ECE/COE 1896

Senior Design

4-20mA Detector for Process Control - Conceptual Design

Team #2

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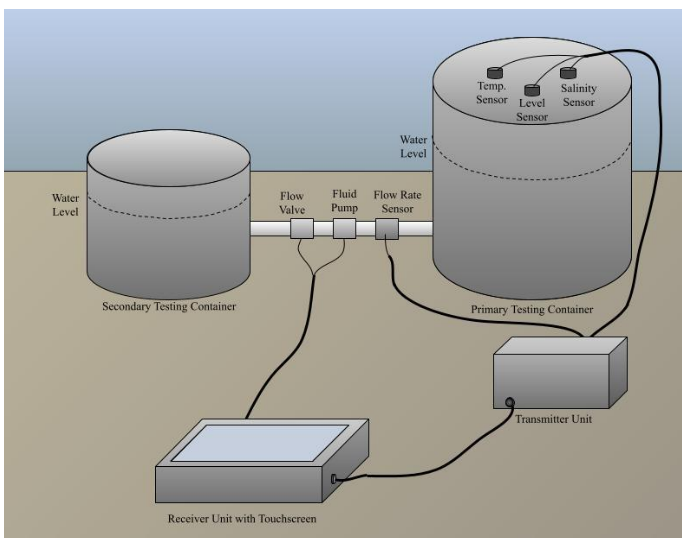
1. Introduction

This project was proposed by Fluor Marine Propulsion (FMP), in conjunction with the Naval Nuclear Laboratory (NNL), in order to provide University students with a challenging project to model real life lab equipment that interacts with sensors. The Naval Nuclear Laboratory is a group of Navy contracted labs that design nuclear propulsion systems for aircraft carriers. Specifically, The Bettis Atomic Power Laboratory, located in West Mifflin PA, is currently leading nuclear reactor design for the new FORD class air-craft carriers. This requires them to perform an abundance of high precision lab testing for their nuclear reactor systems. The data from their lab testing must be accurately recorded and delivered to their engineers in a timely manner in order for them to perform analysis and draw the necessary conclusions. Without the ability to remotely collect, export, and process lab data, lead nuclear engineers would be required to be on site in the lab or in a nearby control room to get access to the information they need. While this isn't impractical to do, it is not ideal, and engineering development could certainly be expedited with the ability to remotely collect and transmit lab data without any loss of time or data precision.

Our goal is to design and present a fully functional prototype for a process control system modeled off of standard lab procedures conducted at the Naval Nuclear Lab. Our prototype is not intended for real use in any of NNL's laboratories. Rather, it is a prototype that demonstrates a system that could be implemented in one of their labs in the future. A diagram for the physical prototype is shown in Figure 1 below. This diagram will be explained in further detail in the conceptual design section. For now, it will serve as a visual reference for the system being described.

Figure 1: System Model



Modeling this prototype off an actual process conducted at NNL is key for demonstrating the utility and practical implementation of our prototype. Therefore, we worked with our advisors from NNL to conceptualize a prototype that closely resembles a process already being conducted in their labs. The final result from this collaboration was a fluid process control system as shown in Figure 1 above. This is very conducive for future implementation at NNL, as they do a large amount of liquid solution testing for their nuclear reactors already. The system shown in Figure 1 above, will allow users to fill a test container to a specified fluid level for solution analysis. Data about the solution will be displayed on a touch screen interface so that users can monitor key metrics about the solution they are analyzing. Finally, these solution measurements will be regularly sampled and wirelessly exported to offline files for engineers to process.

2. Background

In industrial control settings, high precision sensor measurements are key for accurately controlling highly sophisticated lab processes. The need to transmit sensor data from machine to machine over long distances (sometimes in excess of hundreds of feet), poses a great challenge in industrial settings. In the presence of three phase power and highly inductive machinery, electrical noise is unavoidable. Additionally, at these long transmission distances, IR losses are no longer negligible like they were within the safe confines of the 12th floor of Benedum Hall. All of these limitations are responsible for the development of the 4 - 20 mA current loop, a standard for industrial process control instrumentation.

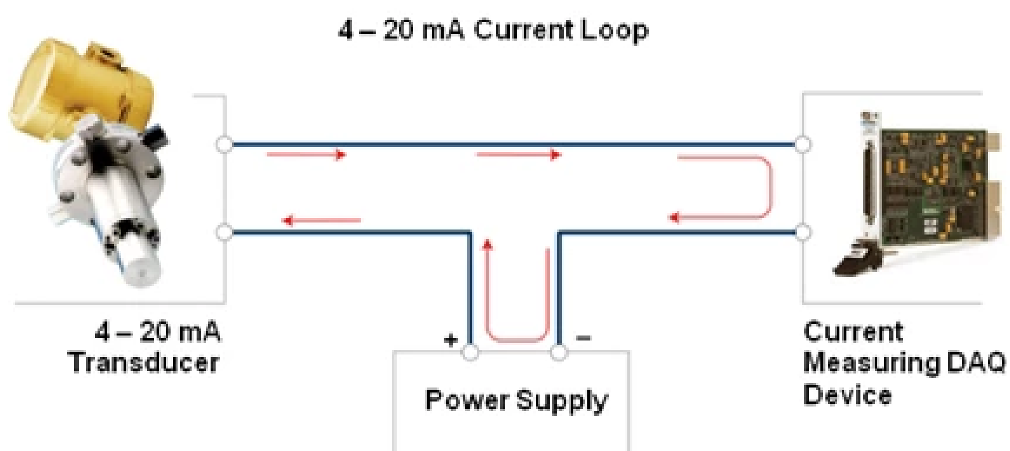


Figure 2: 4-20mA Diagram Example [1]
https://www.ni.com/en-us/innovations/white-papers/08/fundamentals--system-design--and-setup-for-the-4-to-20-ma-curren.html

In Figure 2 above we can see the basic layout for a typical 4-20mA current loop. This “loop” consists of a transducer, power supply, and DAQ (Data Acquisition Device) [1]. A transducer or sensor is a device that transforms an analog physical quantity such as temperature to a 4 - 20 mA current that represents the value of that physical quantity. Here is where the magic of this standard is most evident. If the signal used to transmit the sensor were simply a voltage applied at one end of a wire and received at the other end by a DAQ, this data would be significantly distorted by the time it reaches the receiving device due to the uncontrollable, industrial environment. However, a 4 - 20 mA current loop can be thought of as a constant current source (ie. it always sources a fixed amount of current regardless of the impedance it faces). This means that 4 - 20 mA loops are completely immune to the IR losses prevalent in long transmission distances. Additionally, since we are representing this sensor data with a current signal, it is completely unaffected by the ambient noise riddled throughout industrial environments, completely preserving the integrity of the sensor data being transmitted. This is the magic behind this standard. It faces no constraints when it comes to transmission distance or noise, as it preserves signal integrity with remarkable accuracy. That is why it has become the industry standard for process control instrumentation and will serve as the basis of our project. While there is certainly nothing novel about implementing a 4 - 20 mA loop in theory, we will face challenges in the design and implementation of four unique current loops for our project's application, a liquid solution process control system. While developing this system we will investigate the development of a unique approach to implement this method of transmitting data to our process control application, which is the current industry standard.

3. System Requirements

This section outlines the functional, material, and testing requirements imposed on the system, with these requirements coming from not only the team, but also the project description given by Dr.'s Jacobs and Bayoumy and the requirements listed in the NNL Scope of Work Document prepared by JC Sopczynski of Fluor Marine Propulsion. In the NNL document, the team has been given three options for implementing the system: An implementation utilizing hardware only, an implementation utilizing an FPGA, and an implementation utilizing a microprocessor. Given the team composition detailed in Section 7, we have chosen to draft conceptual designs for the FPGA and microprocessor implementations, with additional requirements having been prepared by MA Kotcher and JC Sopczynski of FMP. These additional requirements are provided as "Extra Requirements" in sections 3.2 and 3.3 respectively [2] [3].

3.1 Functional Requirements

3.1.1) General

The receiver shall operate with a 4 to 20 mA current range, according to the industry device standard.

3.1.2) Physical

3.1.2.1) Dimensions

The receiver shall be confined to a volume of 10 in x 5 in x 3 in (Length x Width x Height). Additionally, the receiver shall not weigh more than 10 pounds.

3.1.2.2) Connectors and Display Indicators

The receiver shall have polarized connections for four 4-20mA sensor channels. The receiver shall provide a polarized connector for an external DC power source. The receiver shall use a touch screen interface to display data and provide the user the ability to control the device.

3.1.2.3) Enclosure / Front Panel

The enclosure of the receiver shall permit the device to be held by the average human hand. The enclosure shall be designed incorporating human factors engineering principles, as discussed in section 3.1.2.4.

3.1.2.4) Human Factors Engineering Principles

The device shall incorporate human factors engineering principles focusing on the ergonomics of hand-held devices. These principles shall be applied specifically to the hardware receiver design and the software user-interface (UI) design.

3.1.3) Electrical

3.1.3.1) Sampling rate

Data acquisition shall occur at a sampling rate of one sample per second or greater.

3.1.3.2) 4-20 Interface Characteristics

The device shall be able to measure DC current within the range of 0.0 to 24 mA. The device shall provide an internal shunt resistor with a value of 250 Ohms in order to convert the 4-20 mA current to a 1-5 VDC voltage measurement. A current of less than 3.5 mA shall indicate a fault condition. A current of greater than 20.5 mA shall indicate a fault condition.

3.1.3.3) Accuracy Requirements

The device shall provide the sensor output in engineering units at an accuracy of ±4% of the physical value.

3.1.3.4) Power Source Requirements

The device shall be powered from an external DC power source. A benchtop DC power supply, typically available in University electrical laboratories, is expected to be sufficient. An additional power supply may be used to power the sensor if necessary. The maximum working voltage output of each power supply in use is 25V. The maximum working power output of each power supply in use is 25W. As an alternative to a benchtop DC power supply, it is permissible to use a battery to power the device as a primary or backup power source.

3.1.4) Component Selection

3.1.4.1) Environmental

All parts chosen for use within the design shall be rated for operation over the temperature range of 0°C to 45°C. All parts chosen for use within the design shall be rated for operation when relative humidity is 90% or less.

3.1.4.2) Financial

NNL (Naval Nuclear Lab) provides funding for procurement of parts and materials only. NNL is not providing funding to compensate the Design

Project Team or the supervising professor for time/labor. The Design Project Team must communicate to NNL all parts selected for purchase for budgetary tracking purposes. Any single part selected for purchase or any single purchase greater than $400.00 must be communicated to NNL and approved prior to purchasing. The Design Project Team should seek mentorship from NNL or their supervising professor before making purchases of any dollar value if they are unsure of their selections for any reason. All parts shall be procurable within the scheduled timeline of the project. All parts shall be procurable with the given funds allocated to the project.

3.1.4.3) Military Specification Components

MilSpec components shall be used where possible, in accordance with financial requirements in section 3.1.4.2. Components that do not meet MilSpec shall be identified in the final documentation report (see item 5.1.2).

3.1.5) Device Hardware

3.1.5.1) General

The device shall provide a means to measure four 4-20 mA channels. All values provided by the interface shall be readily intelligible in ambient light conditions. The device shall provide a means to allow the user to select which of the four 4-20 mA channels is being displayed on the handheld device. Users shall be able to display the results for a given channel in the associated engineering unit, voltage, and current. For logging, the interface shall have a means of providing data to a computer-driven or memory-based interface (external computer or memory storage device).

3.1.6) Device Software

3.1.6.1) General

The software shall take converted sensor data, through a remote connection (Bluetooth). This sensor data will be remotely processed and stored in external files.

3.1.6.2) Microprocessor Implementation

The software shall provide a user interface (UI). The UI shall be visible upon device startup (i.e., no user action is required to open the interface). The software shall provide the user the ability to align (configure scaling at runtime) all four 4-20 mA channels. The UI shall display measurements from four 4-20 mA channels in real-time. The UI shall display the measurements in user-defined engineering units. The UI shall display diagnostic information (i.e., name, status, operational temperature, etc.). The software shall provide the user the ability to enable/disable logging as desired. The software shall provide the user the ability to enable/disable Bluetooth data streaming as desired. The software source code shall be developed in the coding language of the Design Project Team's choosing.

Students are encouraged to use Arduino or Raspberry Pi platforms. Documentation shall be created for the use of the software.

3.2 Extra Requirements for Microprocessor Implementation

3.2.1) General

A Microprocessor shall serve as the central processing unit of the device. The device shall use Microprocessor components to output display values. The device shall use Microprocessor components to perform any system calculations (e.g., voltage or current scaling). Any switching between display features (e.g. switching between °C and °F) shall be accomplished via Microprocessor input components. All indications shall be accomplished via Microprocessor components.

3.3 Extra Requirements for FPGA Implementation

3.3.1) General

The device shall use only a FPGA and analog or digital hardware to output display values. The device shall use only a FPGA to perform any system calculations (e.g., voltage or current scaling). Any switching between display features (e.g., switching between °C and °F) shall be accomplished using the FPGA and physical hardware (e.g. push-button, switches, etc.). All indications shall be accomplished via analog or digital hardware components (e.g. 7-segment LEDs, LED indicators, dot matrix displays).

3.4 Testing Requirements

3.4.1) General

As part of the requirements given by the NNL, the team will develop a test plan to verify the device meets all functional requirements and will use a traceability matrix to depict how individual test procedures are intended to meet each functional requirement. The test plan will also detail the equipment we use during testing.

3.5 Deliverable Requirements for NNL Sponsors

3.5.1) University Reports

The Design Project Team shall provide to FMP all reports required by the University.

3.5.2) FMP Final Report

The final report submitted to FMP shall include the following:

Description of the device from an engineering design perspective (e.g. technical specification or technical manual). Description of standard operating procedures for the device (e.g. user guide). Discussion on the human-factor engineering principles incorporated into the design. List and discussion of any functional requirements deviations. List and discussion of any materials requirements deviations. Test plan(s), Traceability Matrix(s), and Testing results. References to the resources that the Design Project Team found most beneficial in completing the project. Discussion on the Design Project Team's ability to complete the project given their engineering backgrounds at the time of project initiation.

3.5.3) Design Drawings

The Design Project Team shall provide to FMP all applicable drawings, including the following:

Schematic - The Design Project Team shall deliver a finalized schematic of the circuit design used to meet the requirements herein. The schematic shall be developed with the use of computer-aided software (e.g., OrCAD Capture).
Parts List - The Design Project Team shall deliver a parts list of all parts used inthe design. The parts list shall provide for each part a general number (i.e., 1, 2,3…), the manufacturer's designation, and a brief description.
PCB Assembly Drawing - The Design Project Team shall deliver an assembly/layout drawing showing the PCB layout, labels, and connections to support manufacturing of the device circuit.
Mechanical Assembly Drawing – The Design Project team shall deliver an assembly drawing showing the casing, touch screen, and circuit to support manufacturing of the device casing.

4. Design Constraints

4.1 Conventional Contraints

4.1.1) Time

The constraint that is likely to pose the most problems is the limitation of time within the semester, to produce a fully functional product that meets the required specifications. For the senior design project, the team has roughly 12 weeks of working time, in order to produce the 4-20mA current loop receiver and lab setup, which is also going to be cut into by the workload of other classes within the term. This design constraint is being taken into account extensively with the drafting of a term schedule, laying out roles for each of the team members, and what level of progress each member plans to make during each week. This will allow the team to be cognisant of the timeline, making sure to find solutions that can be achieved in order to reach the final goal at the end of the term. In a typical engineering setting outside of school, time is always going to play a similarly large factor, because it is important to produce a product on a shorter timeline, but it is more effective in the long run taking any extra time, in order to ensure the product meets the entirety of the requirements set for it.

4.1.2) Manpower

Manpower is going to factor heavily within the course of this term, because it is crucial that the design team members are on the same page, and making steady progress throughout the duration, in order to ensure a functional product is produced. This is a prevalent constraint for teams working during a 12 week school term, as the team members need to make sure to budget their time appropriately, in regards to school commitments. But if the senior design team is able to stay on pace with the project schedule, and all four members can work together to pick up any slack, the project will benefit from having additional time for last minute modifications to the final product.

4.1.3) Financial

Financial constraints always tend to affect project completion, in a similar way to having a rigid timeline that needs to be followed, and our senior design project is no different. For the senior design project, teams are given $200 as a baseline to finance their project development, which incorporates all necessary part purchases in order to produce a product that meets the requirements. In addition, the 4-20mA project is supported by project mentors from NNL, and afforded upwards of $1000 in funding. This certainly loosens the budgetary constraint placed on our senior design team, by allowing for significantly more flexibility in terms of purchasing higher quality, higher precision components and equipment. However, the design team still needs to pay particular attention to the term budget, to make sure expenses are being tracked, and expensive components are approved prior to purchasing, in order to emulate real world financial constraints. If this device was going to be produced in an engineering setting for a set of consumers, typical funding would likely be much higher, in order to ensure the project team created a high-precision device for lab monitoring, however the budget will always play a factor in what design choices can be made.

4.2 Project Constraints

4.2.1) Material Constraints

Material constraints will play a role in the design decisions that can be made on this project, with regards to the board and enclosure design, the lab/sensor setup, and the wiring used to transfer sensor data to the receiver. For our device components, it is important that the senior design team is compliant with the

Restriction of certain Hazardous Substances (ROHS) standards, which confirms that the portion of hazardous, or difficult to dispose materials and substances is limited to the maximum allowed. By adhering to these standards when choosing components for our hardware design and wiring for our sensors, our product will still be able to produce accurate results, without having safety concerns for using fragile or toxic materials, or substances that pose a fire hazard. This is certainly a constraint for the design team however, because the products ordered for the project need to take into account these specifications, which limits the ability to purchase certain components if they don't comply with ROHS standards. In a professional setting, these types of standards would certainly be accounted for by the design team, when making numerous choices from product manufacturers to acquiring parts for certain aspects of hardware design. As much as it is a design constraint, this is also a necessity in professional settings, when devices are produced on a mass scale.

4.2.2) Mechanical Design Implementation

A design constraint that is involved with this senior design project, is the building of a modeled lab setup that includes two test containers connected by a large pipe, with a fluid pump in between to facilitate the flow of liquid for sensor testing. This is a design constraint because as ECE students with knowledge for electrical and computer systems, the senior design team will need to adapt and learn ways to accurately test each of the device sensors. The lack of knowledge for this type of mechanical implementation will limit the design of the project's lab setup, because in order to have a functional lab device for receiving sensor data, the fluid pump and valves need to be well integrated to connect the two test containers for proper sensor readings. In an engineering setting, constraints like this would be less prevalent, because instead of having four team members with similar skill sets, the project design team would also consist of team members with additional expertise for all aspects of the project.

4.2.3) Safety Constraints

The final design constraint that needs to be taken into account during this senior design process, is the aspect of safety in regards to building a test setup suitable for a professional lab. Throughout industry, process control systems are used to automate and collect data from a variety of volatile chemical processes. Though we would like to make our prototype as realistic as possible, it would be irresponsible of us to meddle with unsafe chemical processes. Being ECE students, we are untrained in this field and lack the knowledge and guidance necessary to implement the proper safety measures. This is why we chose to implement water salinity testing for our chemical analysis. This allows us to perform some form of chemical analysis on the test solution without exposing ourselves to more hazardous chemical agents.

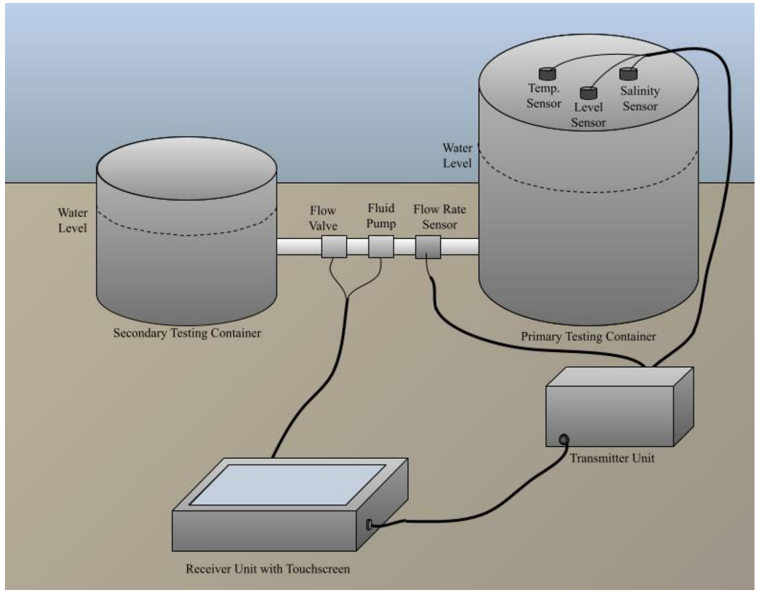
Additionally, the data receiver with the touchscreen interface is intended to be a handheld device. While the frequency with which it will need to be lifted remains unknown to us, any handheld device in a professional setting must adhere to NIOSH (National Institute for Occupational Safety and Health) recommended weight limit standards for a particular lift. We will need to acquire additional information regarding the physical manner users are expected to interact with this device.

5. Conceptual Design

5.1 Device Description

The system shown consists of a primary testing container, secondary testing container (together referenced as the test setup, fluid containers, etc. interchangeably), a pipe connecting the two of them, along with a 4-20mA current transmitter and receiver unit. The primary container stores liquid and will have an exit port to drain it when the final prototype is created. The top surface is intended to be removable for maintenance, and although three sensors are shown mounted to this surface, the position of these sensors is for demonstration and may be different in the final design. These sensors may, in fact, be mounted in the sides of the container if necessary. This container is then connected to a secondary testing container, which also holds liquid. This connection is made by a pipe, which houses the flow rate sensor, measuring the fluid intake of the system, a fluid pump to pump in liquid, and a valve to prevent or allow the pumping of liquid. The liquid pumped into the primary container will come from the secondary container, which will have a removable top for filling with liquid, as well as an exit spout for draining. The sensors attached to the primary container and the pipe will connect to a transmitter that converts the raw sensor signals to a 4-20mA current and transmits them to the receiver device. The connection between transmitter and receiver is wired and intended to be connected from long distances such as 20 - 40 feet, just as a practical system would allow for long-distance connection. The receiver device houses a touchscreen (or other display) that will allow the user to view sensor data in real time. The receiver will also allow users to increase the primary container's water level to a specified value, and will transmit to the flow valve and fluid pump to perform these actions.

Figure 3: Full Physical System

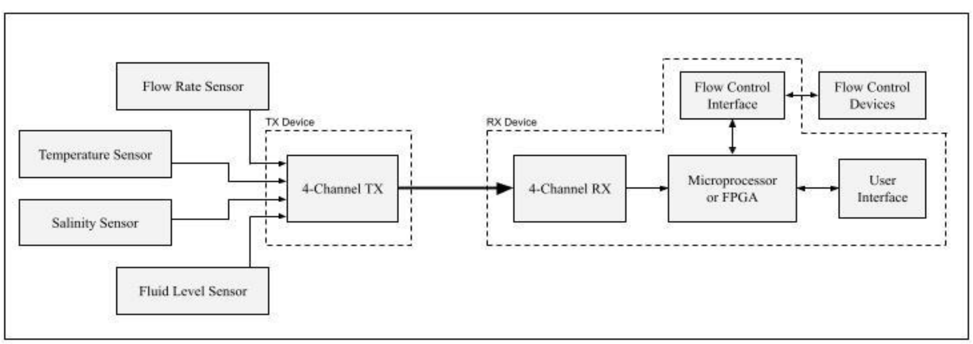


Below shows a mock-up of the physical system that will be designed to meet the requirements of our project. Some features of the system have been omitted for simplicity and the individual objects in the diagram are not shown to-scale.

We will now go into further detail on each section of the physical system shown in Figure 1 above and highlight the different options we have for each section. We will then summarize our choices.

The physical system from Figure 1 can be broken down into 5 separate devices as shown in Figure 4 below. There are a variety of approaches to designing each device. For each block, we will outline two different approaches and explain our choices for the final design approach.

Figure 4: Block Diagram of System Design



5.2 Design Concept 1

5.2.1) Sensors

5.2.1.1) Probes and Top Mounted Devices

The first design option regarding sensor profiles would entail purchasing temperature, salinity, and level sensors whose profile resembles that of a long probe, which would be mounted through the top surface of the fluid container. Using these sensors would be helpful during testing by allowing us to easily test the transmitters with real sensors before the creation of the container system is complete, and this would also lower the amount of waterproofing the system requires by ensuring that only the probe will be submerged, given that the tank will never be completely filled to the top. This limits the system at the same time, as the options probe sensors may limit the varieties of sensors available for purchase. Additionally, these probes limit our ability to adjust sensor positioning for more accurate data, as they will only be mountable from the top face of the container and would limit the lowest allowable fluid level in the container, as the fluid must always be high enough for the sensors to be partially immersed.

5.2.2) Transmitter Design

The purpose of the transmitter is to take a sensor's output and convert this into a constant current output to the current loop in the range of 4-20mA. Each sensor will require its own transmitter specifically designed for that sensor's output range. For example some sensors may produce an output which ranges from 0-10V DC while others may output 1-5V DC. Both examples will have their own transmitter designed specifically for that sensor output in order to convert the sensor's entire output into the 4-20mA range. The transmitter will be powered by an external DC power supply.

There are multiple designs for 4-20mA current transmitters which will be considered during the initial prototyping and testing phase. As previously stated, each transmitter will have a unique design based on the needs of each sensor. While the component values will differ, the circuit's overall design will remain the same and therefore there will only be one design option for each transmitter which will be modified.

5.2.3) Receiver Design

5.2.3.1) On-board microcontroller ADC w / low tolerance resistors

The receiver will consist of the hardware interface that safely connects the 4 - 20 mA transmitter channels to the analog inputs of the microcontroller. As described in the transmitter section, each sensor will have its own transmitter channel that produces a 4 - 20 mA loop. Each of these loops will then be connected to its own receiver channel that transforms the 4 - 20 mA current to a proportional voltage. The current loops must be transformed to a 0 - 5 V signal in order to be safely read into the microcontroller without damaging the pins or any internal circuitry. Since each current loop must remain in the 4 - 20 mA range, this is very easily achieved by terminating each current loop with a nominal 250 ohm shunt resistor.

This resistance will always produce a voltage within the 1 - 5 V range, and any voltage outside this range will be treated as a fault in the system. A huge benefit of using 4 - 20 mA loops is they suffer no IR losses over any transmission distance and they are noise immune. This makes them a very good option for transmitting highly-sensitive, precise signals. However, resistor tolerances can still present a big source of error for data with this level of precision. In order to combat this, we will use 250 ohm shunt resistors with the lowest tolerance level available to us, maintaining as much signal integrity as possible. Another source of data error comes from the resolution of the analog - to - digital converter. The microcontroller we use to process the data comes equipped with analog inputs that use ADC's to read the analog input signal. The microcontroller we plan to purchase has a 12 - bit ADC which gives us 4,096 data points to map our analog sensor data. Additionally, the power ratings for our controller pins should be taken into consideration since we are using a 4 - 20 mA loop, which supplies a constant current. Many microcontrollers have current limit ratings <= 20 mA for their input pins. In order to protect the pins and the microcontroller's internal circuitry, this design will include a voltage buffer interface between the shunt resistors and the microcontroller pins. The signal buffers will accurately translate the resistor voltage with minimal output current, ensuring we remain well under the maximum input current for the controller pins.

5.2.4) Device Controller

5.2.4.1) Microprocessor Implementation

This will be a microprocessor implementation that utilizes a RaspberryPi or Arduino to interface with a 4-20mA current loop.

(a) Implementing the microprocessor through use of a Raspberry Pi, is one option for choice of controllers, and the devices usually range from $10-35. Raspberry Pi's have great processing power, with an ability to run several cores at 0.7-1.5GHz, in addition to utilizing 0.5-1GB of RAM. These controllers operate with 40 GPIO pins for remote interfacing, and they use a microSD for ample storage. Lastly, Raspberry Pi's have the ability to operate off conventional Wifi standards, and have remote bluetooth capabilities. These controllers operate off a 5 volt power source.

(b) Implementing the microprocessor through use of an Arduino is the second option for choice of controllers, and the devices usually range from $23-100+. Arduino's have average processing power, running multiple cores at 16MHz and above, in addition to utilizing 2kB-8MB of RAM. These controllers operate with 14-28 GPIO pins for remote interfacing, and have 32kB-16MB of Flash Storage. Lastly, Arduino's have the ability to operate off standard Wifi, and also have remote bluetooth capabilities. These controllers operate off a 5 volt power source as well.

5.2.5) Graphical User Interface

5.2.5.1) Touch Screen Display

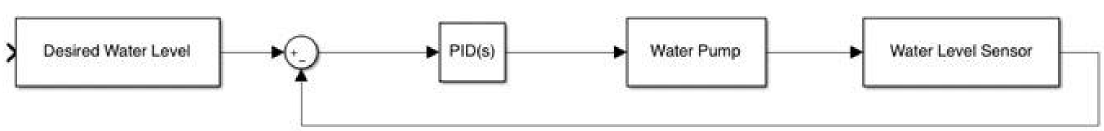
Implementing our user interface through the use of a microprocessor, is one option that affects the type of display, based on the design requirements. Having our controller as a microprocessor means the design team will implement a touch screen display that is visible upon startup, and displays real-time data metrics for each of the four sensors being monitored. This interface will be controlled by software run remotely through a supporting computer, in order to run data conversions from the sensors to display appropriate sensor values, in addition to displaying diagnostic information about each of the sensors. This touch screen will allow users to easily switch between sensors they are monitoring, and it will allow the user to enable/disable data logging and enable/disable bluetooth data streaming as well. These highly integrated displays typically cost more than the average LED display, but will interface smoothly with a powerful microprocessor in order to show real-time measurements that demonstrate high accuracy with low latency.

5.2.6) Water Level Control System

5.2.6.1) Simple Proportional Controller

The water tank control system will allow users to input a desired water level on the receiver's touchscreen interface. The control system will then fill the water tank to that requested level within an accuracy range of 10% . A high level block diagram of the controller we will implement is shown in Figure 5 below.

Figure 5: Control System Block Diagram



As mentioned above, the receiver's touch screen interface will allow users to input a desired water level. This level will be input to the controller which will activate the water pump to begin filling the water tank. The output of the water level sensor will be fed back into the controller in closed loop fashion with negative feedback. This will compare the current water level to the desired one and proportionally adjust the controller output. This means if the actual water level is far from the desired one, the controller will speed pump up. Similarly, as the actual water level approaches the desired level, the controller will slow the pump down to prevent the test tank from overfilling.

5.3 Design Concept 2

5.3.1) Sensors

5.3.1.1) Low Profile Sensors

The second design option would involve making use of low-profile sensor packages designed to be mounted thru container walls. This would allow a wider range of sensor placements by enabling us to place the sensors on any of the container's side walls allowing for possibly more accurate data by adjusting sensor placement. Additionally, this allows us to select a wider variety of sensors than probe-style sensors would, giving us a greater degree of freedom when choosing the exact sensor type to match our needs. Using side-mounting sensors would, however, disadvantage us, as we would need to expend further effort to make sure the system is well sealed to avoid leaks and damage to the electronics.

5.3.2) Transmitter Design

See section 5.2.2.

5.3.3) Receiver Design

5.3.3.1) External ADC with Buffer System

The receiver design approach in Design Concept 1 detailed the usage of the microntroller's on-board ADC to read sensor data into the controller. However, after some testing, we may find that the resolution of the controller's on board ADC is not high enough to achieve the level of accuracy we need. Therefore, this design approach will incorporate an external ADC for each transmitter channel. The external ADC chosen will have a higher resolution (> 16 bits), allowing us to represent the 1-5 V input signals with higher granularity.

5.3.4) Device Controller

5.3.4.1) FPGA Implementation

This will be a Field Programmable Gate Array (FPGA) implementation, in order to control the hardware and software functionality of the handheld receiver device. FPGAs are integrated circuits that are designed to allow users to modify and configure the device for unique purposes after manufacturing.

These controllers are very useful in product design, because at the heart of the device are Configurable Logic Blocks(CLB) (Ex. look-up tables, multiplexers, etc.) which can be used for numerous different processes, performed in parallel. Because the controllers can execute operations in parallel, it would be beneficial when collecting data from 4 sensors and processing them with low latency and high accuracy. A mid-range FPGA has exceptional processing power, with configurable logic blocks operating at 12.5Gbps and above, in addition to utilizing 30MB of RAM. These controllers often are sold complete with 30-40

GPIO pins for remote connection, in order to be able to run an external display in addition to taking data in from the multiple sensors.

5.3.5) Graphical User Interface

5.3.5.1) Non-Touch Screen Display

Implementing our user interface through the use of an FPGA is the second option for the senior design project, which wouldn't require the addition of a touch screen display. Instead, a trivial non-touch screen display would be used, where the ample GPIO pins on the FPGA would be connected, in order to send real-time data metrics to specific locations that could be toggled depending on what the user wanted to see. This option would require that buttons or switches on the FPGA be used to toggle between each of the sensors, as well as switching between engineering units for alternate sensor readings to be displayed on the GUI. These lower-end displays typically are quite affordable, and would be able to accurately and quickly display real-time sensor information, but they are often limited in size, so the user has to toggle between screens in order to get critical diagnostic information.

5.3.6) Water Level Control System

5.3.6.1) PID Controller

In Design Section 1, we described the usage of a proportional controller which either speeds up or slows down the water pump based on the test tank's current water level with respect to the desired level. While this is more than sufficient to achieve the basic level of control needed for this system, a more accurate approach exists. That solution is a PID controller. In addition to the proportional component from the previous approach, this controller adds two key elements: integral and derivative control. The integral component takes the weighted average of the difference between current and desired water level to prevent the pump output from rapidly oscillating. The derivative component takes the derivative of the difference between current and desired water level, which allows us to see how quickly we are approaching the target water level. This will allow us to lock in on the target water level with more precision and prevent from overshooting the desired level. Overall, these additional control elements will allow for much more precise filling of the desired water level, but may exceed the requirements of our application.

5.4 Selected Design Concepts

5.4.1) Sensor Selection

With regards to choosing the appropriate sensor packages, we have decided to seek out temperature, level, and salinity sensors that use low profile, side-mountable packages. This seems our best option because it provides us with the ability to fully submerge sensors and mount the sensors on the container walls. This is beneficial as it gives us a larger range of acceptable fluid levels than the probe-style sensors, a larger surface area to adjust the sensor placement on, and it gives a larger number of sensor types to choose from. For these reasons, this choice will be beneficial to our overall design and sensor calibration.

5.4.2) Transmitter Design

As stated in Section 5.2.2, we will be using one circuit architecture for each transmitter design. The choice of component values will differ depending on the needs of each sensor. This decision will be made during the prototyping process.

5.4.3) Receiver Design

The team will be pursuing the receiver design from design concept 1 (Section 5.2.3.1). We believe that the resolution of the microcontroller's on-board ADC will allow us to process sensor data with a sufficient enough level of accuracy. While the higher level of accuracy has its advantages, the implementation of external ADC's would add clutter to the PCB, which concerns the team. Additionally, the maximum current rating for the microcontroller's input pins is one of our big concerns. We feel that providing electrical isolation between the transmitter and microcontroller is key to preventing damage to the input pins. Therefore, using signal buffers to transmit the resistor voltages to the microcontroller is a very logical choice.

5.4.4) Device Controller

The senior design team plans to drive our handheld receiver device using a higher grade model Arduino, which will provide the top level of capabilities compared with these different controllers. This choice of using a microprocessor over an FPGA was one based on a few main factors. First, it's important to recognize that FPGAs can process operations at a higher rate of speed than high-end microprocessors, and that the cost of an FPGA is low compared with certain controllers as well. However, despite parallel processing capabilities, a microprocessor is the preferred choice for the design, as it allows for simplified hardware and software integration, especially for complex mathematical derivations, and includes wireless data transmission capabilities. This wireless data transmission can be done with FPGAs, but there needs to be additional components purchased in order to get this functionality. Additionally, Arduino controllers offer many different high end GUI's that can be connected to the boards' numerous GPIO pins, in order to run an integrated display for critical sensor information. The display the design team is going to implement is a touchscreen LED display. There are certainly benefits to using Raspberry Pi's over Arduino's, however for the scope of the project, the Arduino will be capable of providing the necessary processing power to create an operational device.

5.4.5) Graphical User Interface

For our senior design project, the team is going to implement the device's graphical user interface through the use of a touch screen display, being controlled by a microcontroller (Arduino). We have chosen this approach over more trivial displays, because we want to allow the user to be able to see critical sensor diagnostic information, without having to toggle between switches. The touch screen display would provide the user with all the relevant sensor metrics in real time, on one screen, and could seamlessly transition between different sensors with a few basic controls. This level of abstraction for the user allows for the device to be transferable to different lab situations or with different sensors, so that the final product is adaptable for more intensive lab setups.

5.4.6) Control System

The senior design team plans to implement the simple proportional controller. While the PID approach has many clear advantages, the team doesn't feel that this particular application warrants that level of accuracy. Adequately tuning a PID controller can be a cumbersome task, which the team fears may threaten some of its more valued deliverables. The purely proportional controller will still allow the team to implement the desired level of process control, without jeopardizing its ability to complete other key system deliverables.

6. System Test and Verification

The criteria we will use to evaluate our systems performance are: sensor data accuracy, data transmission latency, and control system accuracy. Our plans for testing each of these metrics are outlined in the sections below.

6.1 Sensor Accuracy Testing

6.1.1) Software Systems

The software testing will be executed in 3 different phases: Dummy Data, Real Sensor Data, and Data optimization.

Dummy Data Testing

In this phase, the team will test its software's ability to read a variable voltage "dummy data" into the controller, display the values on a screen, and export the data to an offline file with general accuracy. We refer to it as "dummy data" to highlight that it will not be coming from the actual hardware transmitter. At this point, our goal is just to test the GPIO configuration and ADC conversion process to ensure we have the framework in place to read an analog voltage from a microcontroller pin. At this point, we will then evaluate our ability to display these microcontroller values on our user interface and an offline file (latency will not be evaluated at this point). This is a qualitative testing phase where our goal is to ensure that the basic framework is in place to read and display data. We will begin to analyze true accuracy in the next section.

Sensor Integration Testing

In this phase, we will begin testing our software's ability to read true sensor data from the hardware transmitter into the microcontroller. This is where our ability to export raw microcontroller measurements into an offline file will come in handy. None of our sensors will operate throughout the entire 4 - 20 mA range they are capable of. Rather, each one will operate within a much smaller portion of that band depending on the analog quantity it is being used to measure (ie. the temperature sensor can measure a very wide range of temperatures, but we will calibrate it to a more practical range related to the application of our system). This means that the analog voltage we read in will also be defined by the sensor's range of operation. This range of operation will not be perfectly linear. This will require us to develop a more sophisticated model for the sensor's output behavior. We will do this by exporting the microcontroller samples to an offline software package (Matlab, Excel, etc) for processing. This sensor output model is key to be able to associate the voltages we read into their actual physical quantity. Our software has no inherent understanding of the relationship between each sensor's output and the physical action it is measuring. It is our responsibility to develop a model that accurately relates sensor output voltages to the physical metric that produced it (ie. 75 degree fahrenheit will produce a very specific output, 0.5 L / min flow rate will produce a very specific output).

6.1.2) Hardware Systems

6.1.2.1) Dummy Data Testing

In the "Dummy Data" testing portion the team will also be conducting tests on the hardware implementation, specifically that of the transmitters. The transmitters play a crucial role in the accuracy of the systems data collection. In order to reach the accuracy requirements outlined in section 3.1.3.3, the transmitters need to produce a linear output with the minimum and maximum as close as possible to 4 and 20mA respectively. Achieving this accuracy will require the team to use components with high precision. In this testing phase however, the team will be prototyping transmitter circuits on breadboards using components available in the lab. The purpose of this prototyping phase is to ensure that we are able to create an accurate constant current proportional to the input. The input in this phase will be simulated using a potentiometer as a voltage divider producing a range of input voltages. This will allow the team to calibrate the transmitter to the expected value of the sensor inputs. Once the sensors arrive we will leave the dummy data testing phase and move into the sensor integration testing. The accuracy of the receiver will also be tested in this phase in order to ensure that the constant current can be translated to a voltage without losses.

6.1.2.2) Sensor Integration Testing

In the hardware portion of the Sensor Integration phase of testing, the team will remove the potentiometer inputs from the Dummy Data phase and replace them with the actual sensors that will be used in the final prototype. The purpose of this phase of testing is to finalize the transmitter design ensuring that the component values chosen will produce the correct constant current values meeting all accuracy requirements outlined in Section 3.1.3.3. Note that in this phase the team will still be prototyping on breadboards but will be making all final adjustments to the transmitters before ordering the final PCB. In this phase the team will also be combining the transmitter and receiver so that the microcontroller will be able to read in real values from the sensor. The receiver will again be tested to ensure that the current can be accurately translated into a voltage within a range the microcontroller can read and process.

6.1.3) Final Accuracy Testing

In Section 3.1.3.3, the project requirements outlined that the system must be able to read in sensor data with no more than a ±4% deviation from the physical value. In order to meet these system requirements, the system will be tested in a mock control environment designed by the team. This control environment will consist of two water tanks connected through a pipe. The sensors for water temperature, volume, and salinity will be located in one of the water tanks while the flow rate sensor is attached in line with the water pipe. These sensors will gather real data from the test setup. This data will be computed by the software and displayed within the ±4% accuracy range. In order to confirm the sensor readings are true, the team will take measurements of each element individually and compare the results to the output of our system design. For the temperature of the liquid, we will use an external thermometer and compare the thermometers reading to the thermocouple output. To measure the accuracy of the salinity sensor we will obtain water samples of varying salt concentrations from the chemistry lab and compare the salinity reading we obtain to the known concentration of the samples. Measuring the water level will be as simple as measuring the actual volume of the water tank and comparing the sensor reading to the known level. In order to measure the accuracy of the flow meter the team will need to calculate the rate at which one water tank is drained into the other. The team will then compare the reading of the flow sensor obtained on our module to the calculated expected value.

6.2 Latency Testing

6.2.1) Software Systems

This portion of the key measurable criterion will be measured strictly using software testing methods. For the final prototype, the device should be capable of transferring data that is received by the device from the sensors, all through a wireless bluetooth connection. With this wireless connection, when sampling data from the sensors and logging the data to an external file, there must be no more than a 1 second delay in the data transmission from the sensor output to the software system. Once the wireless data transmission is operational within the device, this transmission latency will be monitored by a computer running an application called WireShark. This application can capture bluetooth traffic between separate machines and devices, which will allow us to accurately measure the duration of the data transmission. This will allow our team to verify that the performance latency for remote transmission is maintained at no more than a 1 second delay, so that data logging from all four sensors can be accomplished for use in the final product design. By doing so, we will be able to verify whether or not this performance metric is met for each of the sensors, by observing the latency for each sample, and averaging those transmission times across the testing period.

6.3 Control System Testing

6.3.1) Performance Testing

The key criteria for evaluating our control system's performance will be the accuracy of the delivered water level. The control system will allow users to input a specified water level that they would like the test tank to be filled to. We will evaluate the system's ability to meet the user defined water level by comparing the final test tank level to the desired level. For example, a user inputs a desired water level of 8 gallons. The controller begins to pump water into the test tank and shuts off when the desired water level is close to being reached. Ideally, no more water would be pumped at this point. However, an undesired amount of residual water pressure from the pump will remain in the valve and spill into the tank, causing it to overfill. This flaw can be eliminated by introducing the proper amount of hysteresis. The tuning of this process will be essential to the minimization of error. It is our goal to keep the possible output error under 10% of the desired value. We will be using the tuned water level sensor to determine the actual volume of water in the test tank and comparing this value to what was input by the user.

7. Team

This team is composed of three electrical engineers (Sean Albright, Nate Davis, Logan Trower) and one computer engineer (Cam Ostiguy). Each member possesses a unique skill set that will be applied to the most relevant portion of this project. Sean and Logan will be primarily concerned with the transmitter and overall current loop hardware, while Nate and Cam will focus on the receiver, the user interface, and the remote data processing.

7.1 Sean Albright

Sean will be responsible for designing the hardware for two of the transmitter channels in the 4-20mA current loop, namely the channels that interface with the fluid level sensor and salinity sensor. He will also be responsible for prototyping, testing, and improving the design of these two transmitter channels throughout the course of the project. Sean will also be responsible for compiling all circuit schematics created by the team and translating them into the necessary PCB designs in Altium. Furthermore, he will be responsible for drafting the team's budget, completing any reimbursement forms, and placing all part orders for the team. Naturally, this includes deciding on and placing orders to a PCB manufacturer. Sean's previous experiences with testing circuitry in both the Electronic Circuit Design Lab course and Analog Communications Systems course make him suitable for his work on the transmitter channel designs. Additionally, his previous experiences with PCB design in both Junior Design Fundamentals and ECE Prototyping Fundamentals make him a fitting member to design the PCBs.

7.1.1) Skills learned in ECE coursework

Skills from previous ECE courses will be used in order to both design the aforementioned transmitter channels and to design the PCBs in Altium. Transmitters in 4-20mA current loops generally employ BJTs to transform a voltage range into a linear current range, and the knowledge on how to bias a BJT for this operation will come from ECE 102, Microelectronic Circuits. Some knowledge from ECE 1562, Digital and Analog Filters, may be employed to improve sensory reading accuracy by creating analog filters to isolate data transmitted between the sensor and receiver. The general knowledge of how to create schematics, transfer them to PCB layouts, and how to export these for manufacture all come from both ECE 1895 and ECE 1890, Junior Design Fundamentals and ECE Prototyping Fundamentals, respectively.

7.1.2) Skills learned outside ECE coursework

Research on 4-20mA current loops and transmitter design will be done in order to properly design the transmitters to adjust voltage ranges to the appropriate current ranges (for example adjusting a 0-5V output to a 4-20mA current) and to properly condition the transmitters to emit a fault signal where appropriate. In order to complete this research, circuit design textbooks and the white paper mentioned in the NNL Scope of Work Document will be consulted where possible. While existing circuit designs and datasheets will also be referenced in order to better understand possible improvements and design features that can be used, the implementation will be an original design.

Research will also be done on PCB design methods that can be used to preserve signal strength and reduce noise throughout the circuit. Research will also be done on the use of multiple layers to improve the circuit operation, including the use of a ground and power plane. In order to learn about this, Sean will consult with our NNL sponsors and SERC for general insight and to get help finding more detailed resources on the subject. Online articles, including those published by Altium, and technical papers will also be used to learn about these topics.

7.2 Cameron Ostiguy

Cam will take on the role of designing the systems software components, so that the microprocessor that runs the receiver device, can remotely process data samples from each of the sensors in real time. This sensor data coming into the receiver, will be converted through embedded hardware algorithms, so that Cam can process and transmit relevant sensor metrics to a graphical user interface, which is placed on the top-side of the device for easy user interaction. This GUI will be a touch-screen display that needs to turn on automatically along with the device, and should have four screens, one for each of the sensors, in order to display name, status, operational temperature, and current measurements in the appropriate engineering unit. This display should allow the user to manipulate certains aspects of the sensors, in addition to toggling bluetooth data streaming and data logging. Cam will need to integrate this display into the device, and will be responsible for remote data logging for the sensors in addition to analyzing the results to ensure a high level of accuracy in the device.

7.2.1) Skills Learned in ECE Coursework

Over the course of numerous semesters at the University of Pittsburgh, I've been introduced to many concepts that will be explored and worked on in this project. To begin, taking ECE 102 and 202 helped me gain a knowledge for electrical circuits, their components, and the theory behind certain processes, which will help in broader device discussions to understand the hardware implementation of the product. Next, in Junior design, we worked with Arduino microcontrollers, which will come in handy when interfacing the receiver with the touch-screen display above, in order to display real-time data samples. Lastly, in 402 I gained a better understanding for function sampling, the processing of data in Matlab, and how to manipulate data in Matlab to produce useful results, which will help when doing remote data transmission and data logging.

7.2.2) Skills Learned outside of ECE Coursework

Outside of the classroom, I've become more and more capable of finding reliable sources in order to gain the knowledge needed to complete certain tasks that I would have otherwise struggled with. This is a valuable skill in regards to this senior design project, because although I have learned many useful skills in my coursework, there will be parts of the project that I don't have a complete working knowledge for, so I will need to utilize our resources in order to find creative solutions to the problem out at hand. Additionally, I've worked with measuring data transmission across local area networks using a software called WireShark, which will become useful during the testing phase of the product design, in order to ensure the latency limit is satisfied.

7.3 Nate Davis

Nate will take on the role of designing the receiver's hardware interface and handle the embedded software development for data processing. The receiver hardware design includes the shunt resistors used to convert the 4 - 20 mA signal into an analog voltage between 0 - 5 V for microcontroller processing. This may include external analog to digital conversion depending on the resolution of our microcontroller's built-in analog inputs. Additionally, input power restrictions are of concern as most microcontroller pins have a limit <= to 20mA. Since these loops are constant current, we must be cognisant of the pins' power ratings. This may call for the implementation of some form of electrical isolation between shunt resistors and the microcontroller pins such as buffers or opto - couplers. Regardless of the method used, Nate will be responsible for the embedded software that reads in voltage values from the shunt resistors and transforms them into their associated analog quantity (Temperature, Flow Rate, Water Level, and Salinity Level). Nate will also design and tune the control system used to produce a user - defined water level.

7.3.1 Skills Learned in ECE Coursework

In ECE 1770 (Old Curriculum), I was first introduced to the basics of ARM microcontrollers. In this course, I gained a comprehensive understanding of microcontroller building blocks such as hardware timers, GPIO, and memory addressing. Last semester, in ECE 1138 Cyber - Physical Systems, I was given the opportunity to apply this basic knowledge to more advanced applications. In this course, I interfaced multiple sensors to a microcontroller and implemented various algorithms for processing sensor data and designing control systems. I configured various interrupts, used hardware timers to create PWM outputs, implemented a basic PID controller to navigate a two wheeled robot. The skills I gained from doing this directly relate to the role I will be serving on this project. My previous experience with sensor interfacing and embedded programming will help me design the receiver interface and read sensor data into the microcontroller with accuracy and efficiency.

7.3.2 Skills Learned outside of ECE Coursework

Prior to my education at Pitt, I obtained an associates degree in EET from a technical school in central PA. The program had a great focus on industrial automation. While there, I worked on a project that mimicked a home furnace setup on a PLC. This project included a 4 - 20 mA loop to transmit thermocouple data to a PLC. From this project, I have a strong background in sensor - interfacing. Unlike this senior design project, my previous project didn't require a separate hardware interface because the PLC had 4 - 20 mA inputs with internal shunt resistors built directly into it. However, that experience provided me a lot of insight into different sensor interfacing approaches which will serve me very well in designing the receiver interface for this project. Additionally, for that project at my old school, I used a “look - up” table method to convert the sensor input signal into temperature data. While sufficient for that application, I hope to use a much more mathematical method to convert raw sensor data into meaningful scientific quantities (flow rate, temperature, water level, and salinity). In that class, we used a very rough, linear approximation for the sensor output. That previous experience will aid me very well in using more complex mathematical modeling (no linear approximation) to convert sensor output data into accurate analog quantities.

7.4 Logan Trower

Logan Trower’s primary role will be the testing, calibration, and interfacing of two of the four sensors outlined in the scope of work document. This will involve testing the functionality of each sensor and learning their proper operating conditions. To interface the sensors to the microcontroller, Logan must design a hardware transmitter that will convert the sensor's output into a usable 4-20mA current signal. The transmitters designed will initially be built and tested on a breadboard to guarantee proper operation. Once the transmitter's design has been verified, the design will be created on a printed PCB that will be used in the final design prototype. Logan will be in charge of assembling and testing the PCB once the required parts are obtained. I will also be working on the driver circuits required for the water pump and solenoids used in the implementation of the control system.

7.4.1 Skills Learned in ECE Coursework

Logan has an associates degree in electronics engineering technology where he gained hands-on experience prototyping and testing various electronic circuits. The focus of my study was on implementing, troubleshooting and maintaining industrial control systems. The skills learned will be very beneficial when it comes time for testing and optimizing the operation of the current loop. From this degree I also gained valuable hands-on experience with the test equipment that will be required for the completion of this project. This accompanied with the skills gained from my circuits classes such as ECE 102 and 1286, I believe that I will be well equipped for designing and modifying the transmitter circuits. These circuits rely on transistor and OP amp biasing which I have been practicing in the courses listed previously.

7.4.2 Skills Learned outside of ECE Coursework

During the design and implementation of the transmitter circuits, I expect that I will need to do more research on what makes the best transmitter. I found that there are many ways to accomplish a 4-20mA transmitter but when the accuracy of our sensor data is of high priority, I expect that we will need to dive deeper into the design of a transmitter. While I have taken many circuits courses there is still a large amount of information that I have never been formally taught. I expect to do more research into this level of circuit design in order to guarantee that I am able to fulfill the project requirements that I have been chosen to be responsible for in this design.

8. Schedule and Budget

8.1 Project Schedule

8.1.1 Week 1 (Monday 9/27)

The team aims to begin hardware and software design at this date, as well as place an order for the microcontroller and at least one sensor by Tuesday 9/28. Sean and Logan will target their individual transmitter channel designs for the sensor's they are taking responsibility for. Nate will begin designing the receiver hardware to interface a sensor to the microcontroller. Cam will begin researching touch-screen displays to order that will integrate with the Arduino.

8.1.2 Week 2 (Monday 10/4)

By this date, the team aims to have a functioning base design for transmitters that linearly converts each sensor's output voltage to a 4-20mA current. Sean will have begun breadboarding his designs for the salinity and fluid level sensor channels, while Logan will do the same for the flow rate and temperature sensor channels. Nate will begin writing a basic script to read "dummy" analog values from the receiver into the microcontroller. Cam will have begun developing the software necessary to have this "dummy" sensor data displayed on the touch screen and exported to an external file for processing.

8.1.3 Week 3 (Monday 10/11)

By this date the team should have breadboarded transmitters capable of interfacing with the real sensors (moving past dummy data) and capable of interfacing with Nate's receiver. Sean and Logan will have separately achieved this for their individually assigned sensors. This means testing of the transmitters using the "dummy data" will be complete. At this point the team will have also integrated the transmitters into a prototype of the complete loop. Cam will have taken the sensor data from Nate's receiver, and will look to begin real-time refreshing for data on the display. Nate will begin analyzing the behavior of each sensor's output profile for conversion to real physical quantities.

8.1.4 Week 4 (Monday 10/18)

By this date the team will have integrated the transmitter to communicate with the receiver and have begun testing the interactions between the two in order to read real sensor data into the microcontroller. Sean will have done this for his specific sensors and begin researching PCB design techniques. Additionally, he will begin design for the fluid valve driver. Logan will do the same for his respective sensors and begin designing the hardware driver for the water pump. He will also assist Sean in preliminary PCB design preparation. Cam will begin work on integrating the touch screen controls for easy toggling between sensor readings. Nate will begin to implement the control system software.

8.1.5 Week 5 (Monday 10/25)

By this date the team will make improvements based on initial test data. Sean will begin to design the PCB in Altium based on the circuit schematic produced by Logan. He will also have decided on the power supply that will be incorporated into the system. Cam will begin implementation for wireless bluetooth data transmission. Nate will continue to work on the control system software and test interactions between the microcontroller and hardware output drivers (for pump and water valve).

8.1.6 Week 6 (Monday 11/1)

By this date Sean will have designed and placed an order for the first run of PCB's. He will continue testing the accuracy of the system until the PCBs arrive and he will have decided what cables and hardware will be used to interface the final prototype's transmitter with the receiver. Cam will look to begin the data logging prototyping, by drafting software code to process the transmitted data samples. Nate will begin processing the collected sensor data to develop a precision model for conversion to physical quantities. Logan will be testing the hardware drivers used to operate the control system.

8.1.7 Week 7 (Monday 11/8)

By this date, Cam will work with Bill and Jim to create a prototype of the enclosure for the receiver device. At this time Logan and Nate will be working to implement the proportional controller for the water pump. Sean will continue to test and modify transmitter and hardware drivers. The team will begin working on the construction of the test setup at this point.

8.1.8 Week 8 (Monday 11/15)

By this date, Cam will work to improve the displaying of data on the touch screen, and calibrate receiver to improve accuracy. Logan will work with Nate on the testing of the control system on the new test setup. Sean will continue working on implementing the control drivers hardware.

8.1.9 Week 9 (Monday 11/22)

By this date the PCBs are expected to have arrived and will be assembled by Logan. Sean and Logan will test the functionality of the transmitter system as a whole and evaluate the performance of their individually assigned sensors in the final system. Cam will be evaluating the new test data from the PCB integration, and measuring latency metrics. Nate will test and evaluate the receiver performance on the final PCB.

8.1.10 Week 10 (Monday 11/29)

The team will perform final testing and tuning of the fully integrated system. This is where all key performance criteria will be evaluated, adjusted, and modified. This will include the validation of the control system algorithm for optimized accuracy, exhaustive sensor analysis across the broadest achievable test stimuli, and comprehensive analysis of wireless data transmission latency.

8.2 Project Budget

The preliminary budget breakdown for the project in Table 1 below. The price attributed to each item describes the money spent on the item or combined items listed to the left. For example, $50 will be allocated for the item labeled "TX/RX Enclosures", meaning that the combined expenditure for these two will be $50, and not $50 dollars for each enclosure.

Part/Purchase	Allocated Money
Salinity Sensor	$50
Fluid Level Sensor	$50
Temperature Sensor	$50
Flow Rate Sensor	$300
PCB (TX and RX, 2 runs)	$100
TX/RX Enclosures	$50
Shielded Cables	$50
Touch Screen Module	$100
Microcontroller	$100
TX Components	$100
RX Components	$50
Wireless Transmitter (Bluetooth)	$25
Power Supply(s) (plug to wall)	$50
Fluid Pump	$50
Fluid Valve	$50
Pump/Valve Drivers	$50
Fluid Container/Piping	$75
TOTAL	**$1,300**

Table 1: Fund Allocation

The total expenditure will be assumed to be roughly $1,300, with $200 dollars coming from the funds allocated by the University, and the other $1,100 coming from the NNL account (pending approval). There are 5 purchases and parts listed to be more than $100, each of which are crucial components. The flow rate sensor, based on the available models that can provide linear outputs but do not have excessive features (such as screens), will be allocated \$300 dollars. We feel this is justified as this sensor is crucial to the operation of our intended process control. We are also allocating \$100 dollars for the PCB printing, which should allow for 2 separate runs of transmitter boards and receiver boards. We feel it is crucial that we allow enough money for 2 runs, as it will allow us to order re-designed boards if our first run has critical errors. This allocation will also allow us to order boards of higher quality. Given that the system will be running off of the microcontroller, and the display is the user's main point of interaction with the system, we feel that \$100 dollars for each is justified. Finally, we feel that \$100 dollars will be an appropriate amount of funding for transmitter components, as this gives us the flexibility to purchase high-quality components for the transmitter, improving our design's accuracy.

We expect to place our first part order on Tuesday, September 28th, and intend to order our microcontroller and possibly our sensors. Acquiring the microcontroller will allow the software design to quickly advance, and ordering our sensors early will allow us to transition from testing with lab equipment as sensor data to using actual sensor data by the time they arrive.

8.3 Minimum Standard for Project Completion

The minimum standard for project completion will be to construct a system capable of reading sensor data and displaying it to the user interface in real-time with 10% accuracy. Additionally, the receiver should be capable of wireless data transmission from the microprocessor. This wireless transmission will not be held to a specific latency standard. The storage of this offline file will be handled solely by an external device, such as a computer. Additionally, the minimum standard for completion of the control system is to allow the user to allow fluid to flow into the test container, to a specified level, but the accuracy of this action's completion will not be held to a specific standard.

8.4 Final Demonstration

Students will present a version of the prototype outlined in the conceptual design section to the professors. This prototype will maintain and display active sensor data. We will demonstrate the accuracy of the sensor readings by introducing external stimuli that alters the steady state conditions of the test setup (ie. change the temperature of the test solution, increase the solution volume in the tank, increase the solution flow rate). We will also have past data showing the sensor outputs responding to a wide range of external stimuli from a controlled test environment. This data will be presented in an external file showing that the microcontroller successfully transmitted the sensor data wirelessly.

We will have qualitative test results live that show the system responding to external stimuli that we impose on the system. We will also include quantitative test results for each sensor showing that the data the system produces is accurate. This quantitative data will include measurements of the true environmental conditions compared to the results produced by our system, highlighting any discrepancies and calculating for maximum error.

References

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