

USB-powered Micro-Reader for Self-Powered Health and Usage Monitoring

Sponsored by: MSU Technologies

Final Proposal

10/11/13

Design Team 1

Brett Johnson, Evan Gardetto, Ron Razalan, Thamer Alshuaibi, Yuval Levental

Facilitator:

Fathi Salem



Executive Summary

Overview: The purpose of this document is to outline the Design Team 1 Capstone project scope and describe the teams engineering design proposal based on communication with the customer and thorough investigation of available resources.

Project: MSU Technologies desires a micro-reader that can extract data off of infrastructure stress sensors. Current design utilizes a bulky interface box and requires a laptop running MATLAB to acquire the sensors data.

Objectives: Design a portable, cost effective micro-reader that can successfully communicate with the stress sensors and prove reliable during operation in the field.

Proposed Solution: Battery powered micro-reader unit based around the Raspberry Pi platform, programmed to interact with a touchscreen display peripheral, with a simple to use GUI that can perform all necessary functions to interact with the sensor modules per customer requirements.

Table of Contents

Technical	3
Introduction	3
Background	5
Design Specification	6
FAST Diagram	7
Conceptual Design Descriptions.....	8
Conceptual Designs Comparison.....	9
Proposed Design Solution	10
Risk Analysis	11
Project Management Section	13
Project Management Plan.....	13
Cost	14
Budget	14
References	16

Technical

Introduction

In response to demand from the capital goods industry, MSU Technologies researched methods to monitor and record stress levels over the duration of an infrastructures' lifespan. Access to this data allows engineers to determine the current health of a building, road, or other any type structure. With this information, the condition of the infrastructure can be analyzed, and with proper action, if required, can take place. Applications for this type of device could be expanded further than just infrastructure, possibly being implanted into high impact zones on sports athletes' equipment. Concussions in sports have become a serious area of concern over the last few years, and having the ability to read impact data in such a small device would be a beneficial tool.

Over the course of the last seven years, MSU Technologies successfully developed a piezo-floating gate (PFG) system-on-chip sensor (SOC) that could accurately measure the necessary data and store it via flash memory. Using the self-powered sensor that we are given, our task is to develop a method to extract health and usage data from the sensor and display it on a user friendly interface.

Customer Needs/Requirements

There are five main requirements that our product must incorporate. First, the product must have the ability to extract data from the sensor and easily display the data. Next, the product must be small, portable and durable so that it can be used in the field, and also be very reliable. Third, the product must be able to read/write to all eight of the pins on the sensor, as well as implement eight simple functions. Furthermore, the product must be able to regulate a voltage between 1.8V-2.5V on the chip in order to prevent damage to the sensor. Lastly, the product must include a simple method to connect the sensor to the microcontroller that does not compromise the integrity of the I/O pins on the chip.

To address these various requirements, our team proposes that the final device will be all inclusive meaning that it will be a self-sustaining device. It will have a rechargeable battery capable of powering the Raspberry Pi and the Display. The voltage will be monitored via voltage regulators on the Raspberry Pi and through programming. The quick connect/disconnect port will be designed in CAD software where a custom wire harness will be prototyped. The final enclosure will also be custom designed in CAD software and will be fabricated with a 3D printer.

Background

Michigan State University has developed a PFG SOC that can be used to monitor civil and mechanical infrastructures using voltage inputted to it through the strain and stress on it. This sensor requires approximately 1uW of power through the piezoelectric device. Figure 1 displays a high-level view of the prototype PFG SOC's design characteristics.

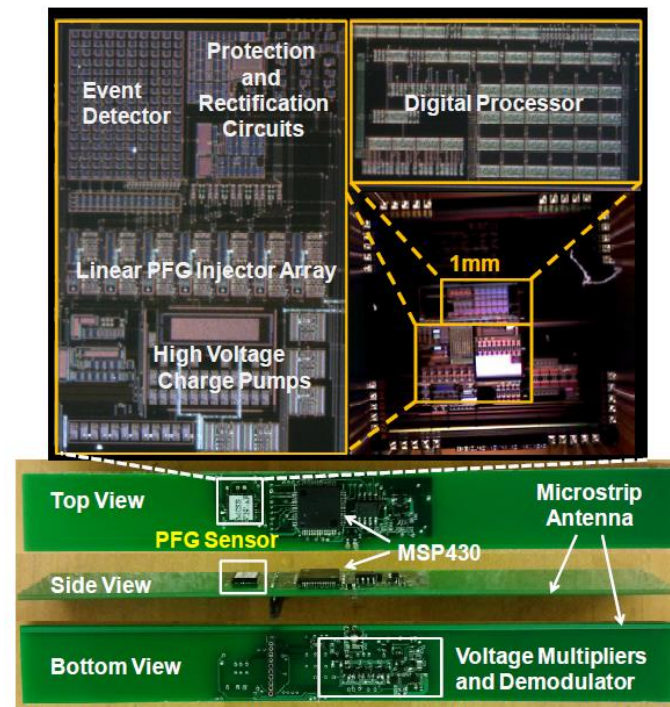


Figure 1

MSU Technologies has created a method to pull data from the sensor using an interface box that responds to MATLAB functions from a Host PC. While this method works, its size is cumbersome and does not meet the demands of a real-world product.

Design Specification

- Small in size as well as portable and durable
- Device must be all inclusive and self-sustaining: power supply, hardware interface, and software programming

The prime goal of this project is to create a device to be used in field in different circumstances and atmospheres. A phenomenal requirement of this device is that it must be designed to all inclusive and self-sustaining. The device is required to be portable and dependable under various environmental conditions. The device needs to maintain the same outcomes wherever it is used. Also, the device power has to last for as long time as possible so it does not force users to consume money and purchase multiple power supplies.

- Regulate an on-chip voltage of 1.8V-2.5V

The design has to include a voltage regulator to step down the inputted power to a range between 1.8V and 2.5V to be sent from the Raspberry Pi to the PFG sensors. The inability of stepping the power down will cause damages on the PFG sensors and not allow users to read out the correct data. Moreover, the PFG sensors may be burned if the power is more than the sufficient amount.

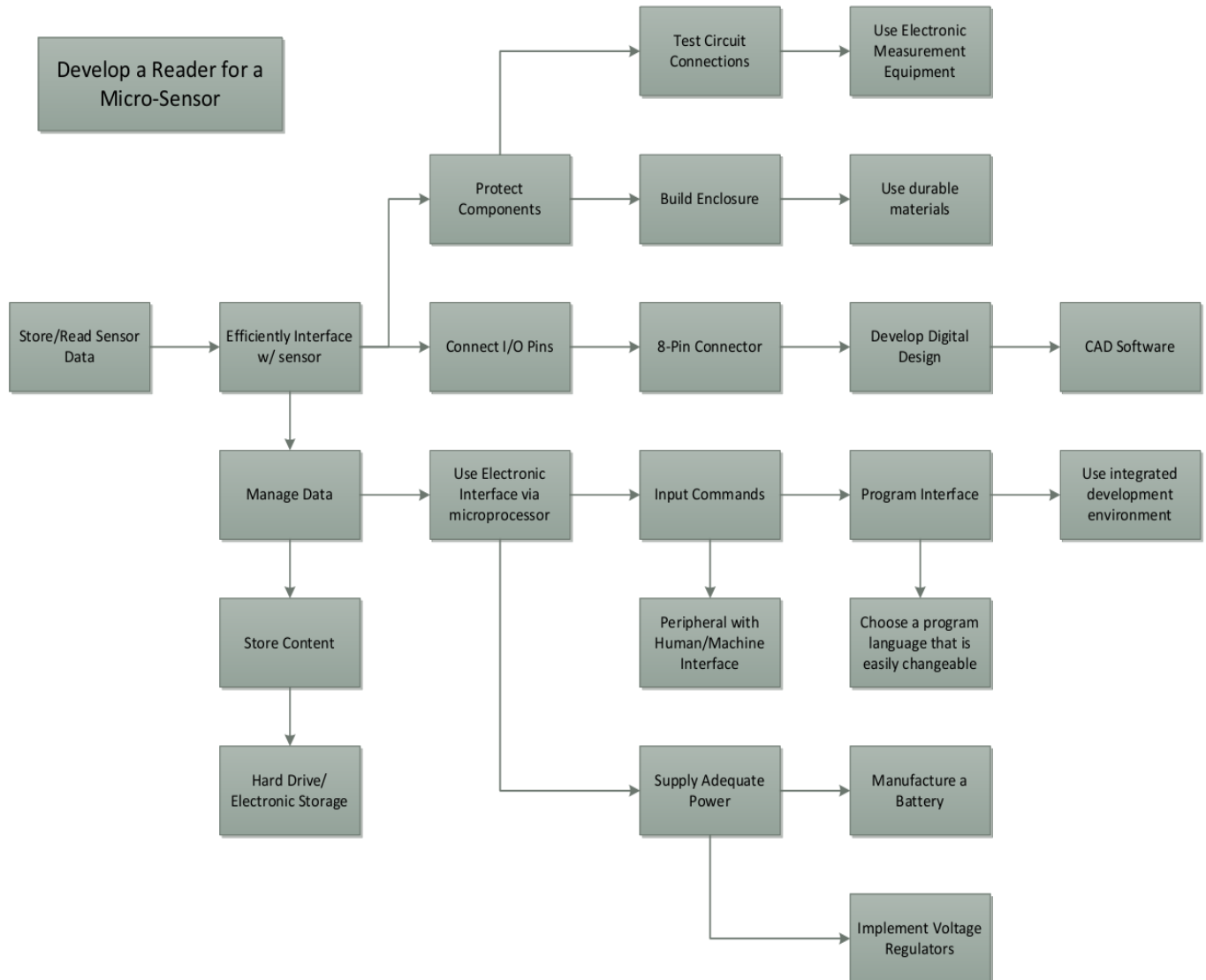
- Extract data from sensor as well as display the data
- Provide hardware that can interface with the PFG

In order to have the device work, it will be designed in a way that allows it to extract the desired data, and that can be implemented through an interface with PFG sensor IC that the device can read through and visualize its outputs.

- Must read/write to all pins as well as implement 6 functions

The design group is required to develop a device to read and write to all pins in the device. The device must be programmed to setup, control and read analog and digital data from the PFG Sensor IC. The anticipated functions to be implemented using the device are the following: ERASE, PROGRAM, AnalogREAD, DigitalREAD, RESET and NEXT. This programming portion can be done through different programming languages.

FAST Diagram



Conceptual Design Descriptions

1) Raspberry Pi Linux-based Interface

Description: Construct a portable Raspberry Pi computer running a Linux OS, complete with battery power and screen display with simple button GUI, all contained within a ruggedized enclosure. Pi connects directly to PFG via custom 8 pin connector. The Raspberry Pi is a more powerful and capable device than the Arduino Uno, but costs about \$20 more.

Required Components:

- Raspberry Pi
- TFT LCD Display (4-7") (Analog or HDMI)
- Battery Power
- Voltage Regulators
- Connector for PFG sensor
- Enclosure for components

2) Arduino Uno/ PC Interface

Description: Use Arduino Uno Microcontroller board as a gateway between PFG and Host PC. Simple computer program created by design team would send commands to Arduino via USB, then Arduino would output corresponding signals to PFG to initiate various actions. Assuming the user already has a computer available, this is a lower cost solution than the Raspberry Pi method.

Required Components:

- Arduino Uno
- Laptop
- USB connection between Uno and PC, providing power and data lines
- Customized 8-pin connection between UNO and PFG Sensor.

Ranking of Conceptual Designs

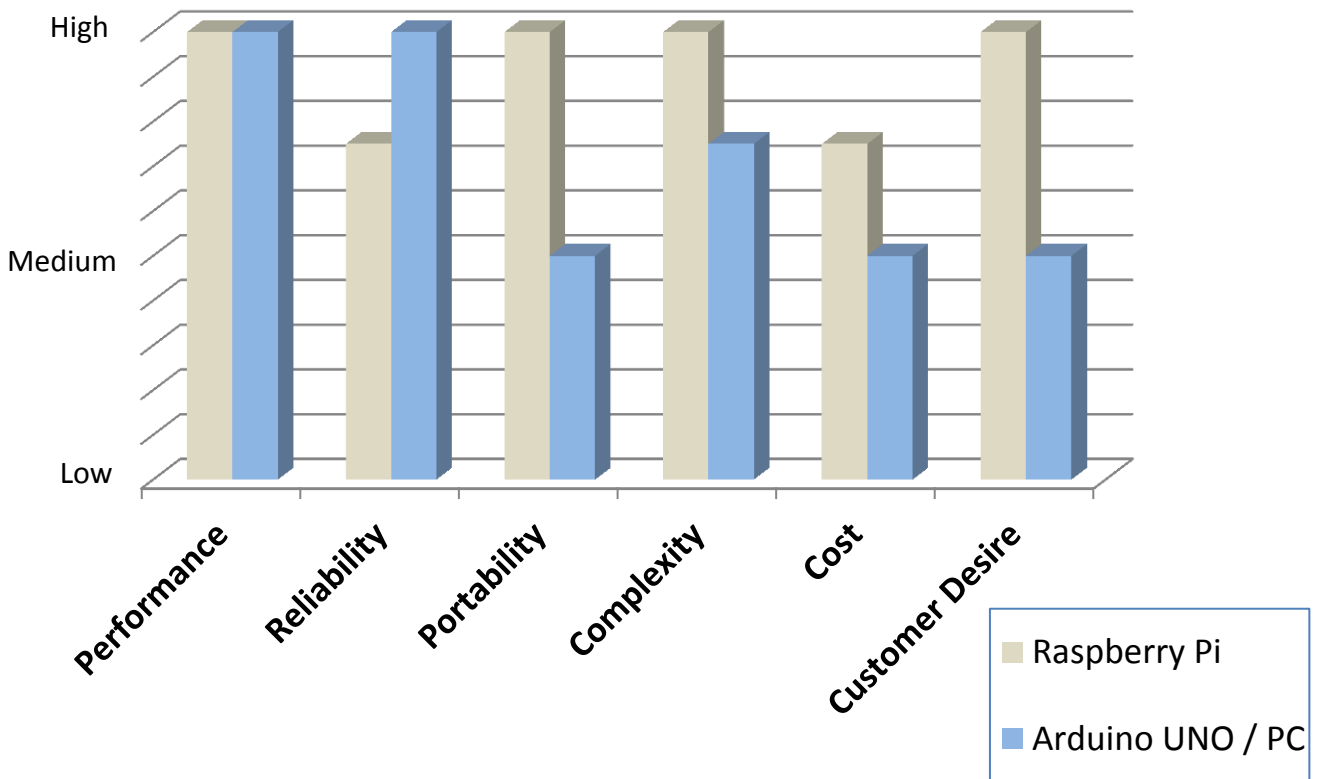


Figure 2

Overall Analysis: Figure 2 above compares the expected outcomes of each designs implementation. The Arduino Uno with a PC is a bulky combination and thus has an impractical implementation in the work environment. While the Arduino UNO/PC would be a simpler, cost-effective design that would accomplish all the requirements, the team would prefer to develop a stand-alone device that provides extreme portability for the user and will be easier to use than a comparable PC program despite the cost and complexity. The easier to use design (simple touch screen interface) coupled with an all-in-one form factor, shows that a custom Raspberry Pi mini-computer is the most practical solution for reading a sensor that will be deployed out in the field.

Proposed Design Solution

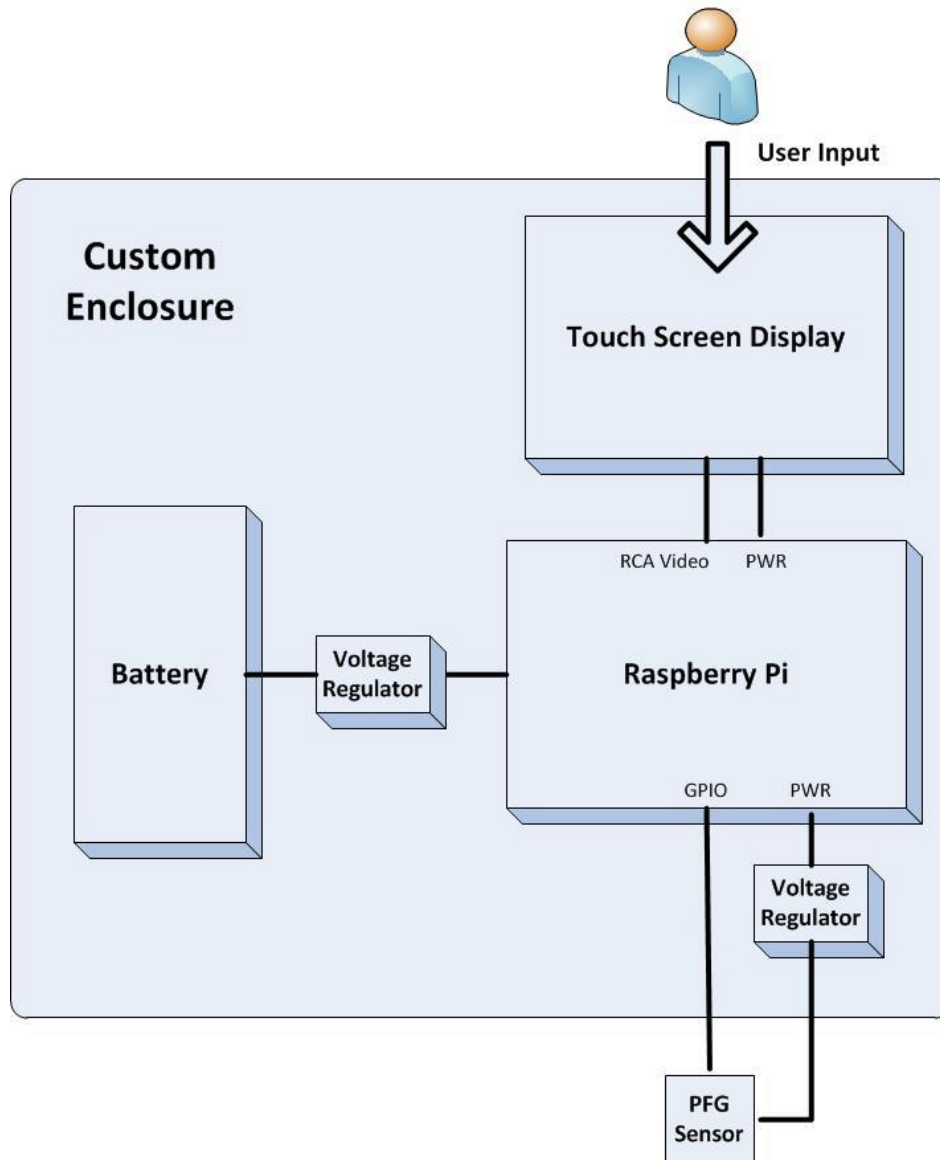


Figure 3

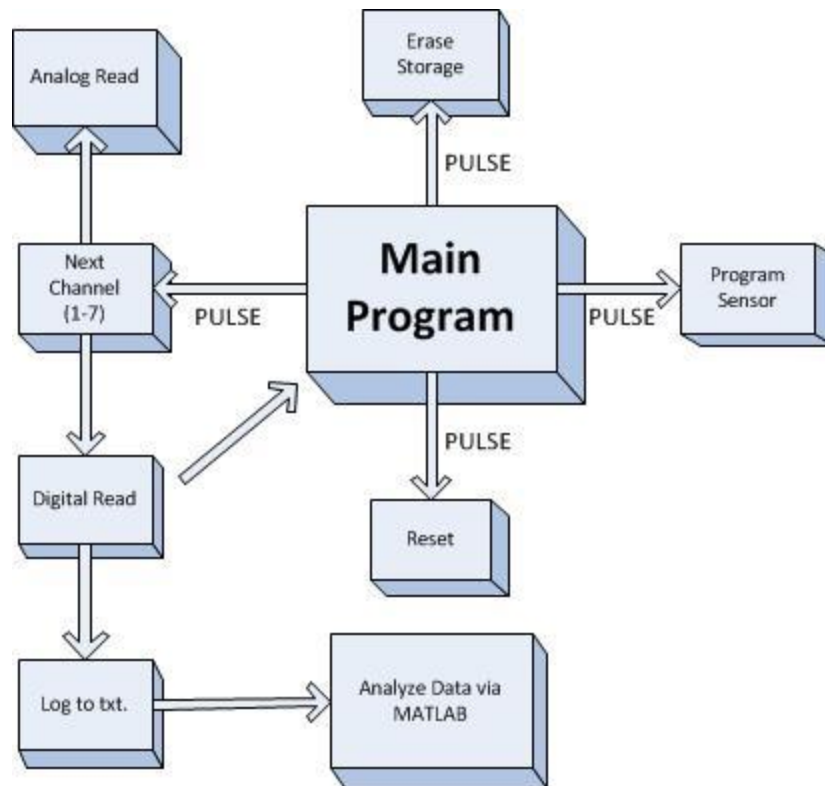


Figure 4

The key component of the project is the Raspberry Pi. The reason that the Raspberry Pi is the ideal choice is that it has the basic necessities that we need (Multiple Input/Output Pins). In addition, it also provides more than just pins; it has a Linux OS, simple programming via C/C++, it is self-diagnosing, it is very low power, and it is a full computer complete with all the inputs that we would potentially need (analog or digital video output). The Raspberry Pi has a multitude of readily available hardware plugins and library of documentation supporting programming the Raspberry Pi. The basic functionality of the end product is detailed as follows. The Raspberry Pi will provide read and write access to the Sensor. The Sensor has 8 pins that each represent a certain function and will be connected to the Raspberry Pi via General Purpose Input Output (GPIO) pins. The touch screen monitor will serve as simple communications from the user; It will display touch buttons that are pre-programmed to implement ERASE, PROGRAM, AnalogREAD, DigitalREAD, RESET, and NEXT. The Raspberry Pi could be re-programmed using two USB inputs. This allows a user to have access to the device with a keyboard and mouse, which makes the device completely independent and with no need of another computer for re-programming.

Risk Analysis

1) Concern: Reader Performance Unreliability

Proposed Action: Perform rigorous testing of the device and explore all possible failure modes during usage in the field. Implement methods to mitigate any failures found during testing. Methods may be hardware or software-based. Use the DMM and oscilloscope in testing.

2) Concern: Limited Device Ruggedness

Proposed Action: Examine use of cases for device and construct an enclosure that meets the requirements of the environment it will be used in. Ensure that electrical connections are effectively wired and the printed circuit board holds up. Check the device's resistance to various impact levels.

3) Concern: Effect of Unstable Power on Components

Proposed Action: Research the effects that voltage changes will have on components during operation. Provide study on reliability of voltage regulation during usage using a voltmeter. Analyze different types of voltage converters and power sources, such as AC or DC sources.

4) Concern: Component Cost Management

Proposed Action: Extensively research component benefits vs. cost to compile group of parts that can provide a solution that is competitive from a financial standpoint in addition to its performance. Research across different companies and different designs that are available.

5) Concern: Product Competition with Simpler, More Effective Designs

Proposed Action: Research and analyze methods employed by different corporations. Tabulate various design specifications and statistics. Study and implement theories and applied designs to produce more effective results.

Project Management

Section

Project Management Plan

The Project will be divided into four sections. The first section will be power management, which will be the design and validation of the power supply for both the Raspberry Pi and the portable touch screen interface. The touch screen interface will be powered by the Raspberry Pi itself. This task will also require that the voltage sent to the sensor from the Raspberry Pi is regulated between 1.8-2.5 Volts. This is due to the fact that the sensor can only operate between 1.8-2.5 Volts because it amplifies the input into a high voltage which is sensed by the rest of the components. If the on-chip voltage exceeds the 2.5 V limit, damage could occur to the sensor. This voltage step down will be achieved using non-linear, DC-DC voltage regulators. Non-linear voltage regulators are more power efficient because power is only drawn when there is an input. This portion of the project will be headed by Yuval Levental, and he will develop the necessary circuitry to provide power and regulate it via the use of the voltage regulators.

The second section is an incorporation of the Input/Output connection between the Raspberry Pi and the sensor. This section is one of the more important requirements in that the physical connection will need to be a simple plug and play (quick disconnect) connection. In this section we proposed the idea of creating a custom wire interface between the sensor and the Raspberry Pi. This portion of the project will be headed by Brett Johnson. He will fabricate a custom port for quick connect/disconnect using AutoCAD or any other computer aided fabrication program.

The third section is the most important in that we will need to implement a custom, programmable GUI program within the raspberry pi to read and write data to the sensor. This section requires programming of the internal General Purpose Input Output (GPIO) pins in the Raspberry Pi that interface with the sensor. This interface will be user friendly and will have contextual touch buttons displayed on the screen that will specify user action. In this portion of the project, there will be programming involved. As such, Ron Razalan will be the lead programmer for the device, developing and troubleshooting all software related issues.

The fourth and final section is the development of a housing/enclosure. This requirement is crucial in that the end product must be portable and all inclusive; this means that Raspberry Pi will have to be implemented in such a way that it is a standalone read/write device that will store data from the sensor, and that the screen is built within the enclosure as well. This task is a conjoined effort due to the fabrication of the housing and overseeing the overall design of the final product. As such, this will be overseen by Thamer Alshuaibi and Evan Gardetto. They are responsible for the full assembly, housing, and overall ease of use.

Cost

Budget

Item(s)	Price (USD)
Raspberry Pi B with 8GB SD Card	40.00
TFT Display	76.27
Battery	5
2x Power Supply Regulators	39.74
Cables	10
Power Switch	2
Enclosure Case	5
Total	178.01 - 188.01

Explanations:

- The Raspberry Pi is the key component of the design. It is the chip that will be used and programmed to input/output data. Model B was chosen to have two USB inputs in the Raspberry Pi and that allows it to be self-sustaining and be reprogrammed without the need of other devices. The Raspberry Pi has an SD Card that gives it a decent memory space. It has an RJ-45 Ethernet in case an Ethernet cable need to be used, rather than the possibility of using a USB wifi chip.
- A 3.2" LCD touch-screen that extract data from the Raspberry Pi and display it to users through a computer. This is designed specifically for Raspberry Pi chips and allow users to send commands to the Raspberry Pi directly. Having a touch-screen enhances its value for the features that could be implemented. This touch-screen has already many built-in functions that can read and extract without the need of reprogramming.
- A power supply is required to turn the Raspberry Pi on, and through the Raspberry Pi can transfer power to the TFT display and the PFG sensor. The power supply must

deliver an adequate amount to power the device and keep it lasting for as long as possible.

- The battery provides the sufficient amount of power needed for the device. However, some inputs cannot accept that voltage because it is too high and may damage the parts. Regulators need to be used to step down the voltage and allows the device to function on its top performance.
- The device will be used in the field and therefore an enclosure case will be set to assure the safety of the device and keep it from being damaged. The enclosure will cover both the Raspberry Pi and the Screen, and allow users to use the screen or the pins of the Raspberry Pi if required.
- Cables-\$10
- A Power switch to control the device and turn it on and off.

References

Lajnef, Nizar, Dr. "Self-powered Sensing in Structural Health and Usage Monitoring." Diss. Michigan State University, 2008. *Google Books*. ProQuest, 2008. Web. 17 Sept. 2013.

Michigan State University. AIM Laboratory. *PFG Self-powered Health and Usage Monitoring Systems (HUMS)*. *Spartan Innovations*. N.p., 2013. Web. 17 Sept. 2013.

Zhu, Dibin, Stephen P. Beeby, Michael J. Tudor, and Nick R. Harris. "A SELF POWERED TAG FOR WIRELESS STRUCTURE HEALTH MONITORING IN AERONAUTICAL APPLICATIONS." *School of Electronics and Computer Science, University of Southampton* (n.d.): n. pag. *University of Southampton*. University of Southampton. Web.

These references are to be used to analyze differing types of sensor systems, including the theory behind them. They may be compared and contrasted to determine the best or most desirable method, or theoretical starting point.