computer without disrupting the network from collecting data. Network operations will resume when the storage device is replaced and the network is re-enabled. Alternatively, commercial parts may be used to allow the base station to transmit the logged data across a cellular network, allowing the user to download the network data remotely.

5 TESTING

Testing the devices can be viewed in two sections: efficiency of wireless charging and success of transmitting data between two nodes. Both sections have different testing conditions that must be adhered to. Wireless charging should be tested by observing the power transmitted through a slab of concrete. Transmission will be tested by observing the success rate of characters sent over considerable distances while in concrete.

5.1 COMMUNICATIONS

Testing for communication will follow a set of stages: transmission through air, transmission through plain concrete, and finally transmission through reinforced concrete. The point of breaking testing into stages is to establish a working model without our specific constraints and then tweak the system until it does satisfy them. The final goal is to design the system such that there is a high success rate in transmission through reinforced concrete. High success rate will be defined as having a majority of the signals transmitted and received without significant data corruption.

5.1.1 AIR

Two nodes will be separated by a distance of a few feet in open air. One node will transmit a large number of symbols to the other. The goal of this stage is to observe a high number of characters received with minimal data loss.

5.1.2 CONCRETE

Two nodes will be contained in concrete boxes and separated by a similar distance as seen in the case with air. The walls of the concrete boxes will be a few inches thick. The dimensions of the concrete box are larger than the actual node itself to allow for the nodes to be encased within the box. The goal of testing with concrete is to see the differences between information being sent by the first node and the information being collected at the second.

5.2 POWER

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

5.2.1 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.

5.2.2 CHARGING EFFICIENCIES

To test the effectiveness of the charging circuitry, the nodes will be placed inside of a concrete box to simulate the node being embedded in a roadway. This way, when charging the nodes, losses due to concrete can be compared to losses when the system is in air. EM and RF charging will both be tested to determine which method is more efficient.

5.2.3 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.

5.3 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.

5.4 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 SPECIFICATIONS

The base station will have some way of displaying information to the user and accepting user input. This device is not currently in design but will most likely have a small LCD screen and a keyboard/keypad for user interaction. The device will also have either a USB port or SD card slot so the user can extract the data to a personal storage device.

6.3 HARDWARE SPECIFICATIONS

The sensor that is used must be able to measure both temperature and humidity of the surroundings. Additional sensors can be added to the system for other data collection requirements. The microcontroller must be able to communicate with the sensor and retrieve data. It will be able to process the data and store it until the allotted transmission interval. The microcontroller will communicate with the transmitter for sending and receiving of data via SPI. The transmitters operate on a frequency of 438 MHz, which is within FCC regulation and allows for the lowest amount of attenuation. The battery is required hold a charge for 5-10 years but during operation, it must last for a minimum of 6 months between charging. From this, the battery capacity must be large enough to accommodate the power consumption of the entire system. The charging circuitry will limit the charging current in order to protect the battery-life. It will monitor the battery and cut off the system if the battery level falls below a minimum charge value. The antenna for charging will be a patch antenna designed to operate at a frequency of 915 MHz. It must also be compatible with the charging circuitry. EM coils will be made of copper coils consisting of at least five windings.

6.4 SOFTWARE SPECIFICATIONS

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 SIMULATIONS/MODELING

PCB design, hardware schematics, antenna schematics, and EM coil 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 AND 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. On top of transmitting data, the system charges wirelessly which will cause lower charging efficiencies when compared with wired charging.

6.7 TESTING, PROCEDURES AND SPECIFICATIONS

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.

Charge time of the system will be measured to ensure it meets the time constraint. Charging capacity and times will be taken and expected charging time will be calculated to make sure that it does not exceed 12 hours.

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

Mouser Part #	Manufacturer	Mfr. Part #	Description	Quanity
81-GJM1555C1H3R9CB1D	Murata Electronics	GJM1555C1H3R9CB01D	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0402 3.9pF 50Volts C0G +/-0.25pF	6
81-GRM1555C1H8R2DA1D	Murata Electronics	GRM1555C1H8R2DA01D	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0402 8.2pF 50volts C0G +/-0.5pF	3
81-GRM1555C1H5R6DA1D	Murata Electronics	GRM1555C1H5R6DA01D	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0402 5.6pF 50volts C0G +/-0.5pF	3
81-LQG15HS27NJ02D	Murata Electronics	LQG15HS27NJ02D	Fixed Inductors 27nH 5% Hi-Freq	9
81-LQG15HS22NJ02D	Murata Electronics	LQG15HS22NJ02D	Fixed Inductors 22nH 5% Hi-Freq	3
712-ANT-433-PW-LP	Linx Technologies	ANT-433-PW-LP	Antennas Perm Mnt Reducd Ht 1/4 Wave Whip 433MHz	3
81-GRM1555C1H221JA01	Murata Electronics	GRM1555C1H221JA01D	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0402 220pF 50volts C0G 5%	2
660-RK73H1ETTP5602F	KOA Speer	RK73H1ETTP5602F	Thick Film Resistors - SMD 56K OHM 1%	1
774-ATS270B	CTS Electronic Components	ATS270B	Crystals 27MHz 18pF 30ppm -20C 70C	1
815-AB26T-32.768KHZ	ABRACON	AB26T-32.768KHZ	Crystals 32.768KHz	1
	Texas Instruments		MSP430F2012 Microcontroller	1
	Texas Instruments		CC1101RGPR RF transceiver	1
	Microchip		MCP7940M Real Time Clock	1
	Sensirion		SHT71 Temperature and Humidity sensor	1
	Linear Technology	LTC4071EMS8E#PBF	Li-Ion/Polymer Shunt Battery Charger System with Low Battery Disconnect	1

Figure 5: Parts list for the design being implemented

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

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[6] “Antenna Theory.” Internet: http://www.antenna-theory.com/antennas/patches/antenna.php, 2011 [Oct. 18, 2014].