Modular Rapid Monitoring System

Martin Engineering, Illinois
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Executive Summary

The purpose of the Modular Rapid Monitoring System is to monitor the status of large three phase motors used in equipment designed and sold by Martin Engineering. The motors used in Martin Engineering's products usually run for long periods of time and in extreme temperatures because of their applications in large scale bulk material systems. Since the failure of one motor can cause the whole system to fail, predicting when a failure is imminent would be greatly beneficial. The Modular Rapid Monitoring System (MRMS) aims to accomplish this. The MRMS will monitor voltage and current of each of the three phases along with vibration data and display the data in a concise and easy to read fashion. By viewing this data, a technician would be able to determine if a motor failure is imminent and may even be able to give an estimated remaining lifespan.

The MRMS will consist of two main subsystems: the Sensor Interface System (SIS) and the Gateway Interface System (GIS). The SIS will collect the voltage and current data from an analog to digital converter (ADC) along with data from a 3-axis accelerometer communicating through I^2C. It will then scale the data and send it through UART communication to the GIS. The GIS will then store the data in permanent memory. A lightweight web server will be hosted on the GIS which will display the data. In order to access the web server, an ad-hoc wireless network will be created using a USB Wi-Fi dongle.

An important factor in the design of this project is low cost. Because of this, the primary factor when choosing components is cost. The GIS will consist of a Raspberry Pi ($30) with a custom embedded Linux build, a RT5370 USB Wi-Fi dongle ($12), and a 2A USB power adapter ($4). In addition to the low cost, the GIS components were chosen because of the compatibility with each other, and the extensive support available online. The SIS will consist of an Atmel UC3-A3 prototyping board ($32), an ADXL335 accelerometer ($15), and a 2A USB power adapter ($4). These components were chosen because of the low cost and extensive features. The Atmel UC3-A3 board has an external memory chip on board that can be used to store the data in case there is not enough internal memory on the processor chip itself.

Abstract

Martin Engineering of Illinois specializes in industrial equipment and has requested the help of the Electrical and Computer Engineering department at Bradley University to create a rapid monitoring system for their machines. The design consists of two subsystems: a sensor interface system (SIS) and a gateway interface system (GIS). The SIS will read the currents and voltages of the machine and process data from an external accelerometer with multiple axes. Temperature will also be monitored through an internal sensor. The information from all sensors will be stored in a rotary buffer that is sent to the gateway interface system. The GIS will permanently store the first five minutes of equipment operation data and the last five minutes before it is powered down. When it reaches this point, the data can be analyzed by Martin Engineering through a web server in order to detect any malfunctions when they present themselves, or before they cause excessive damage. It will also help the company to find the problem that caused a failure in the system much quicker. By installing this monitoring system, Martin Engineering will save money, be more efficient with repairs, and have a lower risk of injury in the field.

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I. INTRODUCTION

A. Problem Background

Martin Engineering is a small company based in Neponset, IL. They have a long history developing innovative products to move bulk materials in mining. In order to improve their current products, they want to monitor the voltage, temperature, and revolutions per minute of the motors used to run the equipment. Since Martin Engineering has a relationship with Bradley University, they decided to sponsor a senior project in the Electrical and Computer Engineering department. In the 2014 and 2015 academic year, one team worked on developing such a system. The team successfully developed a rough prototype to show the feasibility of the project.

B. Problem Statement

Martin Engineering and the Bradley University Electrical Engineering Department desire a cost effective modular rapid monitoring system that is broken up into two subsystems: a sensor interface system (SIS) and a gateway interface system (GIS). Once it is powered up, the SIS monitors six analog to digital channels, three accelerations from a central accelerometer, and system temperature. Within milliseconds after power is delivered, the SIS must send the data to the GIS. The GIS then stores data received from the SIS and makes it available to users using a web server by communicating through Wi-Fi.

C. Constraints

- Overall System
  - System must have a free commercial license.
  - System must keep track of total time in powered up state without time

- Gateway Interface System
  - Must start logging data within ten milliseconds
  - Must log data at 600 samples per second
  - Must store the first five minutes of data after system power up
  - Must store the most recent five minutes of data and keep it available on next power up
  - Must keep the minimum and maximum of the temperature, accelerometer data, current, and voltage for the duration of use

- Sensor Interface System
  - Must communicate through Wi-Fi (ad-hoc or infrastructure)
  - Must not transmit unscaled values to user
  - Must contain a web server to provide read-only access to data

II. STATEMENT OF WORK

A. *System Block Diagram*

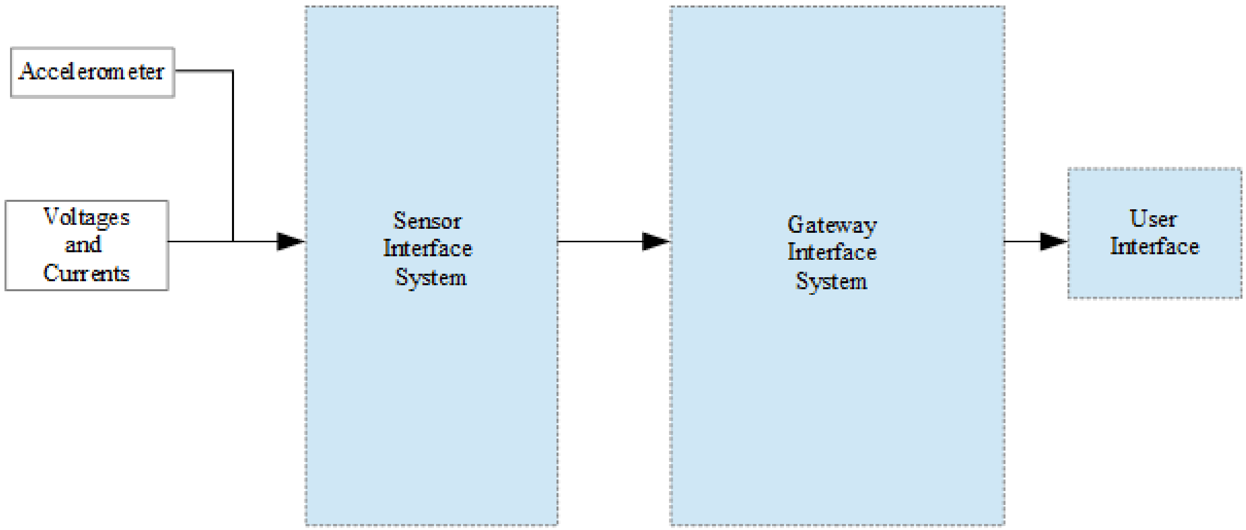


Figure 1: System Block Diagram

B. *Subsystem Block Diagram*

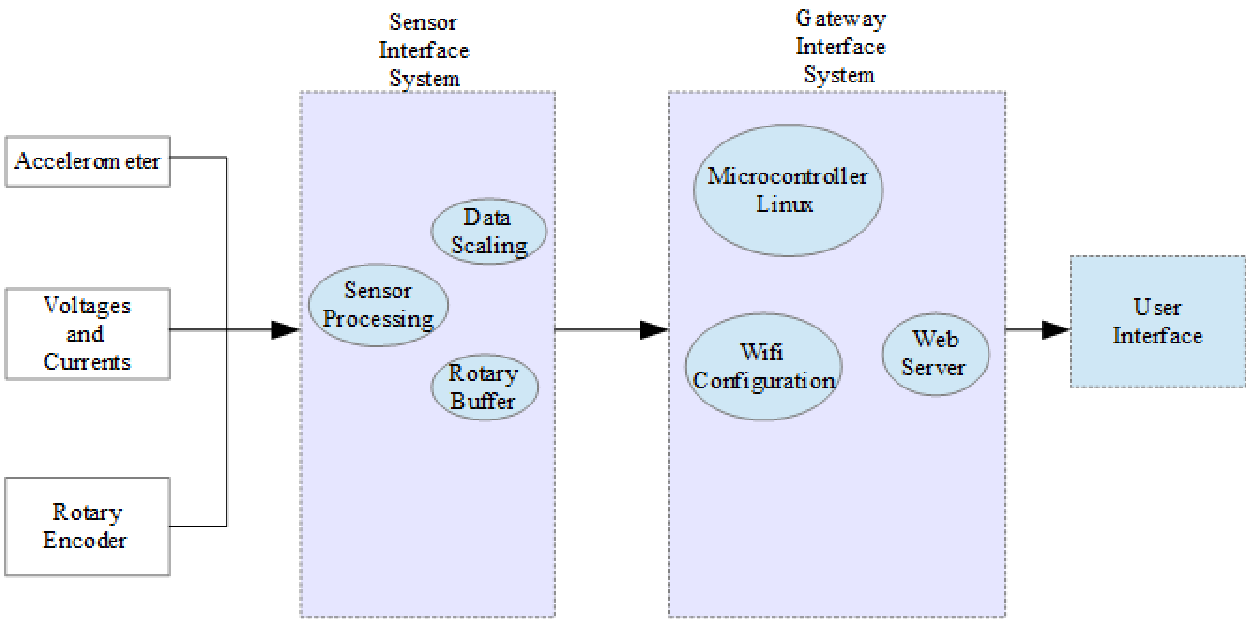


Figure 2: Subsystem Block Diagram

C. System State Diagram

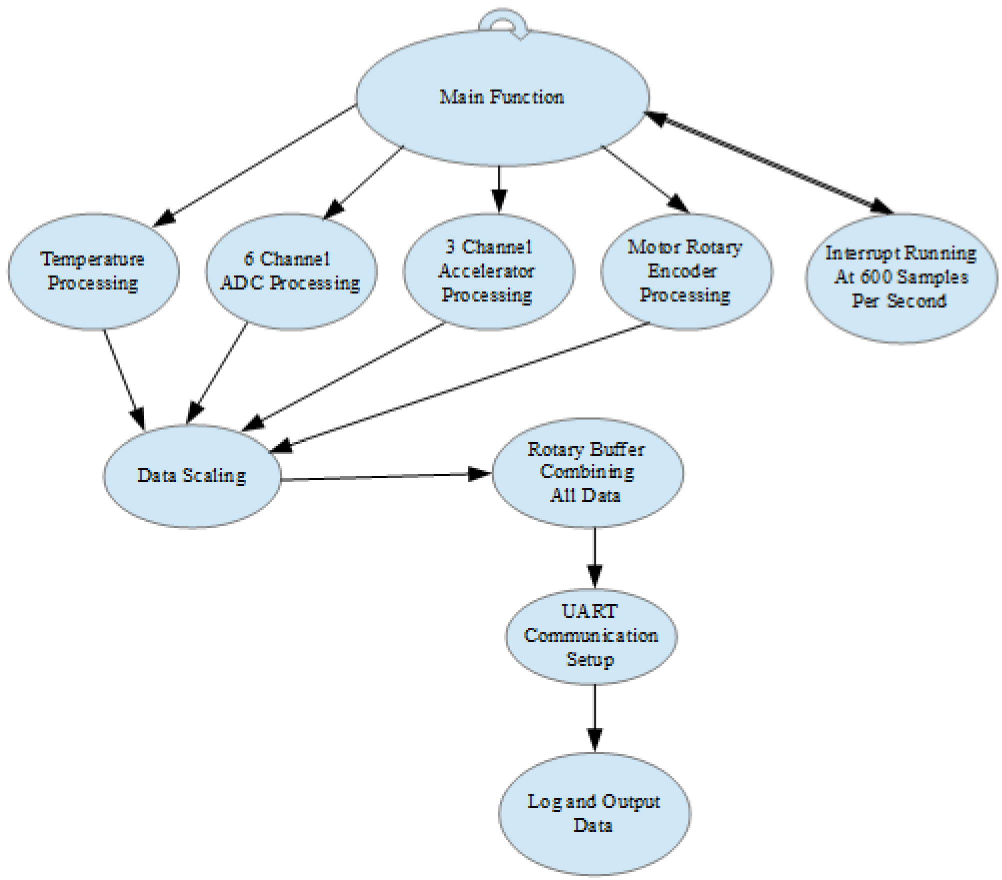


Figure 3: System State Diagram

D. Nonfunctional Requirements

Objectives

- The system should be low cost.
- The system should withstand large amounts of vibration.
- The data format for the web server should be easy for the user to understand.

E. Functional Requirements

Sensor Interface System (SIS)

- The SIS should begin to store data quickly after power is applied.
- The SIS should log six analog channels within a deviation of 0.2 Volts (three for voltage and three for current).
- The SIS should log three digital accelerations (three-axis accelerometer).
- The SIS should log total number of motor revolutions.
- The SIS should log changes in temperature.

Gateway Interface System (GIS)

- The GIS should communicate with rapid monitoring system at 119,500 bits per second

- The GIS should receive and store data from rapid monitoring system and store up to 4 gigabytes of data on a memory card.

III. DESIGN APPROACH AND METHOD OF SOLUTION

Martin Engineering has requested for the product design to contain two separate systems that communicate with each other in order to accomplish the final output to a web server. The first part of the design is the sensor interface system (SIS). Using the work from the previous year's team, the board chosen for this system is an Atmel UC3-A3 Xplained. This board is ideal because it has the capacity for additional external memory if we need it during the data transmission. An AVR Dragon programmer will be used to transfer the programs onto the board. It is also compatible with the accelerometer that was chosen, an ADXL335. This accelerometer was chosen because it fulfills the need for three axes of measurement.

The next system for the product is the gateway interface system (GIS). Again, work will continue off of the previous year with a Raspberry Pi. The Linux that was installed previously was not compatible with Wi-Fi, so a different lightweight microcontroller Linux will be utilized. This will ensure that the previous driver problems will not occur when the RT5370 USB Wi-Fi dongle is interfaced. The SIS will communicate with the GIS via UART communication.

There were many different variations of a 32-bit microcontroller that may have worked with this application. Since there was already an Atmel UC3-A3 Xplained board and there were not many reported problems in the previous year, it was decided that it would remain the choice for the SIS. The GIS could have used a Beaglebone Black, but this design would not have met the constraint that the final product must have a free commercial license.

IV. ECONOMIC ANALYSIS

As stated in the constraints, the cost of the final product must be less than $300. The cost of each component that will be utilized is shown in table I. The two boards that are used for the GIS and SIS have the biggest effect on the budget, but still only use about twenty percent of the requested final price.

Table I: Component Pricing

Part	**Cost**	**Store**
Raspberry Pi	$30.00	Element14 Online Store
Atmel UC3-A3 Xplained	$31.25	Atmel Online Store
ADXL335 Accelerometer	$15.00	Sparkfun Online Store
2x 2A Micro USB Power Adapter	$7.99	Amazon
RT5370 USB Wi-Fi Adapter	$11.99	Amazon

The only expenditures for this project occur in the components. All software used is open source or provided by Atmel. This leads to a total cost of $96.23 which is well within the constraint.

V. PROJECT TIMELINE

For the first half of this project, there are five deliverables to ensure that progress is being made. First, the proposal presentation and document must be completed. Next, the webpage and progress presentation will occur. Finally, there will be an end of semester performance review which will essentially mark the halfway point for the project. A detailed list of these deliverables can be found in Appendix C.

A full Gantt chart is also shown in Appendix C. From this chart, the critical path for the project can be found. Since the project will be split up the whole time until the final weeks, there are two paths that must be fulfilled in order for the project to be successful. These are shown in table 5 of Appendix C with both paths leading to the combined test. For the SIS, interfacing the accelerometer properly will take the most time. For the GIS, optimizing the operating system boot time will take the most time because it is critical that it can receive data as quickly as possible.

VI. DIVISION OF LABOR

As previously discussed, this project has two main modules. This was taken into consideration when deciding how to divide the tasks. One member of the team will have the task of developing the sensor interface system while the other will be in charge of the gateway interface system development. This will ensure that the team accomplishes the tasks in the most efficient way possible because it allows for each member to focus on a single specialized piece of hardware. The website that contains information about the project as well as progress updates will be modified by both members. The specific task breakdown is shown in table II.

Table II: Division of Tasks

Task	Timothy Kritzler	Joseph Mintun
Develop ADC controller		X
Develop Serial Communication with GIS		X
Optimize Rotary Buffer for the Data		X
Accelerometer Interfacing		X
Data Storage During GIS Boot		X
Correct Timings for Sending Data		X
Research and decide base OS	X	
Interface Wi-Fi	X	
Develop UART Access program	X	
Develop lightweight web server	X	
Optimize boot time	X	
Optimize Web server GUI	X	
Combined SIS/GIS Testing and debugging	X	
Develop Progressive Website	X`	X

VII. SOCIETAL AND ENVIRONMENTAL IMPACTS

The main firms impacted by the use of this product are Martin Engineering and any subsidiaries that may receive the device through their company. The extensive data logging system will help to alert these companies to approaching breakdowns which will increase the safety of their employees. It will also help the company to pinpoint the source of any problems that occur. This will reduce downtime for repairs which helps to maximize productivity.

Since the device will be used to sense potentially dangerous breakdowns, the final product must meet the functional and non-functional requirements in all scenarios. Ethically, the team cannot submit any work unless this condition is met due to the liability risk of someone getting injured.

VIII. SUMMARY AND CONCLUSIONS

The modular rapid monitoring system will help to improve the efficiency of repairs and upgrades to the machines that Martin Engineering decides to attach it to. The product contains two main modules: the sensor interface system and the gateway interface system. The SIS, which is utilizing an Atmel UC3-A3 Xplained microcontroller, will log requested data such as temperature, vibrations, current, and voltage. The GIS, using a Raspberry Pi that runs a lightweight Linux, will receive this data and print it to a web server. This data can then be compared to data from operating periods where the machine did not experience any problems. This comparison will make troubleshooting the machine much more efficient which will save the company time and valuable resources that could be allocated elsewhere.

IX. APPENDIX A

A. *Non-functional Requirements Metrics*

Objective: The system should be low cost.
Units: Ratings of design team's assessment of cost, from 1 (worst) to 5 (best)
Metric: Assign points according to the following scale

- Less than $50 — 5 points
- Between $50 and $150 — 4 points
- Between $150 and $250 — 3 points
- Between $250 and $350 — 2 points
- Greater than $350 — 1 point

Objective: The system should begin to store data quickly after power is applied.
Units: Ratings of design team's assessment of boot time, from 1 (worst) to 5 (best)
Metric: Assign points according to the following scale

- Data is stored within 50 milliseconds of external power on — 5 points
- Data is stored within 100 milliseconds of external power on — 4 points
- Data is stored within 150 milliseconds of external power on — 3 points
- Data is stored within 200 milliseconds of external power on — 2 points
- Data is stored within 250 milliseconds of external power on — 1 point

Objective: The data format for the web server should be easy for the user to understand.
Units: Ratings of design team's assessment intuitiveness, from 1 (worst) to 5 (best)
Metric: Assign points according to the following scale

- Extremely easy to navigate. — 5 points
- Very easy to navigate. — 4 points
- Moderately easy to navigate. — 3 points
- Barely able to navigate. — 2 points
- Not able to navigate at all. — 1 point

Objective: The system should be able to withstand large amounts of vibration.
Units: Ratings of design team's assessment of vibration resistance, from 1 (worst) to 5 (best)
Metric: Assign points according to the following scale

- The system can withstand up to 1.5 G's — 5 points
- The system can withstand up to 1.4 G's — 4 points
- The system can withstand up to 1.3 G's — 3 points
- The system can withstand up to 1.2 G's — 2 points
- The system can withstand up to 1.1 G's — 1 point

X. APPENDIX B

A. Glossary

Table III: Glossary

ADC	Analog to digital converter
GIS	Gateway interface system
GUI	Graphical user interface
MRMS	Modular rapid monitoring system
OS	Operating system
SIS	Sensor interface system
UART	Universal asynchronous receiver/transmitter
USB	Universal serial bus

XI. APPENDIX C

A. Project Timeline

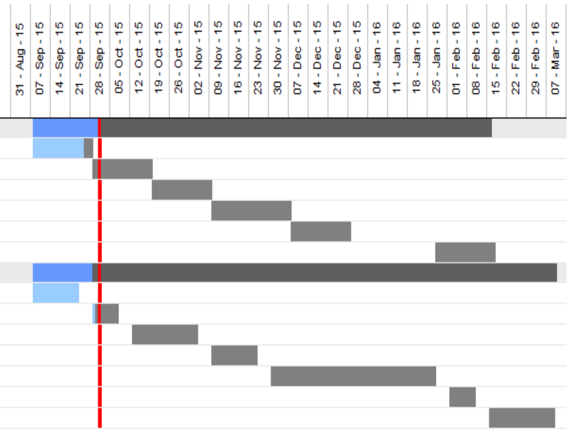
Table IV: Deliverable Deadlines

Task	Start	Finish	Duration
Proposal Presentation	9/16/2015	9/30/2015	2 weeks
Proposal Documentation	10/1/2015	10/14/2015	2 weeks
Webpage Release	10/12/2015	10/26/2015	2 weeks
Progress Presentation	10/26/2015	11/17/2015	3 weeks
Performance Review	11/17/2015	12/1/2015	2 weeks

B. Gantt Chart

Table V: Gantt Chart

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	SIS	Joe	9/8/15	2/16/16	162	14%	116	23	139
1.1	Develop ADC controller		9/8/2015	9/29/2015	21	90%	16	18	3
1.2	Develop Serial Communication with GIS		9/29/2015	10/20/2015	21	0%	16	0	21
1.3	Optimize Rotary Buffer for the Data		10/20/2015	11/10/2015	21	0%	16	0	21
1.4	Accelerometer Interfacing		11/10/2015	12/8/2015	28	0%	21	0	28
1.5	Data Storage During GIS Boot		12/8/2015	1/28/2016	21	0%	38	0	21
1.6	Correct Timings for Sending Data		1/28/2016	2/16/2016	21	0%	14	0	21
2	Task Category 2	Tim	9/8/15	3/10/16	185	12%	116	21	164
2.1	Research and decide base OS		9/8/2015	9/24/2015	16	100%	13	16	0
2.2	Interface Wifi		9/29/2015	10/8/2015	9	20%	8	1	8
2.3	Develop UART Access program		10/13/2015	11/5/2015	23	0%	18	0	23
2.4	Develop lightweight web server		11/10/2015	11/26/2015	16	0%	13	0	16
2.5	Optimize boot time		12/1/2015	1/28/2016	58	0%	43	0	58
2.6	Optimize Web server GUI		2/2/2016	2/11/2016	9	0%	8	0	9
2.7	Combined SIS/GIS Testing and debugging		2/16/2016	3/10/2016	23	0%	18	0	23



XII. APPENDIX D

A. References

This project will utilize previous work completed by Kate Palmer and Stephen Shelton during the 2014-2015 academic school year at Bradley University.