Batterlyess and Wireless Data Acquisition Implant

Submitted To

Dr. Jonathan Valvano
Dr. John Pearce and Dr. Bill Fagelson
Steve Stone

Prepared By

Corey Cormier
Thomas Ermis
Albert Marzullo
Michael Park
Makeila Sorensen
Anish Vaghasia

EE 364D Introduction to Engineering Design
Electrical and Computer Engineering Department
University of Texas at Austin

Spring 2016

CONTENTS

CONTENTS CONTINUED

TABLES

FIGURES

1.0 INTRODUCTION

This system design report explains the design, implementation, and analysis of an efficient, cost effective implanted data acquisition system for lab animals. The report also serves as a progress summary for the work done in EE 364 by this design team. This data acquisition system will aid in research environments that use lab animals for testing purposes. In normal lab environments it can be difficult for researchers to take multiple precise internal measurements of lab animals for experimental purposes. Therefore a system that will allow the researcher to make quick, easy measurements from lab animals and efficiently process the data would provide a great benefit to many research companies.

The project was shaped by the varying needs of the client and the operating conditions by which the system will be operating in. These needs were used to shape the proposed design and steps such as risk analysis and test suite creation were taken to improve the implementation of the project. The client, Dr. Valvano, originated the project and requires a more efficient and cost effective solution for lab environments. Due to part of the system being inside an animal, there will also be certain environmental and performance specifications, specified below, that will shape the operation of the system. The proposed design calls for a three subsystem approach made of an implant, a base station, and a web application. The implant will be surgically implanted inside the rat and will collect the data. This implant will be wirelessly powered and communicated with by the base station. The base station will in turn collect the data and wirelessly transfer the data to a web app that will store and display information to the user. To mitigate the risks of lacking parts and time, the team has already started ordering and testing parts. A thorough cost analysis has also been done and connections have been taken advantaged of in order to get certain parts for free. Finally, to determine the validity of the subsystems as well as the system as a whole, a suite of subsystem and system tests have been devised. This will not only serve as subsystem validation but also serve as checkpoints for the project itself. To conclude, an outline of the work schedule will show how this this project will be implemented in time for December 5th, 2016, the last day of the Fall 2016 semester. The team has currently finished the design phase and will be using this work schedule as they move forward to the implementation phase. The end goal will be to deliver a functioning prototype and its associated documentation.

2.0 DESIGN PROJECT BACKGROUND

In order to make the collection of data from laboratory rats more efficient and less expensive, Dr. Valvano needs data acquisition system. Essentially, the data acquisition system needs to be able to collect data from the rat and display the data back to the user in quick, simple manner. The problem, Dr. Valvano's needs, the key performance and environmental specifications, and the final deliverables are described in more detail in the following subsections.

2.1 Problem Definition

The methods that scientists currently use to collect data from laboratory rats are highly inefficient. Each time that a scientist needs to analyze data from a single rat, they have to manually and repeatedly collect blood or urine samples, which is both time-consuming and expensive. Therefore, our team is tasked with designing a data acquisition system that will allow scientists to monitor data from laboratory rats more efficiently and at a lower cost.

2.2 Needs Analysis

As the primary stakeholder of our project, Dr. Valvano needs a data acquisition system that will allow scientists to analyze data from laboratory rats more efficiently and less expensively. He requests that the data acquisition system consists of three subsystems: an implant, a base station, and a web application. These three subsystems need to function together to collect data from a rat and display the data back to the user. In order for our team to successfully design such a system, Dr.Valvano has provided us with a detailed set of needs for the project.

The following list outlines Dr. Valvano's needs for the data acquisition system.

- The system needs to consist of an implant, a base station, and a user interface in order to compartmentalize functionality.
- The user interface must be in the form of a web application in order to provide an ease of use for the researcher
- The implant needs to accurately collect temperature and acceleration data so that the users can monitor and analyze the temperature and acceleration of a rat.
- The implant needs to be embedded inside a rat. Therefore, it needs to be small, batteryless, and wireless so that it doesn't affect how the rat functions. In addition, it needs to be sterile

and biocompatible so that it doesn't adversely affect the rat's health. Finally, it needs to have a long lifespan so that it doesn't need to be constantly replaced.

- The base station needs to power and communicate with the implant. Because the implant needs to be batteryless and wireless, the base station needs to use induction coils to wirelessly power the implant. In addition, because the implant cannot contain Bluetooth or Wi-Fi modules because of their size, the base station needs to use induction coils to also wirelessly communicate with the implant.
- The base station needs to communicate with the web application. Because the size of the base station is not restricted and it is preferable for the base station to be wireless, the base station needs to use Wi-Fi to communicate with the web application.
- The web application needs to be accessible, scalable, and interactive. More specifically, the web application needs to allow users the ability to request data from the implant. In addition, the web application needs to store the data in a database so that the user can view a historical record of the data. Finally, the web application needs to display the data in real-time so that the user can easily monitor and analyze the data.
- The data acquisition system needs to be secure in order to protect any proprietary information and confidential data.

2.3 Key Performance and Environmental Specifications

In order for our design to satisfy Dr. Valvano's needs the data acquisition system must function accurately and efficiently, independent of varying environmental conditions. By adhering to certain performance and environmental specifications, we can ensure that our system operates correctly under a variety of external settings. These performance and environmental specifications are described in more detail below.

2.3.1 *Key Performance Specifications*

As a piece of equipment that will be used in research laboratories, it is important that our system adheres to certain performance specifications. For example, because the implant will be embedded inside a rat and cannot be easily replaced, the implant must be able to operate for an extended period of time. Additionally, in order to guarantee that data is communicated efficiently, the implant and the base station must transmit bits of data at a certain bandwidth specified in Table 1. Third, the web application needs to be scalable so that it can be accessed by many users at once. Furthermore, because the data that the web application will be handling might be confidential, thus it is important the web application be secure. Finally, the system must respond to the user within a certain timeframe. Table 1 describes these performance specifications in more detail.

Table 1. Performance Specifications

Subsystem	Name	Description	Specification
Implant	Minimum Lifespan	Minimum length of time that the implant must operate for from the time of implantation	6 months
Implant and Base Station	Minimum Bandwidth	Minimum speed at which the implant and base station must transmit bits of data to and from each other	1 Hz
Web Application	Scalability	Level of scalability offered by the web application	Horizontal, Vertical
Web Application	Security	Level of security protecting the web application	Authentication, Authorization, Integrity, Encryption, Auditing
System	Maximum Response Time	Maximum length of time that the system must respond to the user within	1 minute

2.3.2 *Environmental Specifications*

In addition to performance specifications, it is also important that our system adheres to certain environmental specifications. Because the implant will operate within a living rat, this subsystem is subject to the most environmental constraints. For example, because the implant needs to be small enough to be embedded inside a rat, the implant is restricted to a certain size. In addition, the implant needs to be sterile and biocompatible so that it doesn't adversely affect the rat's health. Third, the implant needs to be able to function properly at room temperature as well as at the temperatures typical of a rat. In order for the base station to operate, the base station needs to have access to both a power outlet and secure Wi-Fi so that it can transfer power to the implant and communicate data between the implant and the web application. Finally, the web application needs to run on a wide range of platforms and browsers in order to accommodate varying technical lab environments. Table 2 describes the environmental specifications in more detail.

Table 2. Environmental Specifications

Subsystem	Name	Description	Specification
Implant	Maximum Footprint	Maximum area of the implant	25 cm^2
Implant	Sterility	Minimum sterility assurance level for the implant	SAL of 10^{-6} [1]
Implant	Biocompatibility	Minimum standard of biocompatibility for the implant	ISO 10993 [1]
Implant	Temperature	Range of temperature for the implant to operate in	0° to 45° C
Base Station	Power	Power supply for the base station	Access to power supply
Base Station and Web Application	Internet	Internet connection for the base station and web application	Access to internet connection

Web Application	Platforms	Minimum platforms the web application needs to be accessed on	Windows 7, Mac OS X, Linux
Web Application	Browsers	Minimum browsers the web application needs to be accessed on	Chrome 49, Firefox 45, Safari 9, Opera 35, Microsoft Edge 24, Internet Explorer 10

2.4 Deliverables

The deliverables for our project include a prototype of the data acquisition system and the associated documentation. The prototype of the data acquisition system will consist of three subsystems. The first subsystem will be a small, batteryless and wireless implant that collects temperature and acceleration data from sensors. The second subsystem will be a base station that uses induction coils to wirelessly power and communicate with the implant and Wi-Fi to wirelessly communicate with the web application. The third subsystem will be a web application that allows the user to request data from the implant, stores the data in a database, and displays the data back to the user. The documentation will include documentation for both our stakeholder, Dr. Valvano, and for the typical user of our data acquisition system. For Dr. Valvano, we will provide block diagrams, PCB layouts, and circuit schematics for both the implant and the base station. In addition, we will provide the code that runs on the both the implant and the base station. Furthermore, we will provide full access to the web application and its code. For the user, we will provide documentation containing instructions for installing, operating, and maintaining the data acquisition system. We plan to deliver the prototype and the associated documentation by December 5th, 2016, the last day of the Fall 2016 semester.

3.0 SYSTEM DESIGN

The final prototype of the data acquisition system is comprised of three subsystems that will connect the user to data from a laboratory rat. As illustrated in Figure 1, the three subsystems are an implant, a base station, and a web application. The web application, as seen on the right in Figure 1, will require the user to authenticate before they can use it. Once authenticated, the user will be able to control and interact with the data acquisition system. From the web application, the user will use Wi-Fi to send power and data commands to the base station. The base station will then use induction coils to wirelessly power and relay the data commands to the implant. Once powered, the implant will use a temperature sensor and an accelerometer to measure the temperature and acceleration of the rat. From there, the implant will use the induction coils to relay the data back to the base station. The base station will then use Wi-Fi to transfer the data back to the web application. From the web application, the user can view the collected data.

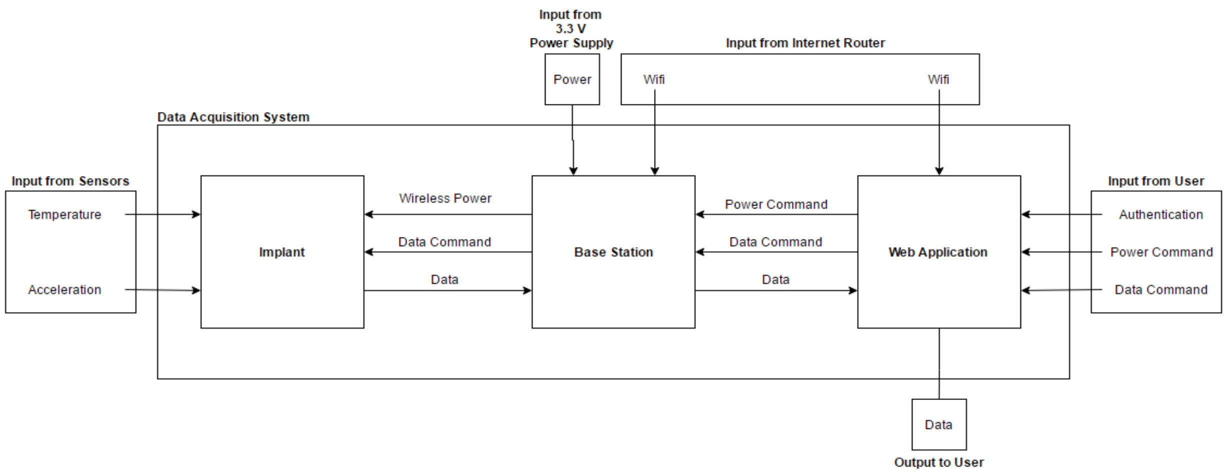

Figure 1. System Block Diagram

In the following subsections, we break down each subsystem of the data acquisition system. First, we describe the functionality of the subsystem. Next, we outline the input and output specifications. Finally, we discuss how we plan to implement each subsystem.

3.1 Implant Design

The first subsystem of the data acquisition system is the implant. As illustrated in Figure 1 above, the base station will wirelessly power the implant. Once powered, the implant will measure the temperature and acceleration of the laboratory rat. From there, the implant will wirelessly communicate that temperature and acceleration data back to the base station. In order for the implant to meet the needs that were stated in previous sections, the implant should adhere to certain input and output specifications. These specifications are described below.

The implant will receive inputs from the base station and the sensors, and will send outputs to the base station. The base station will provide wireless power and data commands to the implant. The wireless power will turn the implant on, while the data command will tell the implant to start collecting data from the sensors. The sensors include a temperature sensor and an accelerometer. The temperature sensor will send the temperature of the rat to the implant, while the accelerometer will send the acceleration of the rat to the implant. Once the implant has collected the temperature and acceleration data, the implant will output that data to the base station. Tables 3 and 4 outline the input and output specifications of the implant in more detail.

Table 3. Implant Input Specifications

From	Name	Description	Specification
Base Station	Wireless Power	Amount of power transferred within a certain distance	Range • 0 to 200 mW • 0 to 18 cm Accuracy • ± 0.00 mW • ± 0.01 cm
Base Station	Data Command	Command to acquire data	See Table D-3 “Data Command Specifications” in Appendix D “Further Specifications”
Sensor	Temperature	Temperature measurement	Range • 0° to 45° C Accuracy • ± 0.01° C
Sensor	Accelerometer	Acceleration measurement	Range • ± 2 g Accuracy • 0.01 g

Table 4. Implant Output Specifications

To	Name	Description	Specification
Base Station	Data	Results from the data acquisition	See Table D-4 "Data Specifications" in Appendix D "Further Specifications"

To meet all our needs, the implant will be implemented by using a microcontroller, an accelerometer, and a coil. As presented in Figure 2 on the next page, the microcontroller will be powered by the coil that wirelessly receives power from the base station, and in turn powers the temperature sensor and the accelerometer. When the coil receives a raw signal containing the data command, it will transfer the data to the microcontroller which in turn will decode and understand the command. Once the microcontroller understands the data command, it will start sampling data from the accelerometer and a temperature sensor using a built-in analog to digital converter (ADC). The collected data will be represented in raw ADC data which in turn will be sent to the base station through the coil.

To meet all the requirements and specifications mentioned previously, we chose the components of the implant accordingly. As shown in Figure 2 on the next page, we decided to use RF430 for the microcontroller. Since the RF430 contains a built-in NFC/RFID transceiver and a temperature sensor, it will alleviate the burden of externally interfacing them. Thus the RF430 will allow us to interface the coil without much external circuitry. The RF430 is also an extremely low power microcontroller which fulfills our need for a low power implant. The LIS3DH will be used for our accelerometer due to its low power requirements meeting the 200 mW maximum of the board. Likewise, our implementation of the implant using the RF430 and LIS3DH will satisfy our needs for it to be wirelessly powered, acquire and transmit data, and consume very little power.

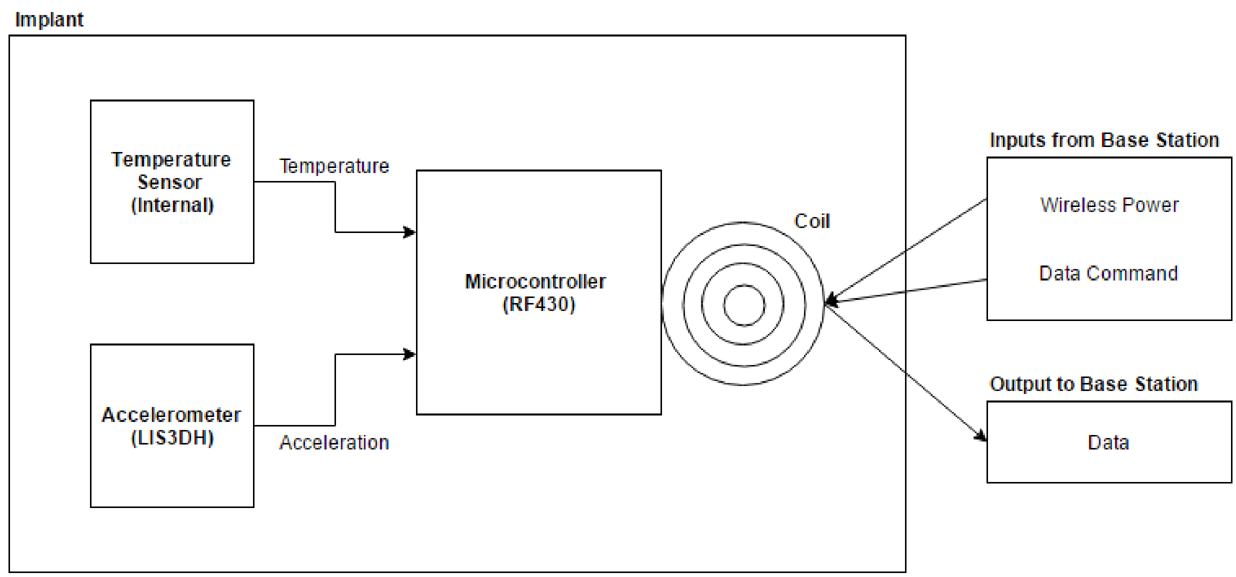

Figure 2. Implant Block Diagram

3.2 Base Station Design

The second subsystem of the data acquisition system is the base station. As depicted in Figure 1 above, the base station will serve as the power source for the implant and as a channel of communication between the implant and the web application. In order for the base station to meet the requirements that were previously mentioned, the base station needs to adhere to certain input and output specifications. These specifications are explained below.

The base station will accept inputs from a power supply, an internet router, the web application, and the implant, and will send outputs back to the implant and the web application. The power supply will provide power to the base station whereas the internet router will provide the base station with access to secure Wi-Fi. From the web application, the base station will receive power and data commands. The power command will tell the base station to switch from standby mode to on, while the data command will tell the base station to start the process of collecting data. Upon receiving a data command, the base station will wirelessly power the implant and relay the data command to the implant. When the implant responds with temperature and acceleration data, the base station will output that data to the web application. Tables 5 and 6 on the next page describe the input and output specifications of the base station in more depth.

Table 5. Base Station Inputs

From	Name	Description	Specification
Power Supply	Power	Power supply for the base station	Value • 3.3 V • 1 A Accuracy • ± 0 V • ± 0 A
Internet Router	Wi-Fi	Wi-Fi for the base station	Secure Wi-Fi
Web Application	Power Command	Command to turn on the base station	See Table D-2 “Power Command Specifications” in Appendix D “Further Specifications”
Web Application	Data Command	Command to acquire data	See Table D-3 “Data Command Specifications” in Appendix D “Further Specifications”
Implant	Data	Results from the data acquisition	See Table D-4 “Data Specifications” in Appendix D “Further Specifications”

Table 6. Base Station Outputs

To	Name	Description	Specification
Implant	Wireless Power	Amount of power transferred within a certain distance	Range • 0 to 200 mW • 0 to 18 cm

			Accuracy • ± 0 mW • ± 0.01 cm
Implant	Data Command	Command to acquire data	See Table D-3 “Data Command Specifications” in Appendix D “Further Specifications”
Web Application	Data	Results from the data acquisition	See Table D-3 “Data Specifications” in Appendix D “Further Specifications”

In order to meet all of our needs mentioned in the needs analysis section, the base station will be implemented using a microcontroller, a NFC/RFID transceiver, a Wi-Fi module, a coil, and a 3.3V power supply. As shown in Figure 3 on the next page, the microcontroller, the NFC/RFID transceiver, and the Wi-Fi module, will all be powered by the power supply, but the coil will be powered by the NFC/RFID transceiver. For the collected data from the implant to reach the web application, it will go through the coil, NFC/RFID transceiver, the microcontroller, and the Wi-Fi module in the exact order. The coil will receive a raw signal that contains the data collected from the implant, which in turn will be converted into a binary data by the NFC/RFID transceiver. Next, the NFC/RFID transceiver will send the binary data the microcontroller using a Serial Synchronous Interface (SSI). Once the microcontroller receives the binary data, it will decode the data, pack it into JavaScript Object Notation **(**JSON), and transmit it to the Wi-Fi module using a Universal Asynchronous Receiver/Transmitter (UART). Once the Wi-Fi module receives the data packed into JSON, it will transmit it to the web application through a secure Wi-Fi. For the commands from the web application to reach the implant, the data will go through the base station modules in the exact opposite order in the path the collected data will go through to reach the web application. The communication protocol and the data format used between each module will be the same.

We chose the components for the modules of our base station to specifically meet all the requirements and the specifications mentioned previously. As shown in Figure 3 below, first, we will use TRF7970A for the NFC/RFID transceiver. The component will allow us to directly power and control the coil to communicate with the implant. Secondly, we will use MSP430 for the microcontroller due to its low power consumption and its compatibility with the TRF7970A. Lastly, we will use ESP8266 for the Wi-Fi module because it is small, cheap, and reliable. The ESP8266 will allow us to interface the base station with the web application in reliable and cost-efficient manner. Likewise, our implementation of the base station using the TRF7970A, the MSP430, and the ESP8266 will fulfill the requirements to wirelessly power and communicate with the implant and wirelessly communicate with the web application.

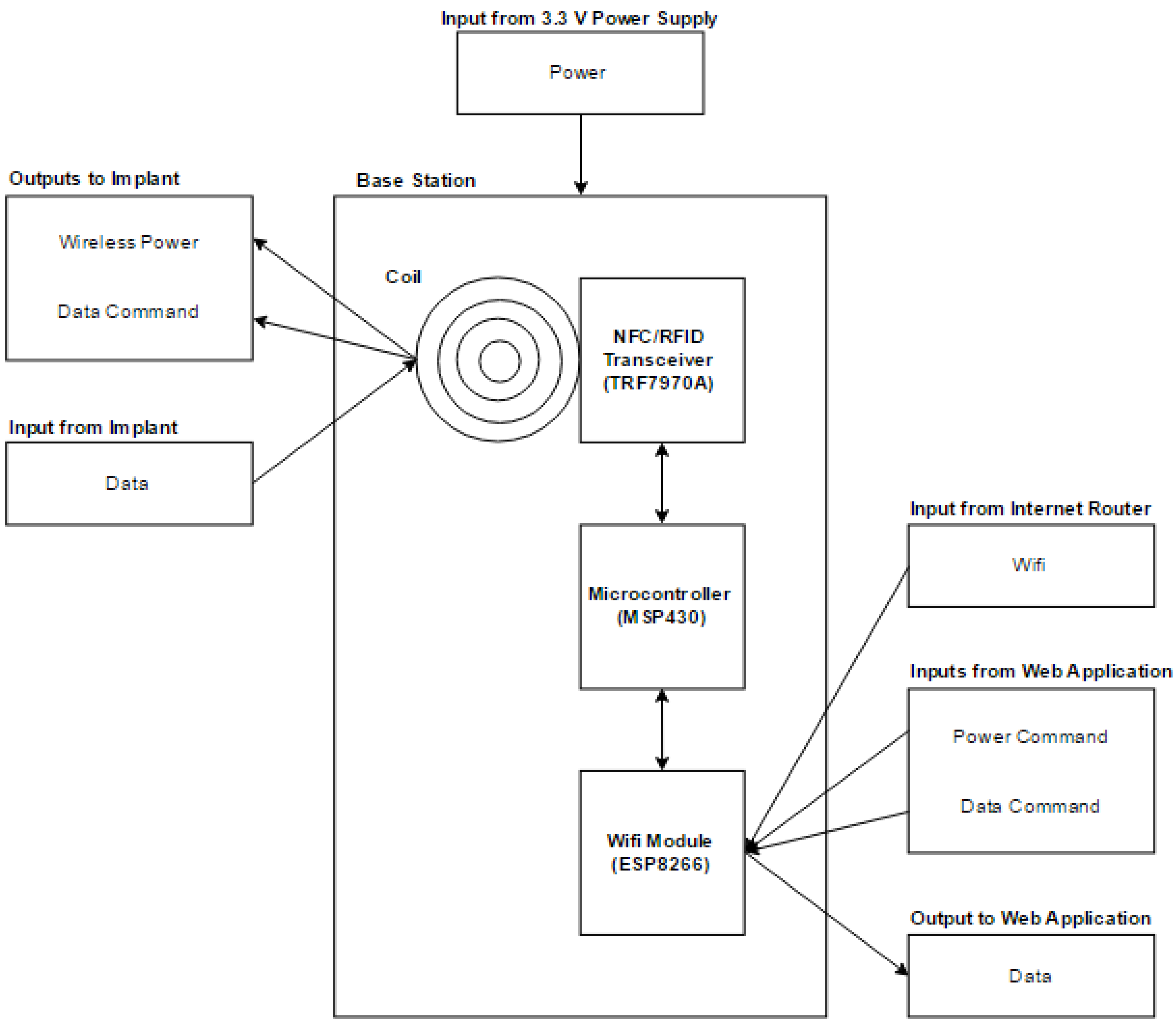

Figure 3. Base Station Block Diagram

3.3 Web Application Design

The third subsystem of the data acquisition system is a web application. As illustrated in Figure 1 above, the web application will allow the user to control and interact with the data acquisition system. In order for the web application to meet the needs that were stated in earlier sections, the web application should adhere to certain input and output specifications. These specifications are defined below.

The web application will receive inputs from an internet router and the user, and will send outputs to the base station and the user. The internet router will provide the web application with access to secure Wi-Fi so that it can communicate with its server and the base station. In order for the user to access the web application, he will have to input his authentication credentials. Once authenticated, the user can send power and data commands from the web application to the base station. The power command will tell the base station to switch from standby mode to on, while the data command will tell the base station to start the process of collecting data. Once the base station has collected the data, the base station will send the data back to the web application. The web application will then output that data to the user. Tables 7 and 8 describe the input and output specifications of the web application in more detail.

Table 7. Web Application Input Specifications

From	Input	Description	Specification
Internet Router	Wi-Fi	Wi-Fi for the web application	Secure Wi-Fi
User	Authentication	Credentials to access to the web application	See Table D-1 “Authentication Specifications” in Appendix D “Further Specifications”
User	Power Command	Command to turn on the base station	See Table D-2 “Power Command Specifications” in Appendix D “Further Specifications”

User	Data Command	Command to acquire data	See Table D-3 "Data Command Specifications" in Appendix D "Further Specifications"
Base Station	Data	Results from the data acquisition	See Table D-4 "Data Specifications" in Appendix D "Further Specifications"

Table 8. Web Application Output Specifications

To	Output	Description	Specification
Base Station	Power Command	Command to turn on the base station	See Table D-2 "Power Command Specifications" in Appendix D "Further Specifications"
Base Station	Data Command	Command to acquire data	See Table D-3 "Data Command Specifications" in Appendix D "Further Specifications"
User	Data	Results from the data acquisition	See Table D-4 "Data Specifications" in Appendix D "Further Specifications"

The web application will be built using IBM Bluemix, a cloud platform for developing accessible and scalable web and mobile applications. In order to secure the web application, we will use the Single-Sign-On service that is provided by IBM Bluemix. This service requires users to authenticate themselves before they can access the web application. As depicted in Figure 4 on the next page, we will use the IBM Watson Internet of Things Platform (WIoT) service to interface the web application with the base station. As long as both the base station and the web application are connected to Wi-Fi, they can use the WIoT service to communicate with each other. In other words, the web application will be able to send commands to the base station and the base station will be able to send data back to the web application. Upon receiving data, the web application will store the data in a database. In order to store the data in a database, we will use the Cloudant NoSQL Database service, which is also provided by IBM Bluemix. Finally, the web application will display the data to the user so that it can be monitored and analyzed.

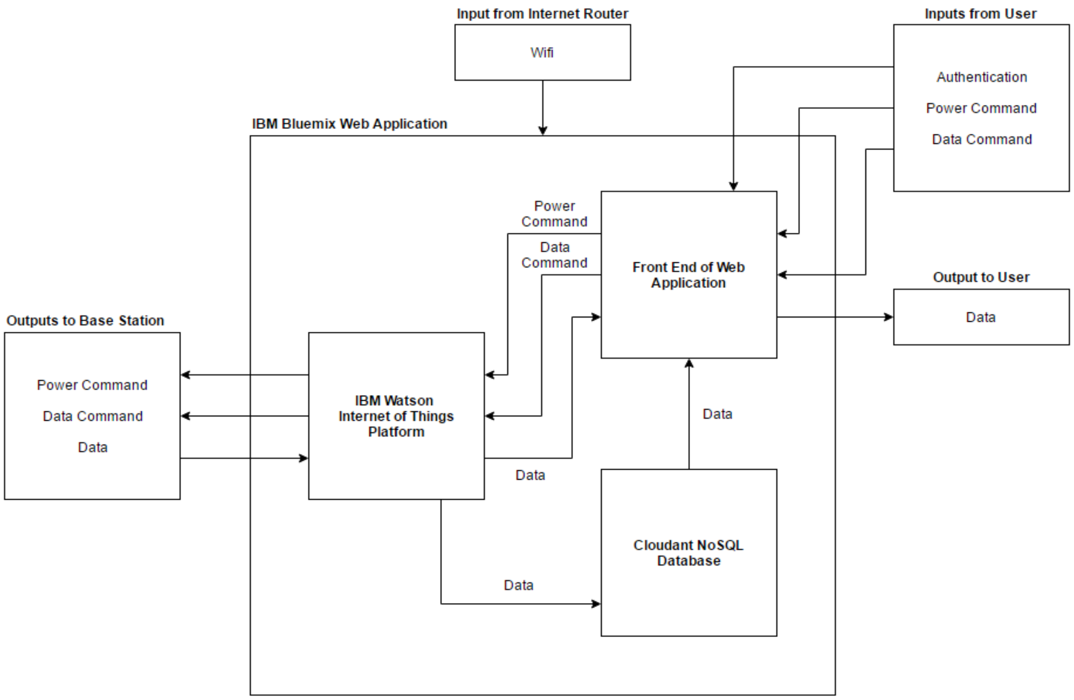

Figure 4. Web Application Block Diagram

4.0 USER INTERFACE DESIGN

The user interface includes the initial setup that is required by the data acquisition system as well as a web page on the web application. Initially, the user will embed the implant into a laboratory rat and place the base station just outside of and adjacent to the rat cage. As illustrated in Figure 5 on the next page, once the implant and the base station are set up, the user will interact with the data acquisition system through a web page on the web application.

At first, the implant will be off and the base station will be on standby. On the web page, the user can send a power command from the web application to the base station in order to switch the base station from standby mode to on. Once the base station is on, the user can send a data command from the web application to the base station in order to acquire data from the implant. When the base station receives the data command, it will wirelessly power the implant. With the implant powered, the base station will send a command to the implant to acquire data from the temperature sensor and accelerometer. Once the implant collects the temperature and acceleration data, the implant will send the data back to the base station. From there, the base station will send the data back to the web application. When the web application receives the data, it will store the data into a database as well as display the data on a web page. The users can then use the web page to monitor and analyze the data that was collected from the rat.

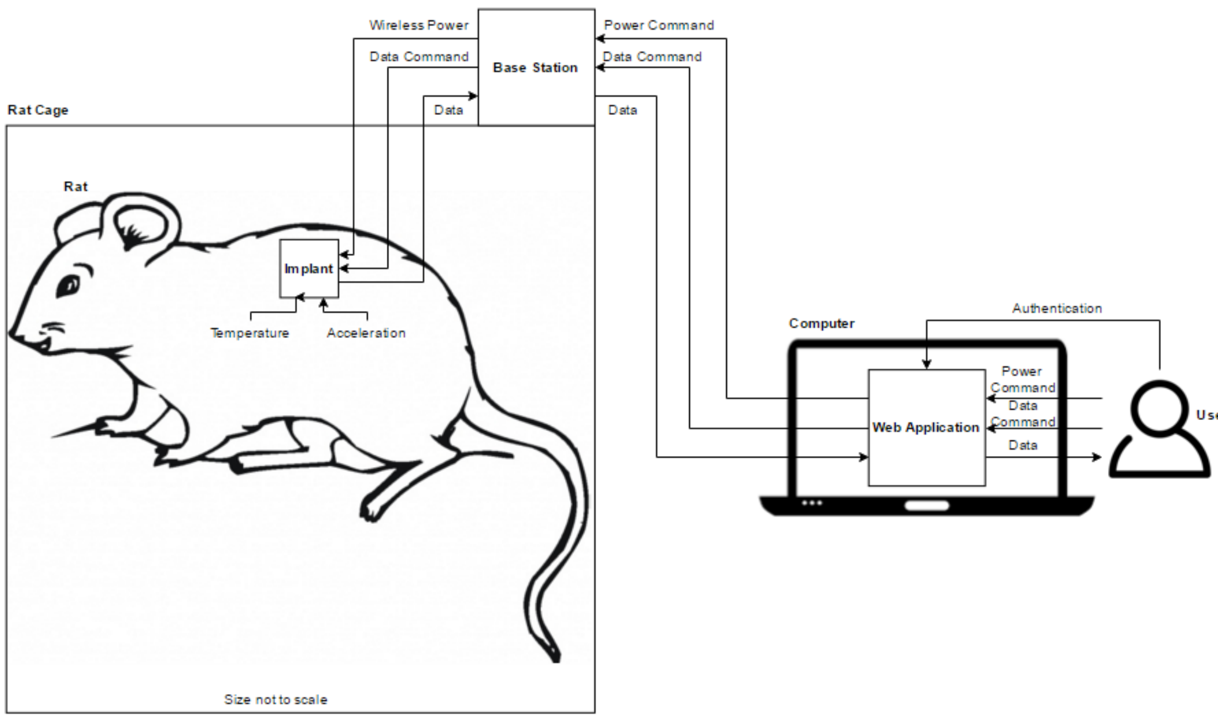

Figure 5. User Interface Block Diagram

5.0 RISK REDUCTION

In order to ensure that we will complete the data acquisition system by December 5th, 2016, we have taken several preventative measures against potential risks. First, we met with Andrew Wang, a graduate student who worked with Dr. Valvano to implement a similar data acquisition system. During the meeting, Andrew discussed several problems that would occur and suggested potential solutions to those problems. After meeting with Andrew, we searched for parts that we could use in our system to help simplify our design. During our research, we discovered the RF430 and the TRF74970A evaluation boards. These evaluation boards provide the radio frequency circuitry for the wireless power transmission and communication internally. We immediately ordered the evaluation boards and performed experiments with them. From these experiments, we determined that the evaluation boards would greatly simplify our design. Although the evaluation boards provide internal radio frequency circuitry, we will still need to construct the external coils that will connect to the internal circuitry. Therefore, we also researched different possible coil topologies that we can use in our coil design. This will provide us with multiple alternatives in case the one we selected fails. The steps that we have taken thus far will help to ensure that we finish our data acquisition system on time.

6.0 PROTOTYPE COST

The majority of the materials needed for our data acquisition system will be provided by our faculty sponsor. These materials include the evaluation boards, additional microcontrollers, a Wi-Fi module, resistors, capacitors, and a flash programmer for the microcontrollers. Although these materials will be of no cost to us, the total market value for these materials is $444.70, as shown in Appendix B. For the implant microcontroller, we will order two RF430 evaluation boards, each valued at $19.90 [2]. For the base station microcontroller, we will order two TRF7970A evaluation boards, each valued at $99.00 [3]. Both of the RF430 and the TRF7970A evaluation boards implement the MSP430 microcontroller. Therefore, we will also order two of MSP430 microcontrollers, each valued at $35.00 [4]. In order to flash program and debug these evaluation boards and microcontrollers, we will order one MSP430 flash programmer, valued at $115.00 [5]. In addition, because the base station needs to communicate with the web application, we will order two ESP8266 Wi-Fi modules, each valued at $6.95 [6]. Finally, we will also order no more than $8.00 worth of resistors and capacitors, which we will use in the PCB design of our implant [7]. With our faculty sponsor providing all of the previously mentioned material, the only materials that we need to purchase are two LIS3DH accelerometers, each valued at $1.63 [8]. The LIS3DH accelerometers are required for the implant to measure acceleration. By ordering two of each material, except for the MSP430 flash programmer, we hope to prevent unnecessary project delays that result from waiting for parts.

7.0 TEST PLAN

In order to ensure that our data acquisition system is as efficient and accurate as possible, we will thoroughly test each aspect of our system. These tests will also serve as checkpoints by which we can measure the progress made throughout the implementation stages. The following sections discus our plans for testing the coils, the individual subsystems, and the system as a whole.

7.1 Coil Testing

The induction coils allow for wireless power transmission and communication between the between the base station and implant. They will be our biggest design challenge and therefore designing, constructing, and testing the induction coils are our number one priority. The first step will involve connecting the base station coil to a function generator producing a resonant frequency of 13.56 MHz, the normal operational frequency for our system. Next, we will place the implant coil 18 cm below the base station coil and cover it with a material that absorbs electromagnetic waves similar to the skin of a rat. We will then connect the implant coil to a DC electronic load with a current requirement matching that of our implant. The voltage across the load should remain at a range of 145 mV to 200 mV, which is the supply voltage range of the implant's microcontroller during operation. In order to measure this voltage, we will use an oscilloscope to plot the voltage across the load for various positions and angles of the implant coil underneath the base station coil.

7.2 Subsystem Testing

In order to confirm that each subsystem functions as expected, we will conduct independent tests on the implant, the base station, and the web application. For the implant, we will test to make sure that it can receive power and communicate data wirelessly. To show that the implant can wirelessly receive power between 145 mV to 200 mV, we will use a test coil to turn on the implant's microcontroller. Once powered, the microcontroller will run code that causes an LED flash on and off. To confirm that the implant can wirelessly communicate data, we will use the same test coil to send a 16-digit dummy data to and from the implant's microcontroller. For the base station, we will connect an oscilloscope to make sure that there is a 13.56 MHz signal present and that the power supplied by its coil is approximately 200 mW, which is the maximum power output of the base station's microcontroller. In addition, we will also test its Wi-Fi connection by sending dummy data to and from the base station's microcontroller and the server. Finally, for the web application, we will test both the front-end and the back-end of the web application. In order to test the front-end, we will experiment with the user authentication, the user's ability to enter commands, and the user's ability to view data. In order to test the back-end, we will send dummy data to and from the server and confirm that data is being correctly store in the database.

7.3 System Testing

Once each subsystem has been tested independently, we will conduct tests on the system as a whole. First, we will attach an oscilloscope to the communication channel of the implant so that we can view the data that the implant is collecting. In addition, we will also attach an oscilloscope to the communicate channel of the base station so that we can view the data that the base station is receiving. Next, from the web application, we will send a power command to turn on the base station and data commands to collect data from the implant. As the implant collects data and the web application displays it, we will compare the data displayed on the oscilloscopes to that displayed on the web application and confirm that they all match. We will confirm the accuracy of the system by comparing the collected temperature data to a digital thermometer reading. Additional tests will also be done by placing the implant in different environments as well varying the distances between the implant and the base station coils. This suite of tests will confirm the correct operation of the subsystems as well as our system as a whole.

8.0 PROJECT SCHEDULE

As depicted in Appendix C, our Gantt chart outlines a schedule to complete the implementation phase of our Senior Design project in 13 weeks. To build, integrate and test our data acquisition prototype, we have organized our activities around several key milestones. First, we will dedicate 20 man hours during the first week in September to finalizing our design for our implant and base station coils. Assigning these extra design hours will decrease the chance of us running into problems during later stages. We will then allocate 120 man hours to complete and test the prototype of our base station by September 28th. By this point, our base station subsystem should be completed. On October 6th, we will finish soldering and testing the PCB for our implant, as well as designing the protocol we will use to communicate between the implant and base station.

We estimate this will take 50 man hours. Thus our implant subsystem will be finished. Next, we will dedicate 200 man hours to interface our implant to the base station and our base station to the web application by November 22nd. Concurrently, we will have also completed our web application subsystem by November 14th. We have allocated the largest amount of time to interfacing the three subsystems due to the projected difficulty in connecting them. Finally, during the two weeks prior to Open House on November 23rd, we will allocate 50 man hours to testing our completed system. This will ensure our system is thoroughly tested while also giving the team enough time to create a good demonstration for Open House. We will then deliver a final written report and oral presentation by end of the Fall semester, December 5th, 2016.

9.0 CONCLUSION

This system design report has outlined the design, implementation, and analysis of an efficient, cost effective implanted data acquisition system for research labs. The team created their proposed solution to fit the needs of the client and the design problem. The client needed a system that would be efficient and cost effective for a laboratory environment. The problem designated the implant subsystem to be able to communicate and be powered wirelessly. The proposed design consists of a three part system: the implant, the base station, and the web application. The implant will be small enough to fit inside a lab rat and will have sensors to collect the temperature and acceleration data. The implant and the base station will have inductor coils attached to wirelessly send power and data between the two subsystems. The base station will then send the data to a web application where it can be viewed by a user. The web application would provide a layer of abstraction between the operation of the system and the user, thus allowing for ease of use.

Careful analysis of the proposed design was also done to mitigate risks, calculate costs, create a testing suite, and plan a work schedule. In order to reduce the risks of waiting for parts and running into issues with the design, parts have been ordered early and the team has already entered into discussions with a grad student who implemented a similar design. Costs have also been analyzed for each subsystem and a total estimate comes just under $450. However, by taking advantage of free parts and university company connections, the cost of the prototype itself will be much lower. Additionally, testing for the design has been broken down into its subsystems. Testing each subsystem separately will ensure validity while also serving as checkpoints for the implementation stages. Finally a Fall semester implementation schedule for the project has been outlined and attached in Figure C-1 in Appendix A. Now that we have finished the initial design stage of the project, we will be ordering more parts and starting first with the implementation of the implant subsystem. The team will be dedicated to finishing the proposed design and associated documentation by December 5th, 2016, the last day of the Fall 2016 semester.

REFERENCES

[1] (2014, December 22). *Guidance for Industry and FDA Staff – Class II Special Controls Guidance Document: Implantable Radiofrequency Transponder System for Patient Identification and Health Information* [Online]. Available: http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm072141.htm

[2] "NFC ISO 15693 Sensor Transponder Evaluation Module." [Online]. Available: http://www.ti.com/tool/rf430frl152hevm

[3] "NFC Transceiver Evaluation Module." [Online]. Available: http://www.ti.com/tool/trf7970aevm

[4] "MSP-EXP430FR5739 Experimenter Board." [Online]. Available: http://www.ti.com/tool/msp-exp430fr5739

[5] "MSP430 USB Debugging Interface," [Online]. Available: http://www.ti.com/tool/msp-fet430uif

[6] "Wi-Fi Module - ESP8266." [Online]. Available: https://www.sparkfun.com/products/13678

[7] "Electronic Goldmine." [Online]. Available: http://www.goldmine-elec-products.com/default.asp

[8] LIS3DHTR," [Online]. Available: http://www.digikey.com/product-detail/en/stmicroelectronics/lis3dhtr/497-10613-1-nd/2334355?enterprise=44

[9] *Radio Spectrum Allocation* [Online]. Available: https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation

[10] *Radio Frequency Safety* [Online]. Available: https://www.fcc.gov/general/radio-frequency-safety-0

[11] (2013, May 31). *RF Exposure Considerations for Low Power Consumer* [Online]. Available: https://apps.fcc.gov/kdb/GetAttachment.html?id=gDJO4az8eyw84%2BgyujPd%2Bw%3D%3D&desc=680106%20D01%20RF%20Exposure%20Wireless%20Charging%20Apps%20v02&tracking_number=41701

[12] Tadlock Cowen. (2013, June 12). *The Animal Welfare Act: Background and Selected Animal Welfare Legislation* [Online]. Available: http://nationalaglawcenter.org/wp-content/uploads/assets/crs/RS22493.pdf

REFERENCES CONTINUED

[13] (2015, October 14). *Guidance for Industry and FDA Staff: General Considerations for Animal Studies for Medical Devices* [Online]. Availabe: http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM466358.pdf

[14] *IEEE Code of Ethics* [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html

APPENDIX A – RELEVANT STANDARDS

APPENDIX A – RELEVANT STANDARDS

There are several standards that factor into the design of our system. First, the frequencies at which the base station powers and communicates with the implant and the communication protocol it follows need to adhere to the standards set forth by the Federal Communications Commission (FCC). Second, because the implant will be embedded into laboratory rat, our system also needs to comply with the Animal Welfare Act of 1966 (AWA) and the regulations set forth by The Food and Drug Administration (FDA). Finally, as engineers, it is also important that as a team, we, and our system, adhere to the Institute of Electrical and Electronics Engineers (IEEE) Code of Ethics.

Federal Communications Commission

The FCC regulates interstate and international communications by wire, cable, radio, television, satellite across the United States. Because the base station needs to use radio frequencies to power and communicate with the implant, it is important that our system adheres to the FCC rules. Below are three excerpts from the FCC that highlight the regulations our system needs to comply with.

"...Currently only frequency bands between 9 kHz and 275 GHz have been allocated (i.e., designated for use by one or more terrestrial or space radio communication services or the radio astronomy service under specified conditions)..." [9].

"...On August 1, 1996, the Commission adopted the NCRP's recommended Maximum Permissible Exposure limits for field strength and power density for the transmitters operating at frequencies of 300 kHz to 100 GHz. In addition, the Commission adopted the specific absorption rate (SAR) limits for devices operating within close proximity to the body as specified within the ANSI/IEEE C95.1-1992 guidelines..." [10].

"...Depending on the operating configurations, wireless power transfer devices may need to be approved under FCC Rule Parts 15, 18 or both. Devices authorized under Part 15 may not transmit in the 90-110 kHz band, which is restricted under §15.205. Part 18 of the rules permits

devices operating in the Industrial, Scientific and Medical (ISM) band to generate and use RF energy locally to perform work..." [11].

Animal Welfare Act of 1966

The AWA ensures that animals intended for research, bred for commercial sale, commercially transported, or exhibited to the public, are treated humanely. Because the implant will be embedded into a laboratory rat, it is necessary that our system complies with the AWA. Below are two excerpts from the AWA that highlight the standards our design needs to abide by.

"...The Animal Welfare Act...expanded animal coverage to include all warm-blooded animals determined by the Secretary to be used for experimentation or exhibition…" [12].

"...The law directs the Secretary to set new minimum standards of care for handling, housing, feeding, water, sanitation, ventilation, and so forth...The law provides that research facilities must have procedures that minimize pain and stress to the animals, and describes practices considered to be painful…" [12].

Food and Drug Administration

The FDA is responsible for protecting the public health by ensuring the safety and security of food, human and animal drugs, and medical devices. Because the implant will be embedded into a laboratory it is essential that our system adheres to FDA standards. Below are several excerpts from the FDA that highlight the relevant standards our system needs to conform to.

"...We recommend that the transponder and inserter be sterile with a sterility assurance level of 10^-6..." [1].

"...We recommend that you ensure the biocompatibility of the patient-contacting parts of your device..." [1].

"...FDA recommends that you identify key biologic response variables at regional sites, at locations adjacent to the implant site, and along all paths to and from the point of implantation…" [13].

"...FDA recommends that you evaluate whether or not the device can have effects 365 remote from the site of placement or use…" [13].

"…We recommend that you conduct testing of the implanted transponder to demonstrate that the transponder will not migrate after implantation..." [1].

"…We recommend that your specifications for a compatible database address the following four components of information security: Confidentiality, Integrity, Availability, and Accountability..." [1].

"…We recommend that you demonstrate the basic EMC of the device (i.e., transponder and scanner together) by performing EMC testing…" [1].

"…We recommend that you demonstrate the magnetic resonance imaging compatibility of your device…" [1].

IEEE Code of Ethics

The purpose of IEEE is to advance educational and technological excellence and innovation for the benefit of humanity. Because we are a team of engineers and our system will be integrated into animal and human life, it is important that we abide by the IEEE Code of Ethics. Below is the full IEEE Code of Ethics.

"We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding of technology; its appropriate application, and potential consequences;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;
10. to assist colleagues and coworkers in their professional development and to support them in following this code of ethics [14].*"*

APPENDIX B – BILL OF MATERIALS

APPENDIX B – BILL OF MATERIALS

Figure B-1 illustrates the bill of materials for our data acquisition system. The majority of the items we need will be provided by our faculty sponsor and will be at no cost to us. These items include the evaluation boards, additional microcontrollers, a Wi-Fi module, resistors, capacitors, and a flash programmer for the microcontrollers. The only other items that we will need to purchase ourselves are the accelerometers.

Name	Description	Party Number	Quantity	Value	Original Subtotal	Comp'd	Final Subtotal
RF430 Evaluation Board	Implant Evaluation Board	RF430FRL152HEVM	2	$19.90	$39.80	$39.80	$0.00
TRF7970A Evaluation Board	Base Station Evaluation Board	TRF7970AEVM	2	$99.00	$198.00	$198.00	$0.00
MSP430 Microcontrollers	Implant and Base Station Microcontrollers	MSP-EXP430FR5739	2	$35.00	$70.00	$70.00	$0.00
MSP430 Flash Programmer	Microcontroller Flash Programmer	MSP-FET430UIF	1	$115.00	$115.00	$115.00	$0.00
ESP8266 Wifi Module	Wifi Module for the Base Station	ESP8266	2	$6.95	$13.90	$13.90	$0.00
Resistors and Capacitors	Resistors and Capacitors for PCB Design of the Implant	N/A	100	$0.08	$8.00	$8.00	$0.00
LIS3DH Accelerometer	Accelerometer for the Implant	LIS3DH	2	$1.63	$3.26	$0.00	$3.26
				Total	**$447.96**	**$444.70**	**$3.26**

Figure B-1. Bill of Materials

APPENDIX C – GANTT CHART

APPENDIX C – GANTT CHART

Figure C-1, on the next page, illustrates the Gantt chart that we will follow in order to complete our data acquisition system by December 5th, 2016. The major tasks for our project include constructing and testing the implant and base station coils, designing and soldering the PCB for the implant, building the base station and web application, and interfacing the three subsystems. Throughout our project we will also deliver several written reports and oral presentations to our faculty sponsor.

Figure C-1. Gantt Chart

APPENDIX D – FURTHER SPECIFICATIONS

APPENDIX D – FURTHER SPECIFICATIONS

The following appendix provides further elaboration on the major inputs and outputs of the data acquisition system. Table D-1 describes what credentials the user is required to provide in order to access the web application. In addition, Tables D-2 and D-3 describe the components of the power and data commands that will be sent from the web application to the base station and the implant. Finally, Table D-4 describes the properties of the data object that is sent from the implant, through the base station, to the web application.

Table D-1. Authentication Specifications

Name	Description	Specification
Username	Username for authentication	Employee Email Address
Password	Password for authentication	16 digit sequence of numbers, letters, and special characters

Table D-2. Power Command Specifications

Name	Description	Specification
Base Station ID	Unique identification number for the base station	16 digit sequence of numbers
Power Control	Command to switch the base station from standby to on	Binary (1 for on, 0 for standby)

Table D-3. Data Command Specifications

Name	Description	Specification
Data Control	Command to start or stop data collection	Binary (1 for start, 0 for stop)

Base Station ID	Unique identification number for the base station	16 digit sequence of numbers
Implant ID	Unique identification number for the implant	16 digit sequence of numbers
Sensor ID	Unique identification number for the sensor	16 digit sequence of numbers

Table D-4. Data Specifications

From	Name	Description	Specification
Web Application	Data ID	Unique identification number for the data	16 digit sequence of numbers
Base Station	Base Station ID	Unique identification number for the base station that the data came from	16 digit sequence of numbers
Implant	Implant ID	Unique identification number for the implant that the data came from	16 digit sequence of numbers
Implant	Sensor ID	Unique identification number for the sensor that the data came from	16 digit sequence of numbers
Implant	Temperature	Temperature measurement from implant	Range • 0° to 45° C Accuracy • ± 0.01° C

Implant	Acceleration	Acceleration measurement from implant	Range • ± 2 g Accuracy • 0.01 g
Base Station	Data Timestamp	Date and time data was received by the base station	Year, Month, Day, Hour, Minute, Second, Millisecond