Project Report

Hydroelectric Data Acquisition and Transmission System

June 3rd, 2019

ECE 19.2
Science and Engineering Project Center
College of Science and Engineering
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Subject: Hydroelectric Data Acquisition and Transmission System
Document: Letter of Transmittal

The Chelan County PUD hydroelectric system consists of multiple sets of hydroelectric generators located in three different facilities and produces roughly 2,000 megawatts of renewable power. In order to ensure efficient and reliable operation of the turbine-generator, Chelan County PUD wishes to monitor the performance of rotating turbine-generator components in real-time. It has been requested that a data acquisition system be developed to measure performance data from sensors mounted on rotating components and transmit that data in real-time to an external, stationary logging system.

This final report describes the design of a Hydroelectric Monitoring System (HMS) to collect data for Chelan County PUD. The report begins by introducing the background, requirements, and technical constraints of this project. This is followed by a detailed description of the HMS, including all components implemented, their technical features, and the reasons for which these components were chosen. Non-physical components, such as programming tools and software packages, are also evaluated.

The results of HMS construction, configuration, and testing are provided to prove HMS efficacy and provide documentation for future project teams. Because non-stationary hydroelectric data acquisition is an active field of engineering research, this report concludes with recommendations for continued project development and supplementary technical materials.

Sincerely,

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Hydroelectric Data Acquisition and Transmission System

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EXECUTIVE SUMMARY

Currently, condition monitoring of Chelan County PUD hydroelectric-turbine generators is restricted to periodic analysis of the stationary components. Implementation of a wireless monitoring solution will support continuous and real-time condition reports of rotating components to aid in the preventive maintenance process.

ECE 19.2's proposed solution is a remote monitoring system that wirelessly transmits real-time condition data.

- After further development, the delivered prototype will have the potential to withstand the harsh environment of a hydroelectric generator during operation.
- The proposed solution is relatively inexpensive (under $500 in components).
- The prototype can integrate a variety of sensors without special physical adaptations, providing system flexibility.

The design prototype consists of two components: one installed within the hydroelectric-turbine generator, and one installed externally. Together, these two components compile real-time condition data for extraction from Chelan County PUD.

Recommendations for future work include improvements to the internally-mounted component containment, transmission methods, and power supplying methods.

- Additional, less vital improvements include the addition of a transmission buffer, improved sensor quality, and cloud server integration.

ABSTRACT

Chelan County PUD has requested a data acquisition system that can collect real-time data on the condition of rotating components in their hydroelectric turbine-generators. In this final report, we describe the hardware and software specifications that comprise our design for a Hydroelectric Monitoring System (HMS). We also outline testing that has been performed to ensure HMS resilience.

The HMS is comprised of two systems: a Data Acquisition and Transmission System (DAT) and a Stationary Unit (SU). These systems both use a Raspberry Pi 3 B+ microcontroller board, as this component is compatible with a wide variety of sensor and component inputs. The DAT is responsible for collecting data from temperature, strain, conductivity, and accelerometer sensors mounted around the generator and transmitting this data wirelessly to the SU. The SU receives this data, caches it in local memory, and pushes it to the Chelan County PUD network for real-time analysis.

ACKNOWLEDGMENTS

This project would not have been as successful without the continued support of Seattle University faculty and our Chelan County PUD sponsors. Their assistance with technical and non-technical subjects has made our senior design experience a truly rewarding one. Our team would like to acknowledge these supporters for generously sharing their time with us to help us develop our skills as engineers and problem-solvers.

First, we would like to thank our project sponsor Chelan County PUD for providing us with the opportunity to collaborate on a real-world engineering problem. More specifically, we would like to thank our liaison engineer John Yale, P.E. for his guidance in developing a technical understanding of the problem and for his superlative support over the duration of this project: hosting our team for two site visits to Rocky Reach Dam and for reserving time weekly to collaborate ideas.

The Seattle University Project Center has been an integral part of this process. We are very grateful for Jorge Vargas, who helped our team purchase numerous parts and secured reimbursement for the travel and accommodations of our site visits. Thank you to the Project Center for facilitating this project opportunity and supporting financial needs for our project's success.

We would also like to thank our Senior Design Coordinator Dr. Henry Louie for his constructive feedback on our project reports and presentations. His assistance with system testing is also appreciated. Others who have helped with the technical aspects of our project include Gary Fernandes, who found us additional parts, and Professor Richard Bankhead, who shared his technical recommendations with us.

Finally, we are incredibly grateful for the help of our faculty project advisor, Dr. Shiny Abraham. All the dedicated hours spent in providing feedback, guidance, and her technical expertise were indispensable to the progress of this team.

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Definitions of Technical Terms

1. **BNC Connector** — A type of wired connector commonly used with coaxial cables.
2. **Faraday Cage** — A grounded metal screen that surrounds a piece of equipment to exclude it from electrostatic and electromagnetic influences.
3. **Rotor** — The rotating component of an electric generator.
4. **Sensor Agnostic** — To be unbiased towards the use of different sensors.
5. **Stator** — The stationary component of an electric generator that surrounds the rotor.
6. **Wicket Gate** — A distribution system of the hydroelectric generator that regulates how much of water enters the turbine.

Acronyms, Abbreviations, and Symbols

A — Amperes (Current)
ADC — Analog to Digital Converter
AD/DA — Analog to Digital signals and Digital to Analog signals
AES — Advanced Encryption Algorithms
BNC — Bayonet Neill Concelman
CSV — Comma Separated-Values
DAQC — Data Acquisition and Controller
DAT — Data Acquisition and Transmission
DC — Direct Current
HMS — Hydroelectric Monitoring System
Hz — Hertz (Frequency)
I/O — Input/Output
IEEE — Institute of Electrical and Electronics Engineers
I2C — Inter-Integrated Circuit
PUD — Public Utility District
RPi — Raspberry Pi
RPi-DAT — Raspberry Pi 3 B+ in the Data Acquisition and Transmission system
RPi-SU — Raspberry Pi 3 B+ in the Stationary Unit
RPM — Revolutions Per Minute

SD — Secure Digital (card)
SPI — Serial Peripheral Interface
SU — Stationary Unit
UTF-8 — Uniform Transformation Format 8
USB — Universal Serial Bus
V — Volts (Voltage)
Ω — Ohms (Resistance)

I. INTRODUCTION

Chelan County PUD has requested a prototype of a data acquisition system that can collect and transmit real-time sensor data from a hydroelectric generator to the Chelan County PUD cloud servers for long-term generator management. Currently, generator condition data is exclusively collected and locally cached by a data logger with sensors mounted around the outer rim of the stationary components (stator); no condition data of the rotating components (turbine runner, shaft system, and generator rotor) is collected. That means to understand the condition status of the rotating components, the generator must be shut down, disassembled, and inspected.

The local storage of the condition data is a roadblock for real-time condition analysis since its accessibility depends on the manual extraction of the data logger. Manual extraction of condition data is not only expensive, as it requires the suspension of generator operations, but also impacts long-term generator performance due to repeated reassembly. Moreover, real-time condition analysis for rotating components is valuable for predictive maintenance, condition monitoring, and for avoiding dangerous operating conditions. For these reasons, Chelan County PUD has requested a design for a data acquisition and transmission system that can be mounted on the generator's rotating equipment, collect real-time sensor data, and transmit data to a stationary external logging system without having to shut down the generators.

A. Background

Chelan County PUD is a publicly-owned utility company which provides electric, water, wastewater public utility and telecommunications services in Chelan County, Washington, USA [1]. Since 1947, Chelan County PUD has operated generating stations and distributions facilities along the Columbia River. This operation consists of multiple sets of hydroelectric generators stationed at three separate facilities: Lake Chelan Dam, Rocky Reach Dam and Rock Island Dam. When combined, the total generating capacity amounts to roughly 2,000 megawatts of sustainable and renewable power [2]. With a large portion of this generating capacity being transmitted throughout the Pacific Northwest, Chelan County PUD customers have enjoyed one of the nation's lowest residential electric rates this past year at around 3.2 cents per kilowatt-hour [2]. The tremendous value of this enterprise is reflected in its 9.5% rate of return and, thus, necessitates detailed analysis of its operations [2].

B. Statement of the Problem

Real-time condition data proves valuable for predictive maintenance, condition monitoring, and avoiding dangerous operating conditions. Presently, Chelan County PUD cannot assess the state of the rotating components in a hydroelectric turbine without shutting down, disassembling, and inspecting the generator. Moreover, Chelan County PUD's daily revenue is approximately one million dollars, meaning any suspension of operations, even for a single day, will have a significant economic impact on the company and its clients. For this reason, Chelan County PUD desires that measurements of generator parameters such as temperature, strain, conductivity, and rotational speed be collected while the generator is operational. Due to nature of the rotating equipment, the device must be able to withstand high centripetal forces, operate within a magnetic field, and transmit reliably through the surrounding dense, signal-diminishing media like steel and concrete.

C. Purpose of Project and Report Overview

Monitoring the rotating components of a hydroelectric turbine-generator is critical to understanding the condition of the asset. As a primer for initiatives to modernize the system's reliability, this project was initiated as a practical yet efficient scheme for data acquisition and transmission of the generator's condition. The purpose of the system, which will be referred to hereafter as the Hydroelectric Monitoring System (HMS), is to optimize and centralize the collection of condition data by providing remote monitoring functionality. This data provides real-time condition reports of the unit's operation and, in turn, aids the operators in the preventive maintenance process.

This report documents the HMS design approach and also serves as a reference guide for HMS operation and troubleshooting. The report highlights and compares alternative technical solutions as well as the major design decisions. The results of these decisions are included in the Results section, where the technical specifications of the HMS are outlined along with the significant outcomes discovered in the testing process. In addition, recommendations for future work are included to support the long-term viability of this project.

II. METHODS & DESIGN APPROACH

Our objective was to design a data acquisition and transmission system that could be mounted on a generator rotor to collect data from a variety of sensors, and then transmit that data in real-time to a device outside the generator. Criteria for a successful solution were established according to this objective and the associated physical constraints of monitoring rotating equipment.

The data acquisition and transmission system that will be mounted on the rotor must be able to operate within the generator's harsh environment for long periods of time. Relevant challenges for the system include operating and transmitting through strong magnetic fields, tolerating high rotational forces, and having a thermal tolerance of up to 40°C. This means the rotor-mounted system must meet these physical constraints to ensure sustainability of the solution. Additionally, the transmission of the system is faced with a dense signal-diminishing mediums of concrete and steel. The client has specified the data acquisition and transmission system should transmit condition data once per revolution of the rotor's maximum RPM.

Because a remote monitoring solution with a single system would not be easily accessible for data extraction by Chelan County PUD, the solution was designed with two subsystems. The first, rotor-mounted system (DAT system) can withstand the harsh generator environment, collects condition data from a variety of sensors, and reliably transmit that data in real-time via Wi-Fi. The second, external system (SU system) collects and packages the performance data that is transmitted from the DAT system. This means both systems must have Wi-Fi capability.

The use of an ADC enables the DAT to receive analog and digital sensor inputs. The ADC also allows for a dynamic set of operations with AD/DA functions to the Raspberry Pi 3 B+. It offers 8 single-ended (or 4 differential) 24-bit channels for analog-to-digital conversion, as well as 2 single-ended (or 1 differential) 1-bit channel(s) for digital-to-analog conversion. Moreover, its functionality features signal amplification, adjustable sampling rate, and—with the PiPyADC open-source Python module—supports customizable sampling sequences of the inputs.

The SU must have the capability to format and store a large amount of sensor data in a CSV file. An advantage of Raspberry Pi 3 B+ components is that they can use Python, a language which contains libraries that make reading CSV files especially convenient.

Industrial pre-designed solutions, such as the Phoenix Contact Wireless Module RAD-900-IFS, were initially considered, but ultimately rejected on the grounds that these systems were neither sensor-agnostic nor affordable. Having decided to create our own customizable system, we designed the HMS around the affordable and sensor agnostic Raspberry Pi 3 B+ modules. See "Component Description" in Appendix D for more details on these modules and other components.

Our team decided to use Raspberry Pi 3 B+ for both the DAT system and SU. The decision was made by considering the module's price and functionality. The Raspberry Pi 3 B+ has 40 GPIO pins compared to the Phoenix Contact wireless module which only accepts wired inputs with an additional peripheral. Using Raspberry Pi modules not only ensured a wide compatibility with I/O's, but also guaranteed the wireless transmission capabilities necessary for real-time data analysis. Components from the Raspberry Pi microcontroller family can be programmed using C, C++, or Python which is beneficial for sensor agnositicity, and have more resources available online than the other microcontrollers our team considered.

III. RESULTS & DISCUSSION

A. Technical Description of HMS

This project's deliverable implements a data acquisition and transmission system for the real-time condition monitoring of the hydroelectric generator rotating equipment. The acronym "HMS" stands for Hydroelectric Monitoring System, and hereafter will be used to refer to the entire system.

The HMS is comprised of two parts:

1. Data Acquisition and Transmission (DAT) System
2. Stationary Unit (SU)

The configuration and the complete flow of data within the HMS is shown in Figure 1.

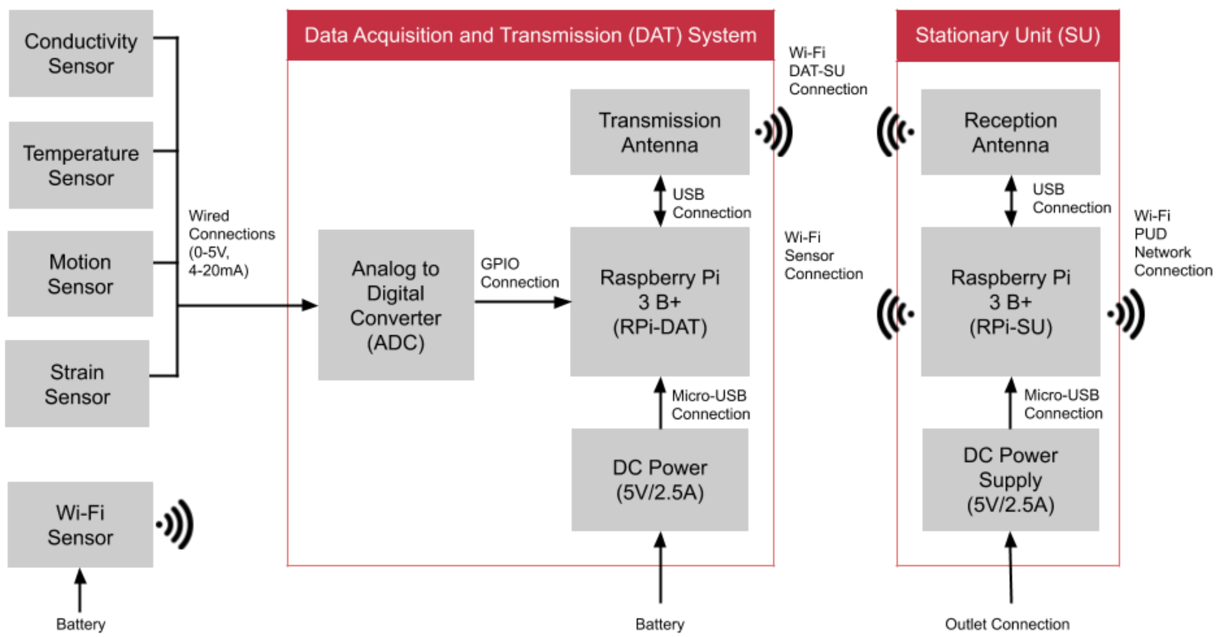

Figure 1: Block Diagram of Hydroelectric Monitoring System

Figures 2 and 3 show the physical construction of the DAT and SU prototypes, respectively.

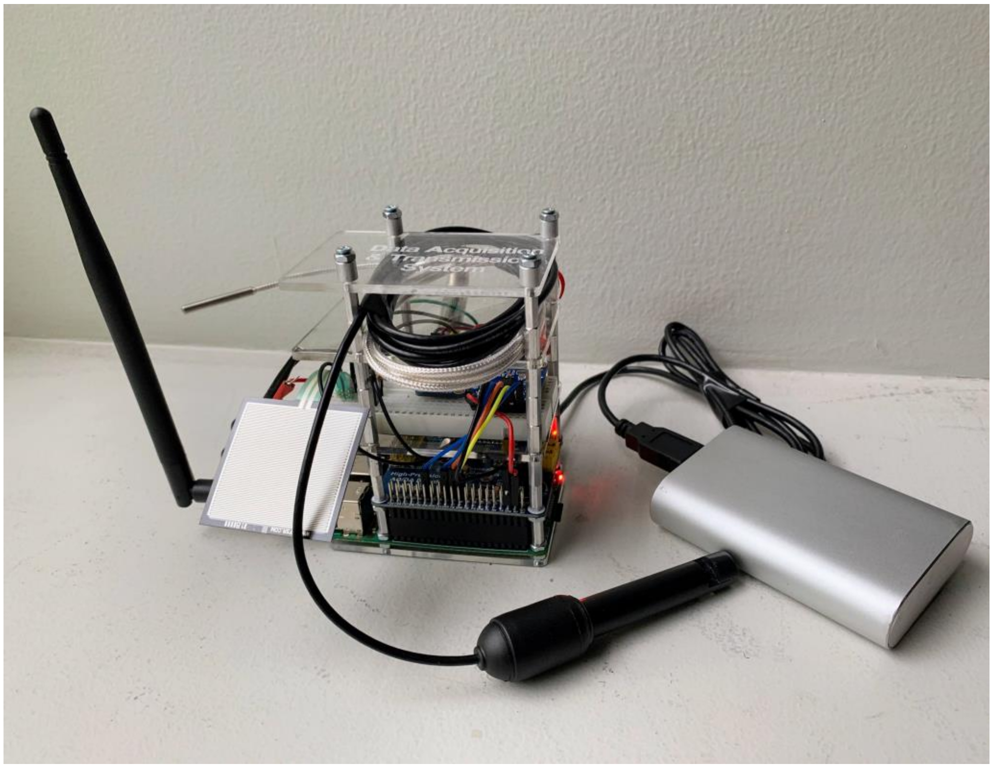

Figure 2: Data Acquisition and Transmission (DAT) System

Figure 3: Stationary Unit (SU)

The RPi-DAT collects sensor values processed by the ADC, packages this data into a tokenized string of binary values, and wirelessly transmits the data to the external data logger called the Stationary Unit (SU). The means of this transmission is an Ad-Hoc connection between the RPi-DAT and RPi-SU.

Following the reception of the DAT's transmission, the SU unpacks the tokenized string and stores the data in a CSV file on the RPi-SU SD card for extraction by Chelan County PUD to the cloud server network.

The DAT chassis design and mounting will be performed by Chelan County PUD. This ensures precise rotor weighting, which is critical for sustainable turbine operation.

B. Specifications

The performance of the Hydroelectric Monitoring System relies on the DAT's ability to withstand generator conditions during operation. Because it will be mounted within the generator's rotor, the DAT must be able to withstand conditions that are typical of the rotor environment during operation. Among these are the rotor's temperature, a strong magnetic field caused by the generator windings, and a Faraday Cage-like environment. The temperature inside the rotor will range from 23–40°C, which all DAT components can withstand (see Appendix D). Because the magnetic field created by the generator will have a frequency of 60 Hz, any form of DAT communication using a similar frequency may be problematic. To understand the effects of this Faraday Cage–like environment, different installation locations were tested at Rocky Reach Dam to guarantee that the DAT would be able to transmit reliably and effectively to the SU.

In order to fulfill the client's request of collecting data samples at least once per revolution, a maximum sampling interval was chosen to be 200ms. This was calculated using Equation 1.

$$\frac{300 \text{ rpm}}{60} = 5 \text{ rps} = \frac{1}{5} \text{ spr} = 200\text{ms}$$

Equation 1

The maximum speed of the rotor, 300 rotations per minute, is divided by 60 to get 5 rotations per second, which is equivalent to ⅕ seconds (200ms) per rotation. This means that data must be collected and transmitted faster than 200ms in order to be logged before the next revolution.

Chelan PUD has specified that the DAT system should be sensor agnostic, meaning that the system must be able to interface with different sensors without requiring special adaptations. Additionally, Chelan PUD has specified the wired sensor inputs to be able to receive values in the range of 0–5V and 4–20mA so that it is compatible with a wide variety of sensors.

In order to verify that our HMS solution is sensor agnostic, a variety of digital and analog sensors have been integrated into the HMS design and configured with our RPi-DAT. Sensors used for agnosticity verification measure temperature, strain, conductivity, and acceleration. The temperature sensor [3] is a single-ended digital output. The conductivity [4] and strain [5] sensors are both single-ended analog inputs. The accelerometer [6] is a differential analog input. More information on these sensors can be found in Appendix C. Our team also purchased an Wi-Fi module [7] to test whether the SU can directly receive sensor data transmitted via Wi-Fi. Connecting an Arduino C–based client to the server side of a Python-based Ad-Hoc connection for Wi-Fi sensor implementation is described in more detail in "Recommendations."

Since data transmission is one of the most important parts of the HMS design, signal transmission and reception will be amplified using two long-range Wi-Fi antennas instead of using the built-in Wi-Fi transmitter and receiver from the Raspberry Pi 3 B+ module. No software is required to configure the antennas to an RPi, and the antenna is physically attached to the RPi through a USB connection. This 5 dBi antenna was advertised to be able to transmit a signal 500 meters line of sight. However, after performing an evaluation at Seattle University, the actual range proved to be significantly shorter. Without the long-range antenna, the RPi-DAT can detect a Wi-Fi signal that is being transmitted by RPi-SU up to 34 meters away with an obstructed path. With the long-range antenna, the RPi-DAT can detect the RPi-SU Wi-Fi signal up to 61 meters away with an obstructed path. This setup was also tested at Chelan PUD's Rocky Reach Dam to evaluate the optimal location for the SU installation. See Section III.E.e "On-site Transmission Testing" for test results.

C. Constructions Methods

The DAT is comprised of three separate components: an Analog to Digital Converter (ADC), a Raspberry Pi (RPi-DAT), and a transmission antenna. Due to the ongoing research of magnetically-induced power supplies, the initial implementation of the DAT will be powered by a portable charger. The Stationary Unit receives and stores the data that has been sent by the DAT. It is comprised of a Raspberry Pi 3 B+ and a USB-connected antenna. Both the RPi-DAT and the RPi-SU were programmed in Python for its convenient libraries.

For data to be wirelessly transmitted, a connection between the DAT and the SU must first be established. The team has chosen to implement this connection via Wi-Fi using Ad-Hoc connection, as it is supported by the Raspberry Pi platform. Ad-Hoc wireless transmission is possible due to the SU being set up as a wireless access point. By doing this, the SU serves as a local network facilitator to which the DAT can connect and transfer data. The data transmission requires the use of the Python module named *socket*, which uses TCP/IP protocol. To test that the HMS is sensor agnostic, digital and analog sensors were implemented.

During an on-site visit to Chelan County PUD's Rocky Reach Dam facilities, our team conducted an experiment to determine the optimal position of the SU. These tests concluded that there are two possible locations for SU installation: on top of the rotor or within the maintenance passage beside the stator, as shown in Figure 4. In either location, the SU may be powered by a DC power supply connected to a standard wall outlet.

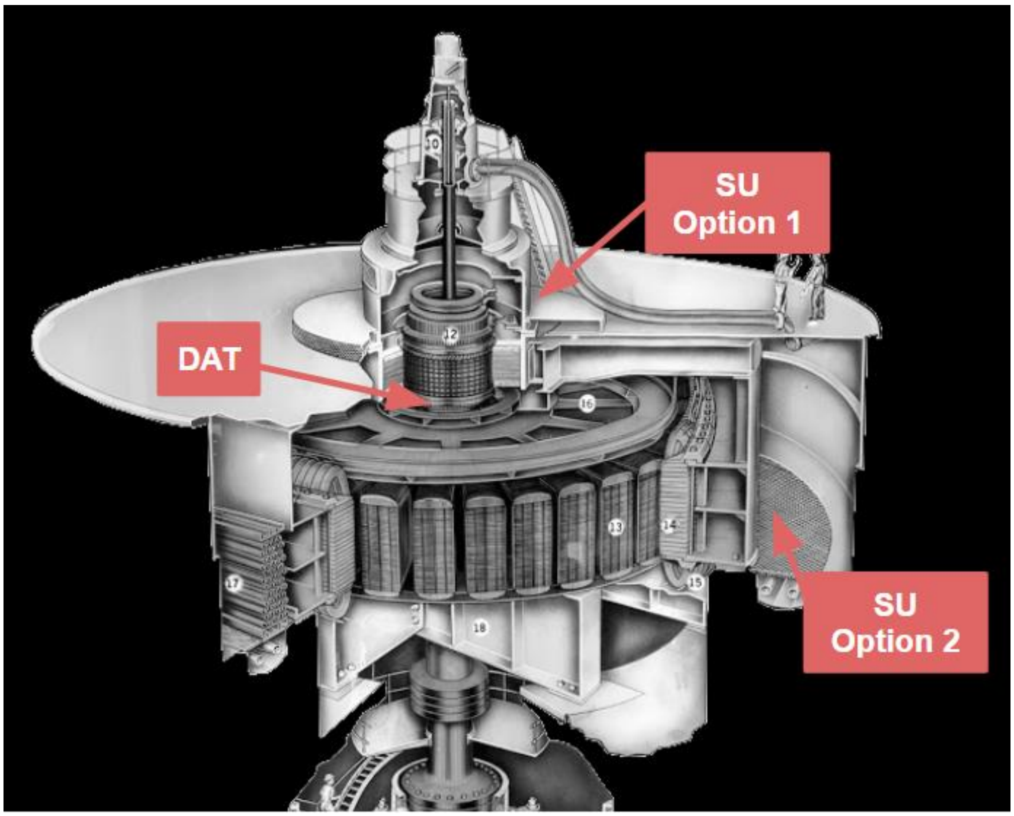

Figure 4: HMS Positioning Options

D. Operation

HMS operation is characterized by seamless data transmission. The SU system serves as the server side of the DAT-SU Ad-Hoc connection. The SU receives the encoded string, decodes the string, and appends it to a local CSV file. The local CSV file data is stored for a period of 24 hours. Every day at 00:00 hours a new CSV file is created; data from the new day is appended to this new file. After the CSV data is stored locally, it is available for collection by the Chelan County PUD cloud server network for further processing.

A sample of CSV file data is shown in Figure 5. Units of measurement are not included within the tokenized string because unnecessary characters reduce transmission speeds. These values have been added to the CSV file in a header, and are Celsius for temperature readings, G-force for acceleration readings, Newtons for strain readings, and Volts for conductivity. In Figure 5, conductivity values are zero because the sensor probe is not submerged in a solution but the sensor is still connected. The temperature sensor was temporarily disconnected, which is why some values are “XXXX”.

Time	Temperature[C]	Accel(X)[G]	Accel(Y)[G]	Accel(Z)[G]	Strain[N]	Conductivity[V]
06/02/2019 16:38:15.650 PDT	26.242	-0.535	-0.5	-0.5	0	0
06/02/2019 16:38:16.115 PDT	26.242	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:18.126 PDT	XXXX	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:18.343 PDT	26.276	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:18.563 PDT	XXXX	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:18.686 PDT	26.276	-0.5	-0.182	-0.5	-0.3391	0
06/02/2019 16:38:18.892 PDT	26.242	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:19.074 PDT	26.242	-0.5	-0.5	-0.5	0	0
06/02/2019 16:38:19.259 PDT	26.242	-0.563	-0.5	-0.5	0	0
06/02/2019 16:38:19.470 PDT	26.242	-0.52	-0.5	-0.5	0	0
06/02/2019 16:38:19.683 PDT	26.242	-0.5	-0.5	-0.5	0	0

Figure 5: Example of CSV File Data

All analog sensor readings are converted to digital readings with the use of an ADC. The Python module used to interact with the ADC is pipyadc [11]. This Python module facilitated the integration of the ADC to our system. For the digital sensors, the library used the *board*, *busio*, *digitalio*, and *adafruit_max31865* Python modules.

The Python module *socket* facilitated wireless transmission of the data. Since the TCP/IP protocol is used, the string must be converted into bits before being sent from the DAT. The string is encoded by default into ASCII, but may be changed if the scope of characters needs to be expanded. Furthermore, the string is decoded at the SU where it is appended to a CSV file. The Python module used to interact with the CSV file is appropriately named *CSV*. The Python module *datetime* assisted with temporal organization.

E. Testing and Calibration

a. Magnetic Field Testing

The rotor environment where the DAT system will be installed is subject to strong magnetic fields. Although these fields do not affect the Wi-Fi signal because the frequency range is very different, it is possible for the metal in the magnets to change the RPi-DAT antenna characteristics, blocking or changing signal transmission or reception.

DAT electronics could be wrapped with magnetic shielding film. This film shields electronics from low-frequency alternating magnetic fields, protecting the cables and components of our system from the potential of an induced current. Although it is unlikely that magnetic fields will interfere with the HMS communications, our team purchased MCF5 film which has a width of 5 cm and is recommended for shielding in electronic applications.

b. Sensor Failure Testing

In the event that one or more of the sensors fail during operation, the sensor values will be replaced with a unique value such as “XXXX”. This is visible for the temperature sensor in Figure 5. Such a label will make it obvious that there is a malfunction while allowing the RPi-DAT to continuously transmit and avoid data flow disruption.

c. Power Consumption Testing

Understanding the power consumption of the DAT system is critical in optimizing its operation. Additionally, power estimations of the system—with regards to the number of sensor inputs—will provide a valuable resource for the other design team Chelan County PUD is collaborating with to develop a sustainable wireless power source.

To quantify the power consumption of the DAT system, the voltage and current drawn by the RPi-DAT were measured when 0, 1, 2, 3, and 4 wired sensors were receiving data. Of these five tests, the power consumption was measured in two operational states: when the DAT first turns on and while it is operating. The average current (I) and average voltage (V) measurements from five tests in each of the five setups were then used to calculate the power consumption with Equation 2. The results of these tests are shown in Table 1 and graphed in Figure 5.

$$P = I \cdot V$$

Equation 2

Sensor Config-uration	**Turning On**			**Operation**		
	Voltage (V)	**Current (A)**	**Power (W)**	**Voltage (V)**	**Current (A)**	**Power (W)**
0	5.04	0.59	**2.97**	5.03	0.57	2.87
1	5.07	0.57	**2.89**	5.07	0.54	2.74
2	5.07	0.58	**2.94**	5.07	0.55	2.79
3	5.07	0.57	2.89	5.07	0.59	**2.99**
4	5.04	0.64	**3.23**	5.04	0.59	2.97

Table 1. Power Consumption Results (With Max Power per Sensor Configuration Bolded)

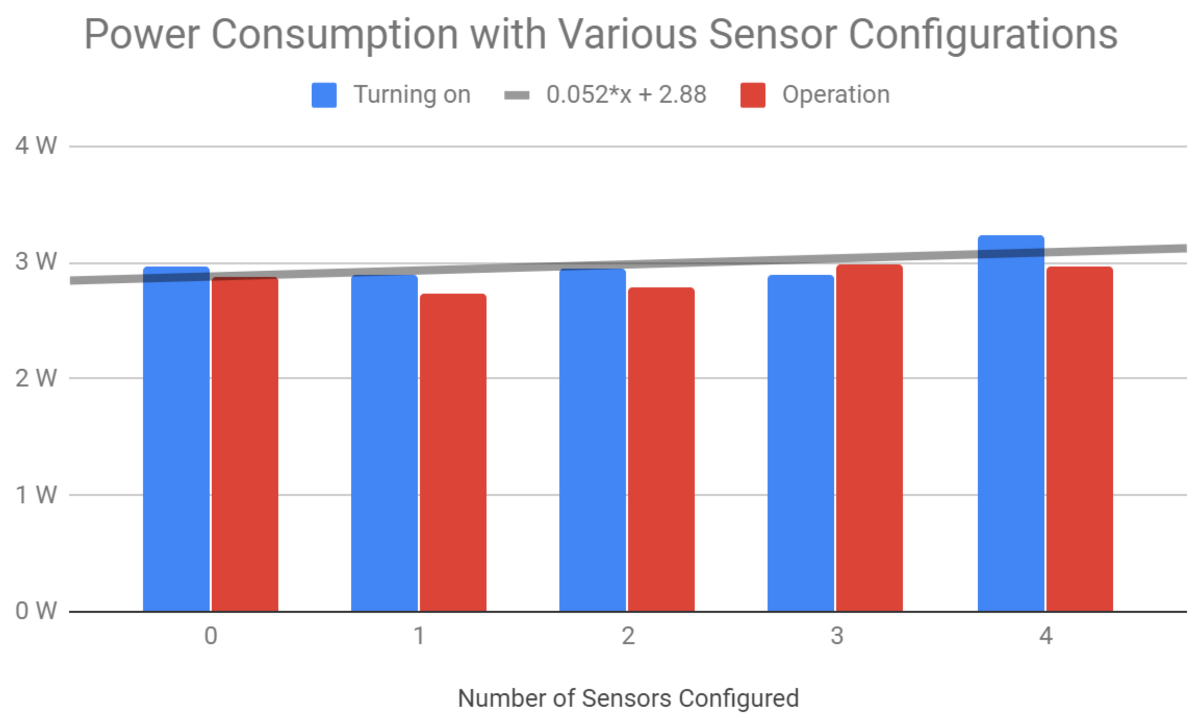

Figure 5. Graph of Power Consumption Results

The trendline in Figure 5 shows that the approximate slope of power consumption wattage is 0.052*x+2.88, where the x is the number of sensors configured. If in the future Chelan County PUD wishes to power 25 or even 100 sensors with the DAT, according to this equation, the DAT must be able to supply 4.2W or 8.1W, respectively.

d. Sustained Testing

Numerous endurance tests of up to three days have been performed at Seattle University. These tests have verified that data can be continuously transmitted for many hours without disruption or data loss. These tests have also verified that files are appropriately created each night at 00:00 for multiple nights in a row. One peculiar thing that these tests have revealed is that occasionally multiple strings are concatenated into a single string.

e. On-site Transmission Testing

This experiment measured HMS connection strength and performance, as the DAT continuously transmitted real-time sensor data to the SU, in various installation configurations. The purpose of these tests was to provide insights into the placement of the SU. Table 2 illustrates the range of transmission speeds measured while experimenting with DAT and SU locations.

Test Number	DAT Location	SU Location	Transmission Speed (sec)
1	Inner Rotor Rim	Generator Floor	0.6–0.8
2	Rotor Central Axis	Generator Floor	0.3–0.5
3	Rotor Central Axis	Outer Stator Rim	0.3–0.5

Table 2. On-site HMS Transmission Performance

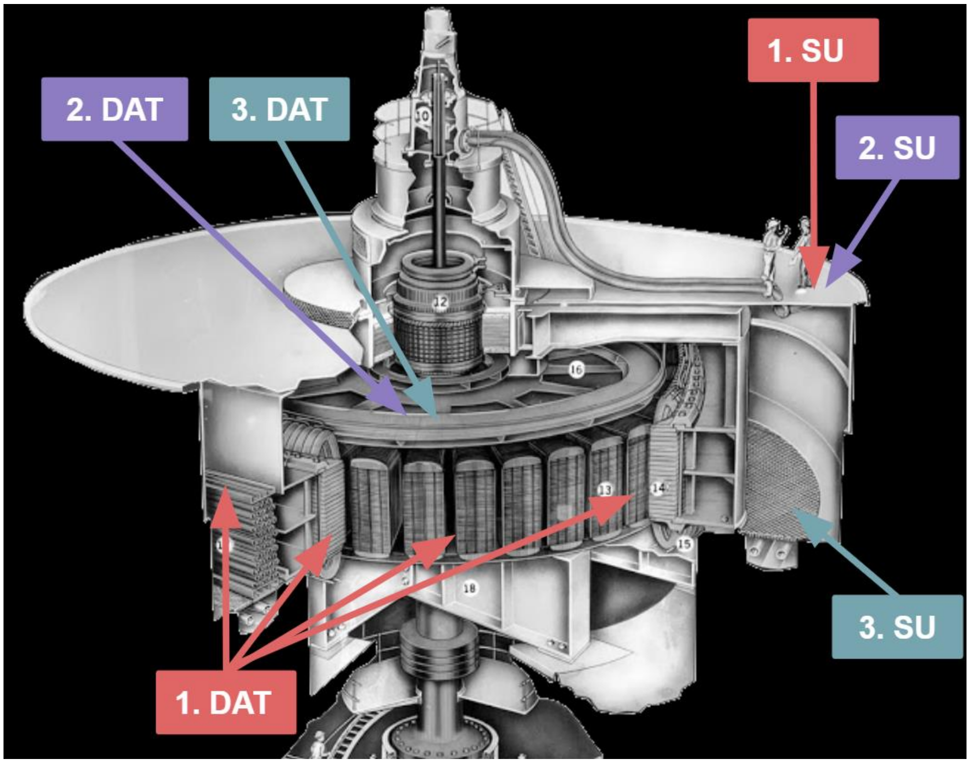

Figure 6. On-site Transmission Test Setups

The first test positioned the DAT around the rotor's inner rim while the SU was located approximately 12 meters away from the unit's central axis on the generator floor. The HMS transmission speed was then observed as we relocated the DAT to different points around the inner rim. These results demonstrated a reliable, yet significantly reduced transmission speed. This reduced speed was understood to be a result of the DAT transmission increasing up to twice the distance from the initial test point.

In the second test, the DAT was positioned around the rotor's central axis while the SU was kept in the same position as in the first test. The transmission speed in this configuration showed a marked improvement. From these results, the team concluded that moving the SU closer to the generator's central axis would further improve the transmission speed.

The third test maintained the DAT's position around the central axis of the rotor while the SU was relocated to the stator's outer rim, as shown in Figure 6. These results demonstrated near identical transmission speeds to the second test, leading the team to conclude that this setup would also be another viable installation solution for the Rocky Reach Dam facilities.

IV. CONCLUSION

ECE 19.2 designed the Hydroelectric Monitoring System (HMS), in which one Data Acquisition and Transmission (DAT) system mounted inside a hydroelectric-turbine generator can collect sensor data and communicates this data via Wi-Fi to a Stationary Unit (SU) mounted outside the generator. The DAT receives data from a variety of sensors, compiles sensor data into a tokenized string, and transmits this string in real-time to the SU via Wi-Fi. Following this transmission, the SU appends this string to a CSV file that is created daily. This data may then be extracted this by Chelan County PUD for conditional analysis.

Various types of sensors were added to the HMS to perform sustained tests at Seattle University for transmission fidelity and data collection. The HMS was also tested for high-current resiliency, power consumption, and sensor failure performance. The results of these tests led to the conclusion that what Chelan County PUD wishes to implement is feasible, though the HMS prototype delivered requires numerous additions before deployment, including a wireless power source for sustained operation. Along with this hardware addition, the team recommends that future prototype development focuses on the HMS Wi-Fi connection strength, as the range of the SU is limited to a single generator. Other recommendations by ECE 19.2 are outlined in the "Recommendations" section.

V. RECOMMENDATIONS

To assist and promote future initiatives for this project, the following sections list future work suggested by John Yale and the ECE 19.2 design team.

A. Wireless Power Solution for DAT

Due to the ongoing research of inductive power sources in generator environments, the initial DAT system implementation is powered by a portable charger. Tests to measure the power consumption of the DAT with varying sensor configurations have been provided to aid in the future development of a wireless power solution for the DAT. See "Testing" section for details.

B. DAT Containment

Without a protective case, the DAT system is not durable enough to withstand the continuous centripetal forces of the hydroelectric generator environment. Prior to installation, a DAT chassis must be designed to accommodate additional wired sensors and constructed from materials that will not cause harm to the generator. Because rotor weighting must be precisely balanced for sustainable turbine operation, a study to determine exact mounting location for the DAT within the hydroelectric generator will also need to be performed prior to installation. Tests to determine the general positioning for fastest transmission have been performed at Rocky Reach Dam to assist future teams. See “Testing” section for details.

C. Sensor Improvements

Four affordable sensors were implemented to test data transmission rates and ADC inputs. Sensors to be installed within the generator environment must be able to withstand much harsher conditions than these sensors are capable of. In future iterations of the HMS design, wired and wireless sensors should be more durable. Expansions upon the ADC/DAT are also recommended in order to provide more wired sensor inputs.

a. Email Alert of Sensor Failure

In the event that one or more of the sensors fail during operation, the RPi-DAT system could alert Chelan County PUD through email. This could work having a flag be triggered in the SU following a certain period of inactivity on the compromised sensor channel. A flag could also be triggered if a sensor value was collecting data outside of the expected range of operation, perhaps even replacing the values of the compromised sensors with a unique label such as “ZZZZ” until the issue has been resolved. During this flagged period, the RPi-DAT would likely continue to transmit at the expected rate to prevent data flow interruption. Such a system would would assist with operations management by enabling the system to alert operators for maintenance in a timely manner.

b. Wi-Fi Sensor Implementation

A Wi-Fi sensor [7] with an ESP8266 chip was configured to collect data from a spare temperature sensor and connect to the Seattle University Wi-Fi network. However, our team encountered difficulties connecting the Arduino C–based sensor to the Python-based Ad-Hoc connection of the HMS. In future iterations of this project, it is recommended that teams refer to resources [12] and [13] for assistance with this integration.

D. Transmission Improvements

Following tests at Rocky Reach Dam, it was concluded that the optimal installation locations for the DAT and SU were near the center axis of the rotor and adjacent to the outer rim of the stator, respectively. This positioning demonstrated an average transmission time of approximately 400ms. With transmission signal amplification, the SU can be relocated to allow additional iterations of the DAT system to be implemented with other generator units. For more information, see Section E of “Results & Discussion”.

a. Transmission Buffer

When the Wi-Fi signal is weak, the sample rate tends to slow down because of the sequential implementation structure that is currently implemented. Sequential implementation means that the sensor readings are retrieved, converted to a tokenized string, and sent to the SU in one continuous data flow. Because of this implementation, the transmission rate between the DAT and SU impacts the sample rate of the DAT directly. This problem could be solved by implementing a transmission buffer, which makes the sample and transmission rate independent of one another. A transmission buffer records data expediently, buffers the data, and sends string tokens in short bursts to the SU.

E. Cloud Server Integration

The final step for complete integration of the HMS into the Chelan County PUD diagnostic workflow is uploading sensor data from the SU to the Chelan County PUD cloud servers. This would entail the implementation of an ETL (Extract, Transform, Load), enabling the files to be consumed by a data analysis software. Cloud server integration has been reserved for Chelan County PUD to ensure their network's security standards are met.

VI. CITATIONS

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[5] https://www.adafruit.com/product/1075

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[10] https://detroit-electronics.com/Long-Range-Wi-Fi-Raspberry-

[11] https://github.com/ul-gh/PiPyADC

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[13] https://realpython.com/python-sockets/#multi-connection-client-and-server

APPENDIX A

Request for Proposal

Understanding of the condition of hydroelectric turbine-generator units is key to effective management of the asset. These large electromechanical devices have stationary and rotating parts. One of the challenges in monitoring is collecting data on the rotating part (turbine runner, shaft system, and generator rotor) and transmitting it in real time to stationary data acquisition and logging systems. This project is to develop an acquisition and communication system that can be mounted on the rotating equipment (generator rotor) to collect data from a variety of sensors and transmit that data to a receiving device outside the unit. A stretch objective is to design it such that it can be located inside a turbine runner or shaft and communicate through water as well as air.

APPENDIX B

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Abraham Hutauruk

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hutauruk@seattleu.edu

Education

B.S. Electrical Engineering, Seattle University

Computer Specialization 3.12 GPA

Relevant Coursework (to be completed by June 2019)

Embedded Systems, Signals and Systems, VLSI Circuit, Machine Learning, Semiconductor Devices, Digital Operations, Analog CMOS, Circuits I and II, Linear Algebra, Microprocessor Design, Programmable Devices, Probability and Statistics, Computer Systems, Computer Tools, Data Structure, Global Engineering Economics

AS-T, Edmonds Community College 3.66 GPA

Calculus I, Calculus II, Calculus III, Differential Equations, Engineering Physics I, Engineering Physics II, Engineering Physics III, Computer Science C++ I, Computer Science C++ II, Computer Science C++ III

Experience

Internship at Argenta Adhiloka Pratama, Jakarta, Indonesia (August 2012 - August 2013)

With the help of professionals, designed a database system using SQL and PHP for all the incoming and outgoing spare parts

Performed installation of ATMs and DVR on site

Repaired damaged ATM spare parts using all the tools provided by the company

Internship at Rasco Company, Jakarta, Indonesia (June 2017 - September 2017)

Worked in professional digital forensic team solving a given case

Used digital forensic tools to gather data, analyzed all the data from the disk and deduce the findings

Delivered oral and written reports of all the findings to the person in charge and the employer

Projects

Line Following Robot, Embedded Systems Lab (September 2018 - Present)

Used PIC32 microcontroller to control sensors through Pmod LS1 chip, and 2 motors using an H-bridge

Created an algorithm and wrote a C program for the robot to detect line and follows it smoothly

Persistence of Vision Clock, Junior Lab (September 2017 - June 2018)

Used raspberry pi to control PWM that is directly connected to motor RPM and control LEDs timing

Assembled a series of LED, IR sensors and other parts into a board that can be mounted to the rotor

Troubleshoot and analyzed the circuit behavior using oscilloscope

Microprocessor, Microprocessor Design Lab (March 2017 - June 2018)

Wrote a MIPS and VHDL program to create a single cycle MIPS 32 bit processor for registers, ALU and RAM modules.

Skills

C, C#, C++, Python, MATLAB, VHDL, MIPS assembly, PHP, SQL, CSS, Arduino, Raspberry Pi, MultiSim, ModelSim, LTSPICE, LaTeX, Circuit Design, Basic Filter Design, Soldering, Breadboarding, Frequency Analysis, Forensic Toolkit, Sleuth Kit, MS Office, Teamwork, Written Communication, Problem Solving, Fast Learner, Time Management, Project Management

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Mirka Mandich

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Research

Undergraduate Researcher, NSF/DOE CURENT Engineering Research Center (June 2018 – August 2018)

Developed a MATLAB program to optimize the placement of PMUs within the IEEE 9-Bus System
Improved network resiliency by integrating stochastic methods with integer linear programming
Presented research at the Undergraduate Poster Symposium, REU Presentation Day, and in a final paper

Undergraduate Research Assistant, Seattle University (September 2017 – June 2018)

Implemented digital image processing and machine-learning techniques to optimize RPCA
Analyzed and debugged graduate-level applied math algorithms in MATLAB
Delivered regular feedback reports with detailed descriptions of progress and project team objectives

Education

B.S. Electrical Engineering, Seattle University

Power and Energy Systems Specialization | Mathematics Minor | 3.45 GPA

Dean's List of College of Science and Engineering, Bannan Scholar, Trustee Scholar, ECE Ambassador, Ignatian Leader, Eta-Kappa-Nu Honor Society, Rotary Club Scholarship, WaCLA Essay Contest Winner

Relevant Coursework (to be completed by June 2019)

Embedded Systems, Signals and Systems, Fields and Waves, Electrical Energy Systems, Semiconductor Devices, Digital Operations, Circuits I and II, Linear Algebra, Microprocessor Design, Probability and Statistics, Programmable Devices, E&M, Differential Equations

Projects

Persistence of Vision Clock, Junior Lab (September 2017 – June 2018)

Performed passive and active filtration, signal amplification, voltage regulation using MOSFETs and linear regulators, speed regulation using an H-Bridge, pulse width modulation, and voltage multiplication
Investigated circuit behavior using an oscilloscope, multimeter, waveform generator, and power supply

Electrical Engineering Intern, UniEnergy Technologies (June 2017 – August 2017)

Wrote a program using C# that monitors cell voltages within a vanadium redox-flow battery
Analyzed voltage data to display in a WinForms GUI while conforming to Modbus TCP protocol

Leadership

Event Director, CODE 21 Hackathon

Organized first engineering hackathon at Seattle University
Independently fundraised over $2000 from the IEEE Seattle Section and SU Student Government
Created the twenty-one-hour event agenda, itemized budget, catered menu, and all promotional media

President, IEEE Seattle University Chapter

Organized biweekly membership meetings with tech speakers
Led the annual Soldering Workshop and Mock Interview Night

Freelance Editor, Personal Business | editsbym.weebly.com

Revised professional and academic writing to improve clarity and grammatical accuracy
Built an international client base for regular assistance with book publishing, translating, and proofreading

Skills

C, C#, C++, Python, MATLAB, VHDL, MIPS, Arduino, Raspberry Pi, MultiSim, LTSPICE, LaTeX
Circuit Design, Basic Filter Design, Soldering, Breadboarding, Proto-boarding, 3D Printing, Laser Cutting

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Austin Shardo

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shardoa@seattleu.edu
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Education

B.S. Electrical Engineering with Computer Specialization

Mathematics Minor | 3.1/4.0 GPA

Relevant Coursework (to be completed by June 2019)

Embedded Systems, Machine Learning, Signals and Systems, Semiconductor Devices, Digital Operations, Circuits I and II, Microprocessor Design, Programmable Devices, Computing Systems, Foundations of CS, Data Structures, Computing for Engineers, Probability & Stats, Linear Algebra, and Differential Equations

Skills

C, C++, Python, MATLAB, VHDL, MIPS assembly, Raspberry Pi, MultiSim, ModelSim, LTSPICE, Mathematica, MS Suite, Circuit Design, Soldering, Breadboarding, Proto-boarding, Frequency Analysis

Projects

Persistence of Vision Clock, Junior Lab **(September 2017 – June 2018)**

Performed passive and active filtration, signal amplification, voltage regulation using MOSFETs and linear regulators, speed regulation using an H-Bridge, pulse width modulation, voltage multiplication, and thermal regulation

Investigated circuit behavior using an oscilloscope, multimeter, waveform generator, and power supply

MIPS 32-bit Processor, Microprocessor Design **(April 2017 – June 2017)**

Programmed and integrated various modules including an ALU, read/write register and RAM using VHDL

Supports the MIPS assembly instructions using a Control block to direct data and operations

Sentiment Analysis Program, Python language **(December 2017)**

Programmed a RPi 3 to scan and analyze the specified Twitter account's recent tweets

Classification continuously improves as more data is sampled

Work Experience

Point of Sale, Bon Appetit

Worked to provide customer service and organizational initiatives within a high-traffic, fast-paced work environment

Enhanced time management and communication skills within a team-based structure

Technician, N. Hollywood Maintenance

Provided detail-oriented asset service and facilitated clientele relations/project logistics

Improved problem-solving skills through implementing innovative solutions within ambiguous project constraints

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Objective

Proactive, detail-driven engineering student with capabilities in completing projects with competing deadlines. Eager to learn and gain hands-on experience in an organization that embraces creativity and innovation.

Education

- Seattle University | Seattle, WA
  Bachelor of Science in Electrical Engineering, Computer Engineering specialization | GPA: 3.104
  Computer Science Minor | Expected Graduation 06/2019
  - Dean's List of College of Science and Engineering, Society of Hispanic Professional Engineers, Tau Sigma, Eta-Kappa-Nu (HKN) Honor Society, Romano Scholarship, Nabarrete Scholarship, Loyola Scholarship
  - ***Relevant Courses:*** Electrical Circuits I and II, Semiconductor Devices and Circuits, Electrical Energy Systems, Signals and Systems, Microprocessor Design, Digital Operations, Differential Equations, Linear Algebra, Embedded Systems
- Everett Community College | Everett, WA
  Associate of Science in Electrical and Computer Engineering | 08/2017
  - 3.47 GPA, graduated with Distinction
  - ***Activities:*** SHPE, Treasurer

Work Experience

Intern, Technology at T-Mobile | June 2018 – February 2019
Worked full-time during the summer and part-time during school as part of a team which acted as consultants for the entire Procurement team, helping sourcing managers in supplier negotiations, baselining, RFP analysis, program management, and promoting procurement best practices. Engaging in activities such as,

- Data Analytics
- Negotiation Training
- Supplier Research
- Dashboarding

Projects

Persistence of Vision Clock, Junior | September 2017 – June 2018
Year-long project in which a POV clock with LEDs as the creator of images was developed. Powerful enough to create alternate images, if desired.
Performed active and passive filtering, signal amp, voltage regulation using MOSFETs and linear regulators, speed regulation using an H-Bridge and PWM, and voltage multiplication.

Skills

- Python
- C#
- Java
- C/C++
- Debian/Linux
- Fluent in Spanish
- Alteryx
- MS Excel
- Tableau
- MultiSim
- Project Management
- Ultiboard
- Soldering
- Power BI
- Interpersonal skills
- MATLAB

APPENDIX C

Sensor List

PT1000 - Platinum RTD Sensor (Temperature Sensor, S1)

The PT1000 is a 1000 Ω resistor which changes resistance according to changes in the temperature. This type of thermistor measures the voltage difference between the ends of the resistor and subtracts any voltage drop from the wire. The output of this sensor is digital.

More sensor information can be found at [3].

E201WM Conductivity Sensor Probe (Conductivity Sensor, S2)

This probe measures a liquid's electrical conductivity. The probe can be physically wired via BNC connection. The output of this sensor is analog.

More sensor information can be found at [4].

Square Force-Sensitive Resistor (Strain Sensor, S3)

The force-sensitive resistor detects physical pressure, squeezing, and weight. It has a 38mm square sensing region. It works by changing resistance value based on pressure. The output of this sensor is analog.

More sensor information can be found at [5].

High-G Triple Axis Accelerometer (Rotational Speed Sensor, S4)

This accelerometer can withstand and register up to 200 G's of force. The sensor produces three analog outputs for X, Y, and Z–axis measurements and can be wired or directly to a PCB board with four mounting holes.

More sensor information can be found at [6].

ESP8266 Wi-Fi Module (Wi-Fi Sensor Module, S5)

The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. It does not have sensor capabilities, but it can receive and transmit digital data collected from a sensor. Integration of this sensor was not completed.

More sensor information can be found at [7].

APPENDIX D

Component List

Raspberry Pi 3 B+ (Miniature Computer)

The RPi 3 B+ is the central unit for the DAT and SU. They are programmed in Python and utilize open-source modules to optimize the collection and transmission of data. All components of the DAT are plug-and-play which simplifies physical construction. Additionally, 64GB SD cards have been included to support and fortify the data collection process in cases like connection failure. The operating temperature range for the Raspberry Pi 3 B+ is from 0℃ to 50℃.

More component information can be found at [8].

High Precision AD/DA Expansion Board (Analog-to-Digital Converter)

This ADC allows for a dynamic set of operations with AD/DA functions to the Raspberry Pi. It offers 8 single-ended (or 4 differential) 24-bit channels for analog-to-digital conversion, as well as 2 single-ended (or 1 differential) 1-bit channel(s) for digital-to-analog conversion. Moreover, its functionality features signal amplification, adjustable sampling rate, and--with the PiPyADC open-source Python Module--supports customizable sampling sequences of the inputs. The operating temperature range for the ADC is from -40℃ to 105℃.

More component information can be found at [9].

Long-range Wi-Fi Antennas

Signal amplification will be implemented using two long-range Wi-Fi antennas instead of using the built-in Wi-Fi transmitter and receiver from RPi module. No software is required to configure the antennas to an RPi, and the antenna is physically attached to the RPi through USB connection. The antenna that we use in this project is a 5 dBi antenna which was advertised to be able to transmit a signal 500 meters line of sight. However, after performing an evaluation at Seattle University, we found the actual range to be significantly shorter. Without the long-range antenna, the RPi-DAT can detect a Wi-Fi signal that is being transmitted by RPi-SU up to 34 meters away, with an obstructed path. With the long-range antenna, the RPi-DAT can detect the RPi-SU Wi-Fi signal up to 61 meters away, with an obstructed path. The operating temperature range for a Long-range Wi-Fi Antenna is from 0℃ to 50℃.

More component information can be found at [10].

APPENDIX E

Code for the ECE 19.2 Hydroelectric Monitoring System has been uploaded to Github and is available at the following link: www.github.com/ECEChelanCountyTeam