Surface Water Information Management
Project Plan Document

CSET Junior Project 2018

Fall Term 2018 Week 10

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Modules & Sub Assemblies

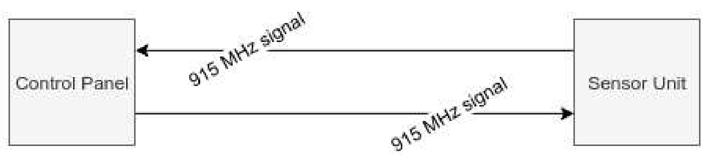
In order to simplify design of the project, the system was divided into modules, or subassemblies. Each sub assembly includes the hardware and software necessary to achieve a granular task. The following table describes each subassembly in basic terms as an introduction to their purpose.

Table. 1

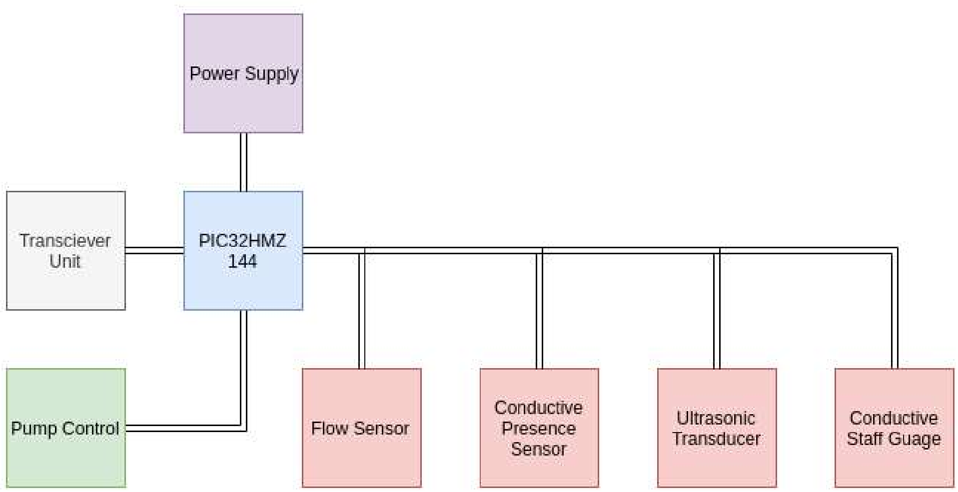
No.	Name	Description	Unit
1	Transceiver	Sends and receives commands and data.	Both
2	Piezo-Electric Buzzer	Generates alert tones.	Interface
3	Ultrasonic Transducer	Measures the reservoir level.	Sensor
4	Flow Sensor	Measures the flow rate into the pump.	Sensor
5	LCD Display	Displays the GUI, and accepts touch input.	Interface
6	Conductive Presence Sensor	Detects the presence of water on the overflow outlet.	Sensor
7	Buttons	Accepts user input to navigate GUI.	Interface
8	Power Supplies	Provides power to both units, and accompanying peripherals.	Both
9	Pump Control	Circuitry used to turn the pump on / off	Sensor
10	Conductive Staff	Sensor replacement for traditional staff gauge	Sensor

	Gauge	used in the water source.	

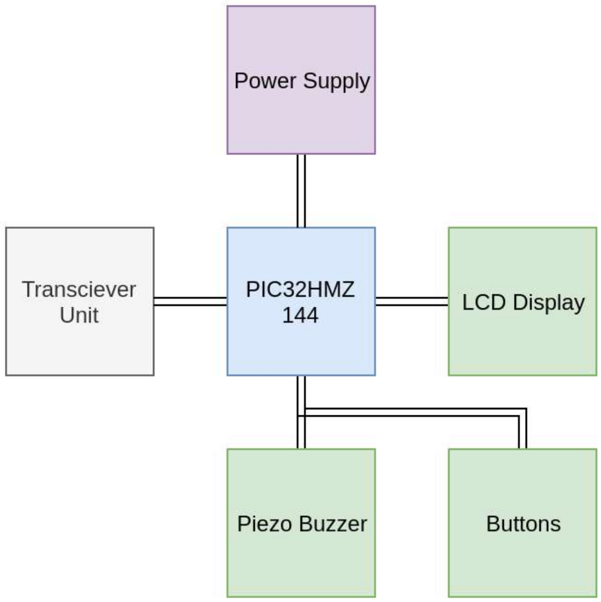
Schematics/ Hierarchical design diagrams



The above block diagram is the top-level organization for the system, specifying the wireless communication. The following block diagrams provide contextual connections between each of the electrical schematics in this section.

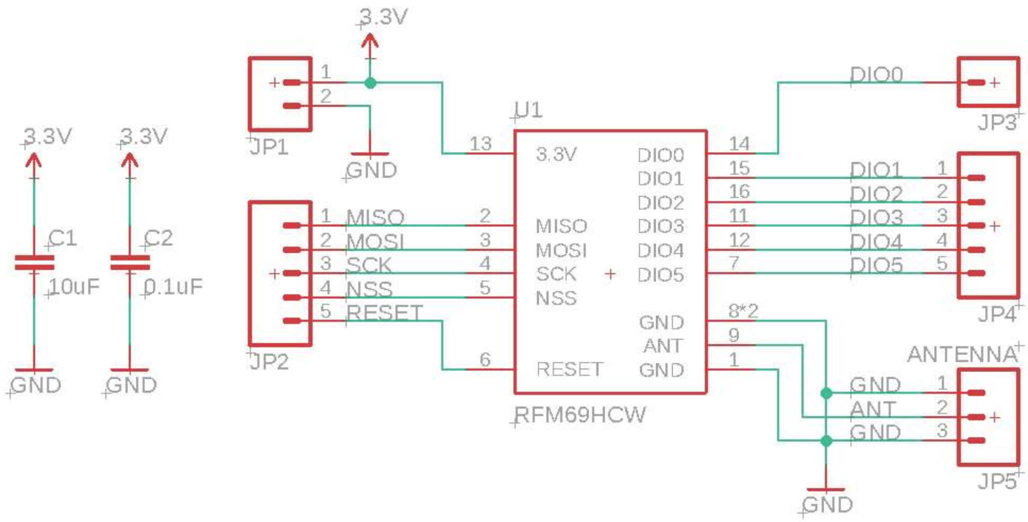


The diagram above describes the Sensor Unit and each sub module. All connectors imply data and sourced current/voltage is transported bidirectionally.



The diagram above specifies the Interface Unit, the main component of user interaction. The overall hardware design is centered around the PIC32HMZ-144 microcontroller, which is the top level dependency for all nodes in the network of Transceivers.

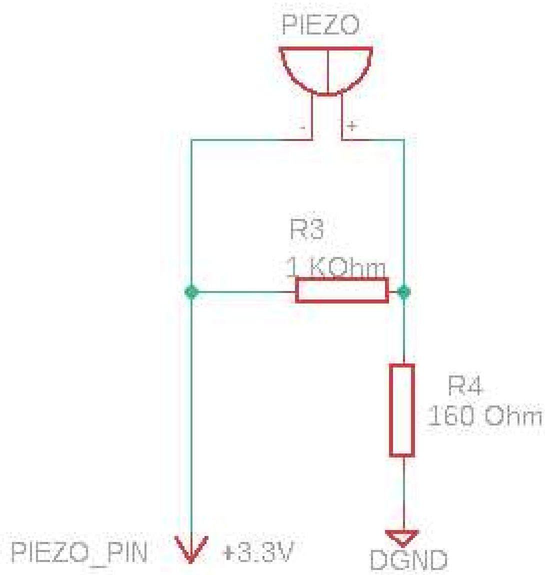
1. Transceiver



The Transceiver module draws 3.6V at 130mA producing a range of less than 400 meters with horizontally spread signal. Packet transmission is fully configurable in software using the SPI bus. To construct a network, two Transceivers are needed, one node to transmit and the other to receive; hence the term “Transceiver”. The network node and network number fields are assigned to each node so they can identify each other.

The packet header and footer will be 228 bits, while the data payload will be only 32 bits. The packet total size is 488 bits. Header will contain network and node numbers, as well as a timestamp. Network number is from 0-255 and node number is from 0-254; node number 255 is reserved for whole network broadcast. Data payload is the only component that will be recorded to SD card storage, and is sized to be compatible with the PIC32MZ 32-bit SPI receive buffer. The packet footer will contain the cyclic redundancy checking value.

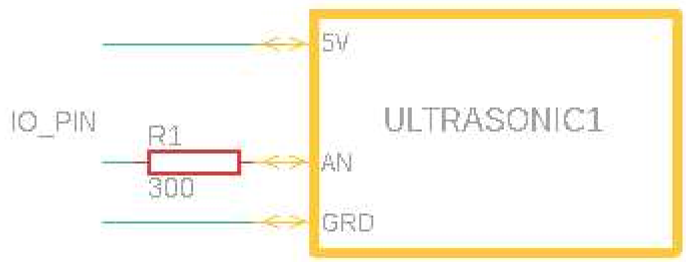
2. Piezo-Electric Buzzer



The Piezo Buzzer requires a 1,000 Ohm bleed resistor, and 20 mA @ 3 Volts to operate.

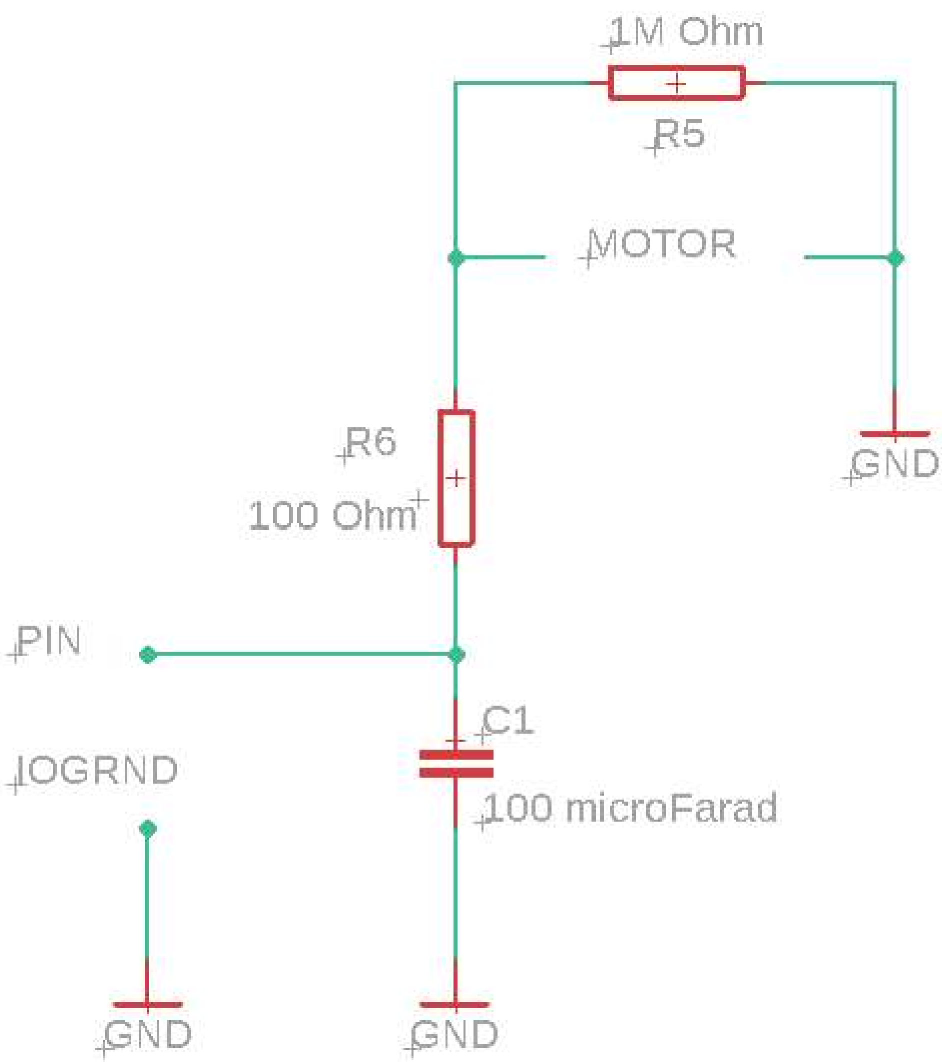
The 220 Ohm resistor limits the current to 20 mA to avoid damaging the part. The 1,000 Ohm bleeder resistor forms a divider, which means the voltage across the part is actually lower than the 3.3V logic level. Since the part operates at 3 Volts, this difference in voltage should not affect performance.

3. Ultrasonic Transducer



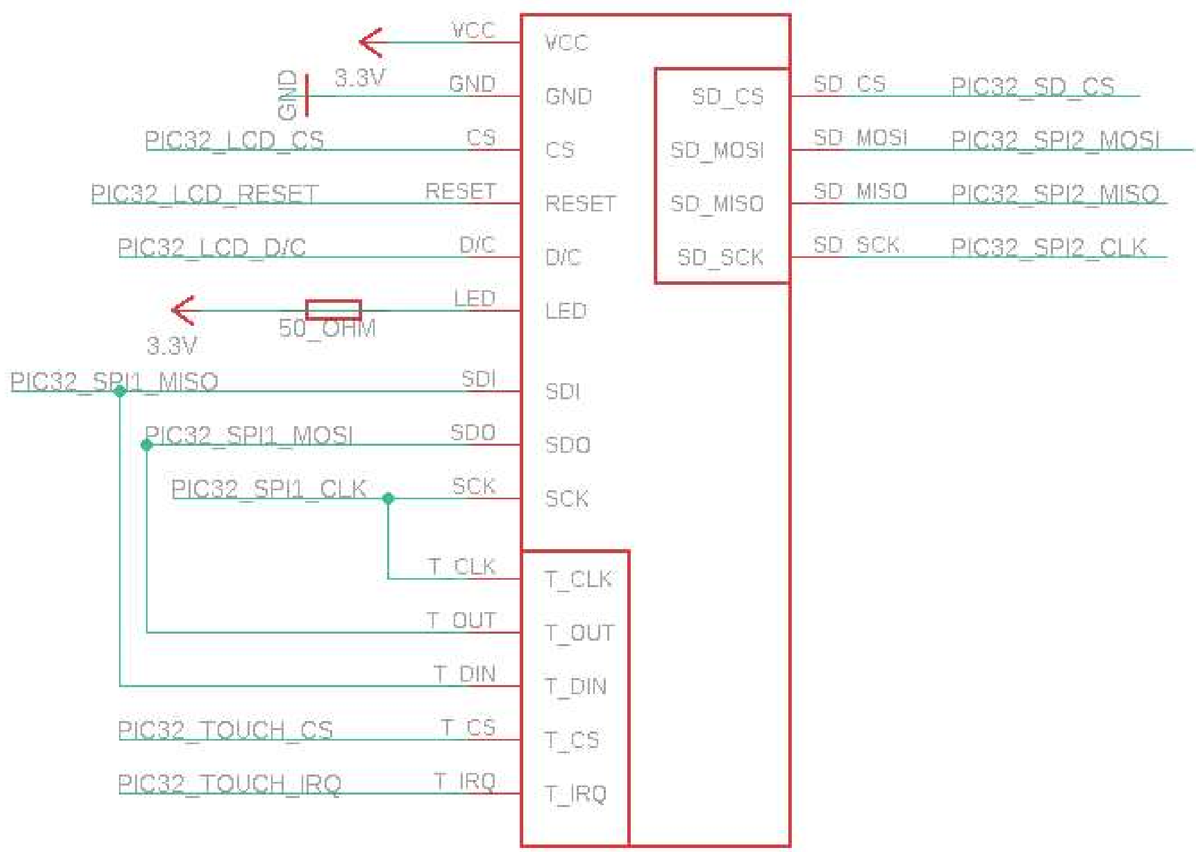
The Ultrasonic Transducer will measure the water level by volume “bouncing” ultrasonic waves off the surface of the water. The result will be a voltage from the surface to the tip of the sensor. It will sample at 0.05S roughly at 20 samples per second. The distance is measured at 9.8mV/Inch at 5V Source Voltage and 6.4mV/Inch at 3.3V Source Voltage.

4. Flow sensor



The 100 uF capacitor and 100 Ohm resistor form a low pass filter, which filters out frequencies greater than 16 Hz. This value was obtained through experimentation with a test DC motor by observing the waveform on the Arduino serial plotter. The YF-B5 flow sensor uses a hall effect sensor transducer to generate a reciprocating waveform, whose frequency is proportional to the flow rate through the sensor. The flow sensor may output at a higher frequency than the preliminary test motor, so the values of the filter are subject to change, but the measurement principle remains the same.

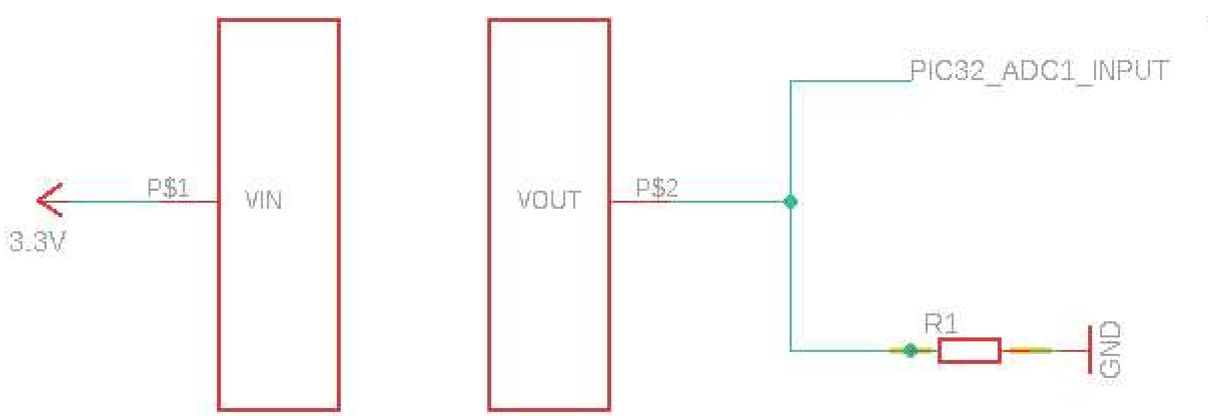
5. LCD display



The LCD display is a 2.8” SPI unit, that utilizes an ILI9341 controller to interface between the Pic32 and the LCD panel. The LCD also provides support for a resistive touch panel, and a SD card for image storage. The touch screen and LCD will be tied to the same SPI channel, since interaction with the screen will require the LCD to change its current display. In order to keep the user experience as real time as possible, and touch screen action should change the current image on the display, even if it requires interrupting a screen change in progress.

The SD card will utilize a separate SPI channel, so that the SD card and LCD can operate in parallel. By using separate SPI channels, the LCD does not have to wait for an SD read to complete before it can upload the block of data to the display. The touch screen also has an interrupt pin, that will be tied to the PIC32 using a change notification interrupt to signal when a touch is registered.

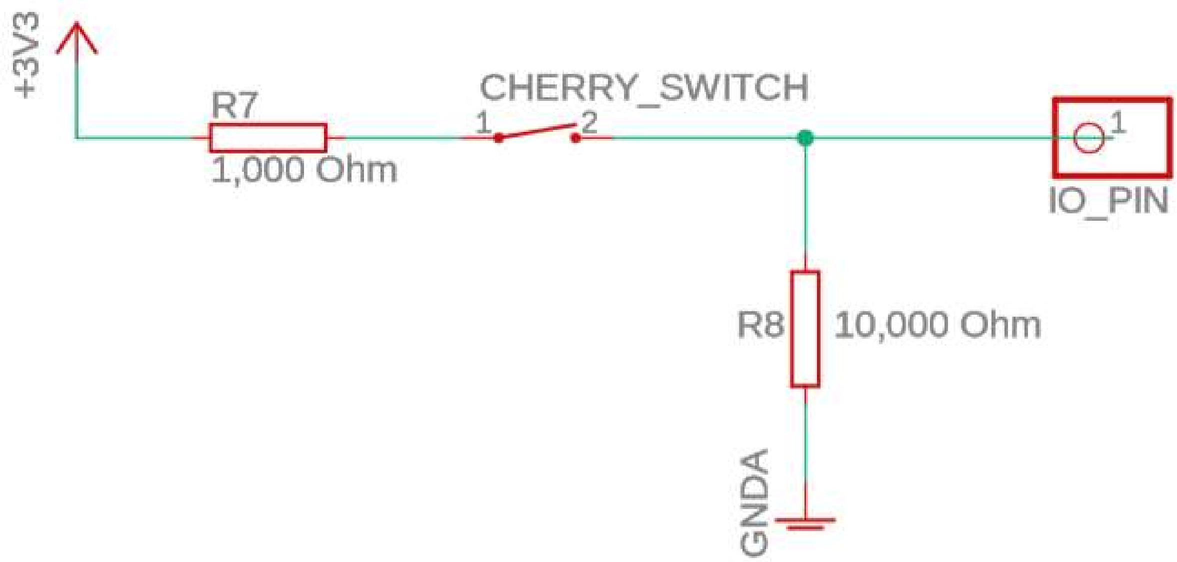
6. Conductive Presence sensor



The presence of water will close the circuit, and a will be input into the microcontroller. 5V-tolerant pins with up to 32 mA source/sink, Page 14 of 26, Pic32 family reference manual[1].

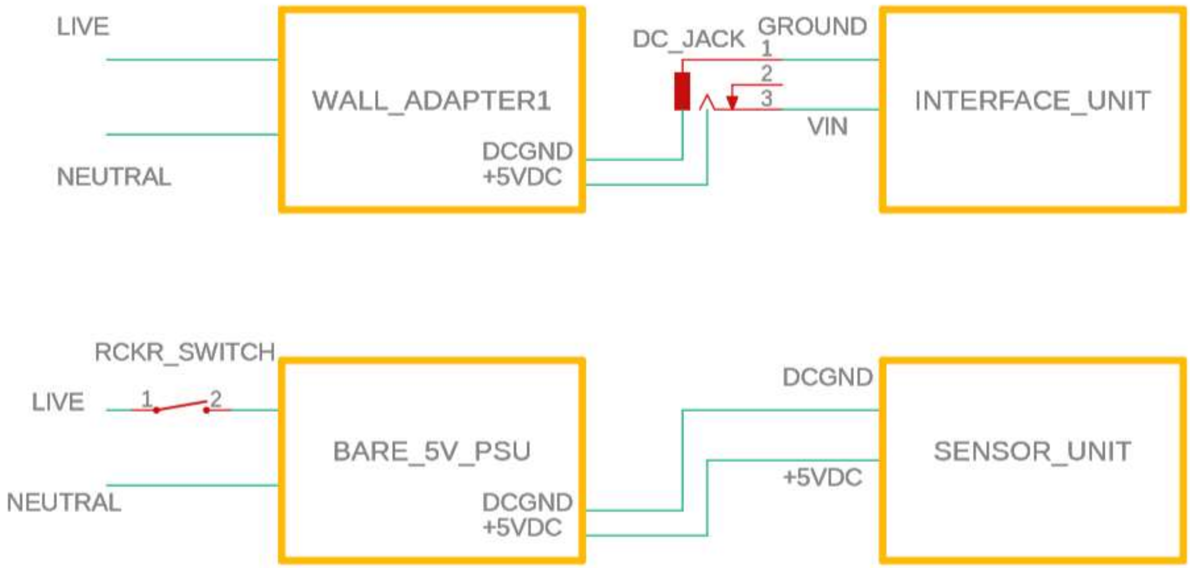
The level of voltage is less of a concern than the presence of a signal. Signal presence is the only criteria required to determine if there is water flowing out of the reservoir overflow outlet.

7. Buttons



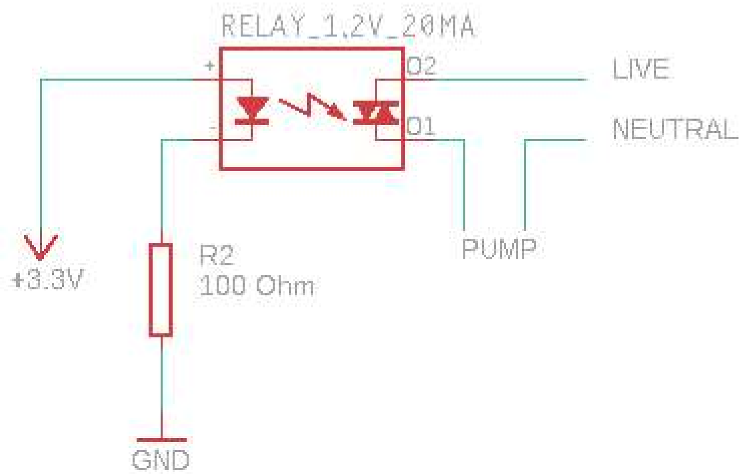
The button layout cherry MX switch buttons with a pullup resistor to detect when the button is pressed. The 1k Ohm resistor was chosen to limit current and prevent the button from being damaged. The 10k Ohm resistor was chosen to make sure that the button would only trigger if pressed fully.

8. Power supply



The sensor unit is equipped with a bare 5 Volt power supply, which is directly wired to the microcontroller. A rocker switch is used as a power switch for the sensor unit, and will be mounted on the outside of the power enclosure. The interface unit has a DC power jack so that the wall adapter power supply can be unplugged by the user.

9. Pump Control



The solid state relay requires 1.2 Volts across the input, and a current of 20mA must be supplied to energize the relay. The effective resistance of the relay input is therefore 60 Ohms. A 100 Ohm resistor divides the logic level 3.3 Volts to 1.2V across the relay input terminals. The total series resistance is 160 Ohms, so 20 mA of current flows through each component.

$$R_{Relay} = 1.2V / 20\ mA = 60\ Ohms$$

$$R / Rtotal = V / V total$$

$$60\ Ohm / Rtotal = 1.2V / 3.3V$$

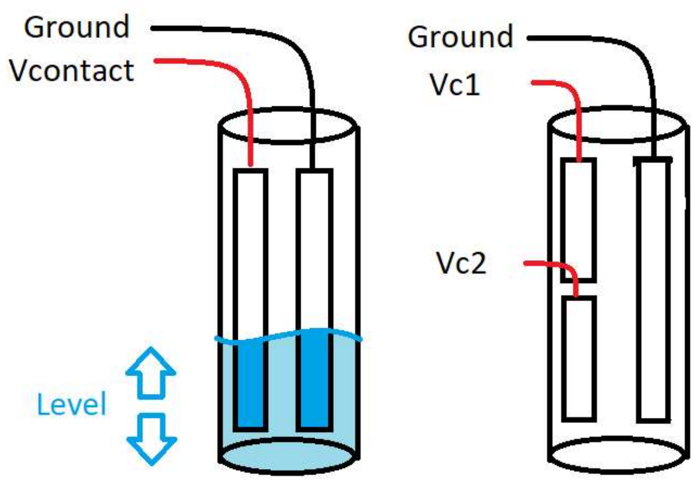
$$Rtotal = (3.3 * 60) / 1.2$$

$$Rtotal = 165\ Ohm$$

$$R2 \ = \ 165 \ Ohm \ - \ 60 \ Ohm$$

$$R2 \ \approx 100 \ Ohm$$

10. Conductive Staff gauge



A voltage is supplied across conductive plates submerged in the source water. The conductivity of the water between the plates is a function of the water level, since the conductivity is proportional to the contact area. The water between the plates therefore acts as a variable resistor. The plates are set up to act as the variable resistance in a voltage divider, or wheatstone bridge to obtain voltage readings on the sensor unit. An Analog to Digital Converter will be used to encode the voltage into a binary value.

It is possible to increase the resolution of the sensor by adding n number of conductive plates. This will likely increase the accuracy and precision of the sensor as n increases. This technique would also require additional conductors, or even sequential circuitry to achieve.

Test plan

It is just as important to know whether equipment is functioning as it is to know how to put it together. A test plan has been developed for each module so that functionality can be fully verified before integration.

1. Transceiver

- A set of Arduino Uno boards will be wired to the transceivers. Open source example code from the sparkfun GitHub repository will be used to verify operation of the transceivers. This test will be conducted indoors with each antenna spaced 1 meter apart, in addition to an outdoor test with each antenna placed 100 meters apart. Both antenna tests will be conducted using direct line of site, as well as through standard interior drywall, i.e., each transceiver will be in two separate rooms.

2. Piezo Module

- Piezo Buzzer
    - The buzzer will be tested using an Arduino Uno board, and the example piezo buzzer code.
- Both resistors can be tested using a multimeter in resistance mode.

3. Ultrasonic Sensor

The Ultrasonic will be tested with an Arduino Uno board ADC to receive varying ranges of measured distances of water in a bucket.

4. Flow Sensor

- Hall-Effect Sensor
    - The flow sensor will be tested by connecting the input to a bucket or container. The flow will induced a voltage on the sensor output, then the signal can be observed on an oscilloscope. If the voltage is a reciprocating function related to the flow rate, then the sensor will work.

5. Display Module

- ILI9431 Based LCD Display
    - The LCD functionality will be tested by wiring it to an Arduino, and using a test library from Adafruit to ensure that it works as expected.
    - The touch screen will also be tested using the same Adafruit library.
- Integrated SD Card

    - The SD card will be tested using a known working SD card, and an Adafruit library on the Arduino to ensure that the hardware functions as intended.

6. Conductive Presence Sensor

- The testing procedure for the conductive presence sensor will consist of constructing the circuit in accordance with its circuit diagram listed in the Schematics / Hierarchical Diagrams portion of this document. Once completed, the sensor leads will be tested with different solutions of water, and the voltage measured on an oscilloscope. The first type will be pure distilled water, Klamath Falls Tap Water, followed by 0.5% sodium chloride.

7. Buttons

The buttons will be tested to see if the debounce works properly from a Arduino board using them as switches.

8. Power Supply

- Interface Unit PSU
    - This power supply will be tested by connecting the output to a 2 Amp load, then ensuring the power supply continues to function, and does not get excessively hot. The DC load could be a resistor, or another DC device such as a brushed motor.
- Sensor Unit PSU

        - This power supply also features a switch. The switch can be tested by using a multimeter on resistance mode. A 3 Amp load will be used to test this power supply.

9. Pump Control

- The relay can be tested by constructing the circuit with the pump connected to the relay. The relay will be energized so that the pump draws full power. AFter a few minutes, the temperature of the relay will be measures, and the pump will be verified as still functional.

10. Conductive Staff Gauge

- Water Conductivity
    - Since the water conductivity changes based on temperature and mineral content, various types of water should be tested for conductivity. An experiment for this involves two square conductor sheets, which are submerged underwater a small distance from each other. Using the conductivity formula R = Rho * L / A, the conductivity can be found by simply taking a resistance measurement. Such an experiment has already been done, and it showed that the conductivity of tap water was similar to the value found online.
- Sensor Resolution

- The staff gauge will be placed in a bucket full of water and the voltage output monitored as the gauge is placed in the water at varying heights. A plot will be created from the data, and then a function for determining water height will be formed.

Updated parts list

Table. 2

Part
2.8" SPI LCD
PicKit-4
PIC32-HMZ144
100 uF Capacitor x 10
SS Relay x 2
Prototype Board
Piezo Buzzer
Bare PSU
Brick PSU
Power Connector

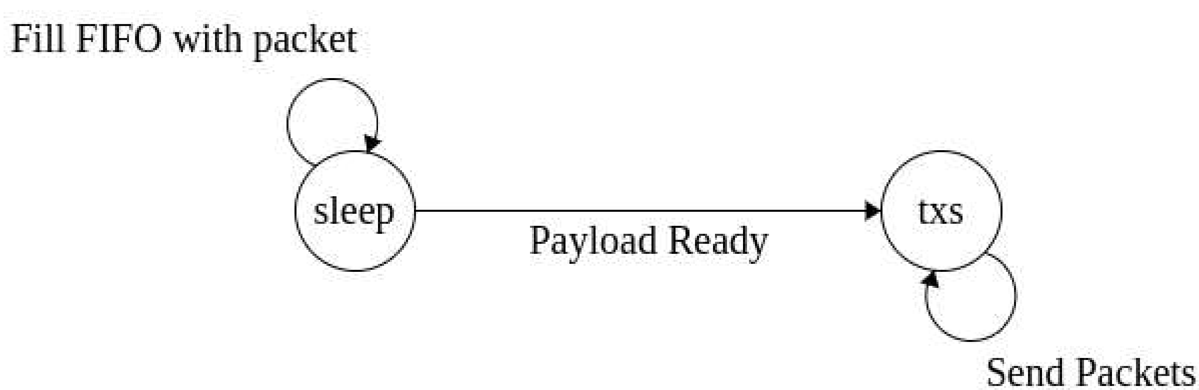
Power Switch x 2
Transceiver x 2
Ultrasonic Transducer

Software Specification

Each Module requires software to run, even if it is a simple service routine which polls sensor data.

1. Transceiver

RFM69HCW Transmitter Logic



States:

TXS: Transmit Sensor Data (current draw = 130mA)

SLEEP: Antenna is not transmitting to conserve power (current draw = 16mA)

Inputs:

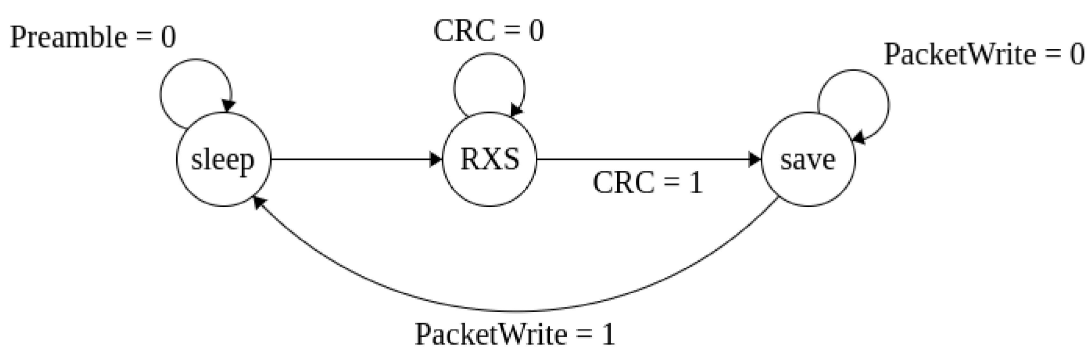
FIFO_Buffer_Register: Will hold data to be transmitted and shift bits out into antenna.

Payload_Ready: FIFO is filled with a packet.

Outputs:

Antenna: Will oscillate at 915 Mhz and for each period the electrical signal will either be at logic 1 or logic 0 depending on the bit value shifted out of the FIFO buffer register.

RFM69HCW Receiver Logic



States:

RXS: Receive Sensor Data (current draw = 16mA)

SLEEP: Antenna is not transmitting to conserve power (current draw = 16mA)

SAVE: Save 32-bit packet payload to SD card

Inputs:

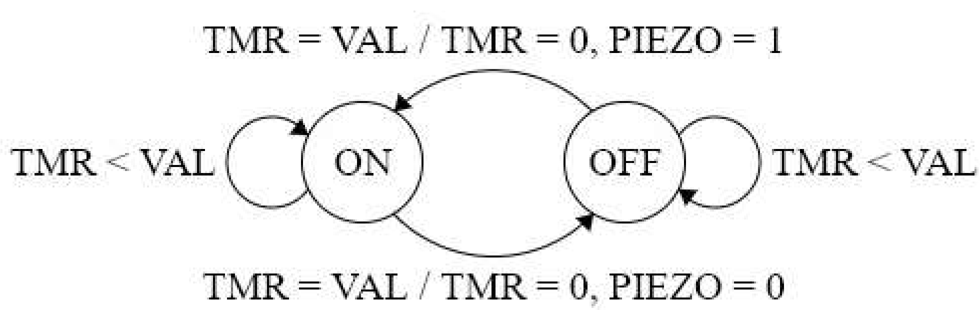
FIFO_Buffer_Register: Will hold data received and will shift bits out onto the antenna.

Payload_Ready: FIFO is filled with a packet.

Outputs:

SPI: Serial Peripheral Interface will send a data payload to the PIC32MZ microcontroller to be stored on the SD card.

2. Piezo-Electric Buzzer Pulse Width Modulation



The Piezo-Electric Buzzer is a simple binary state noise maker which requires pwm signals to operate. The piezo output is a single output pin which drives the buzzer high or low. Unlike a normal speaker, the piezo buzzer cannot generate analog sound; only a single square wave frequency is generated. The state machine oscillates between a piezo ON state, and a piezo OFF state. The value ‘VAL’ in the timer ‘TMR’ represents half of the desired frequency’s period.

$VAL = f_{CLK} / f_{Note}$

3. Ultrasonic Transducer

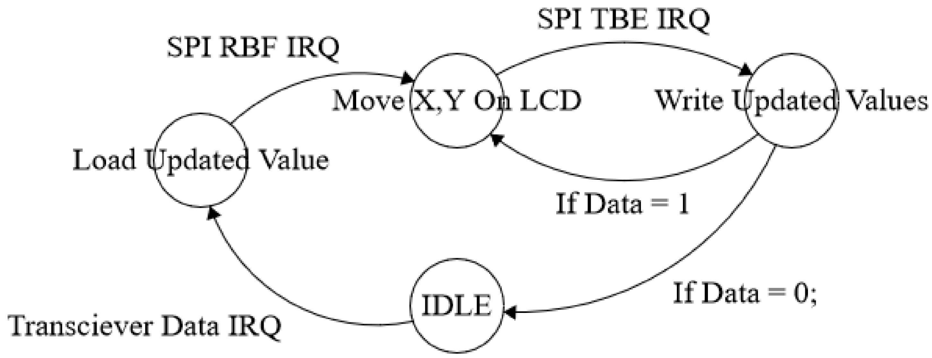
Pseudocode:

```
Voltage received / 9.8mV = Distance from surface.

Distance x Pi x r squared = Volume of space not filled.

reservoir volume - volume empty = Water volume.

(reservoir volume - Water volume / reservoir volume) (100) = Percentage full.
```

This is the algorithm used by the Ultrasonic Transducer to measure the water level in the reservoir and develop a percentage for the display. This is all assumed with a source voltage of 5 volts.

4. LCD Display

LCD Data Update



States:

IDLE: The system waits here until it receives an interrupt from the transceiver.

Load Updated Value: The system sends a request to the transceiver for the data.

Move X,Y On LCD: The system sends a command to the ILI9341 to move its selected pixel.

Write Updated Values: The system updates the pixel with the value needed to create an image that corresponds to the received data.

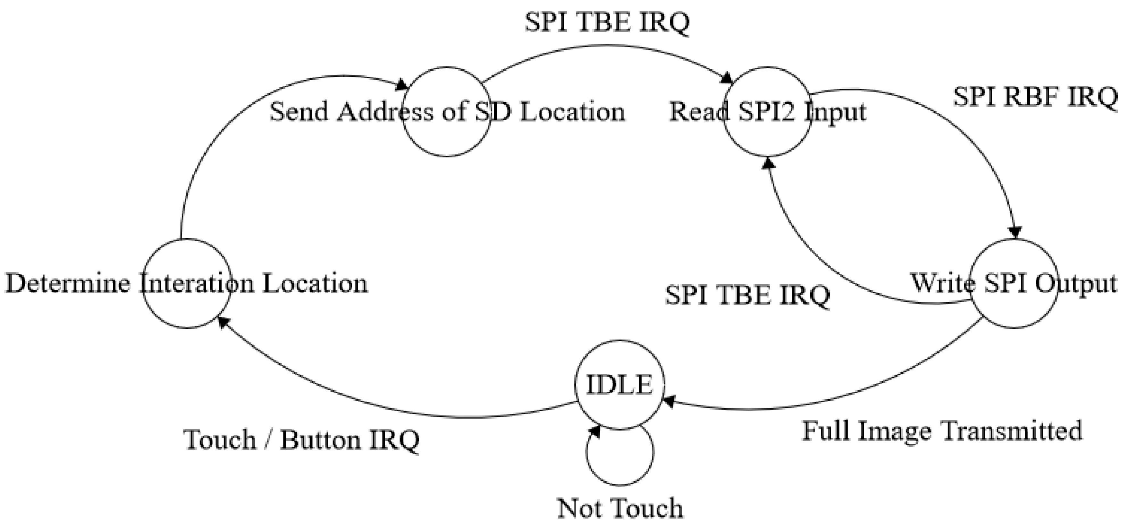
Inputs:

Transceiver Data IRQ: IRQ generated by the transceiver when data is received.

SPI RBF IRQ: IRQ generated by the SPI module when the receive buffer is full.

SPI TBE IRQ: IRQ generated by the SPI module when the transmit buffer is empty.

LCD Screen Change



States:

IDLE: The system waits here until it receives an interrupt from a button or the touch Screen.

Determine Interaction Location: The system determines either where the screen was touched, or what button was pressed to determine what screen needs to be loaded.

Send Address of SD Location: The system sends a command to the SD card to have it return image data for the requested image.

Read SPI2 Input: The system reads the data that has come in from the SD card.

Write SPI Output: The system sends out the data that came in from the SD card to the ILI9341.

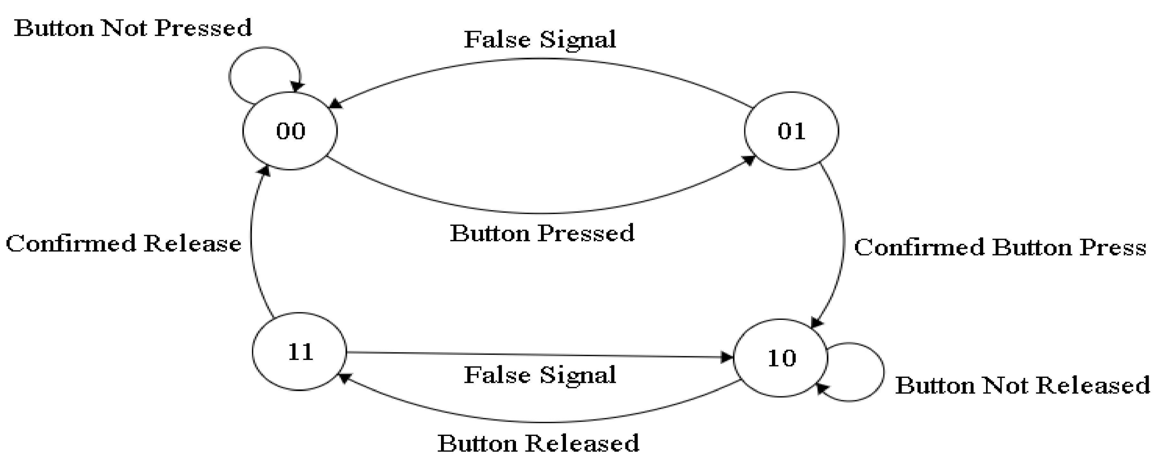
Inputs:

Transceiver Data IRQ: IRQ generated by the transceiver when data is received.

SPI RBF IRQ: IRQ generated by the SPI module when the receive buffer is full.

SPI TBE IRQ: IRQ generated by the SPI module when the transmit buffer is empty.

5. Button



States: 00 Idle

01 Press Confirmation

10 Button Pressed

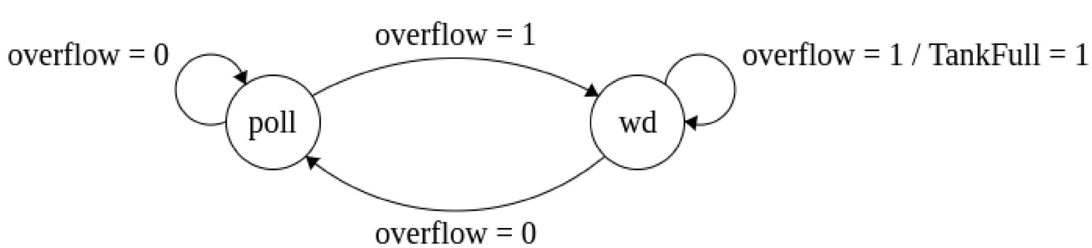
11 Release Confirmation

Input: Button Press.

Output: Button response.

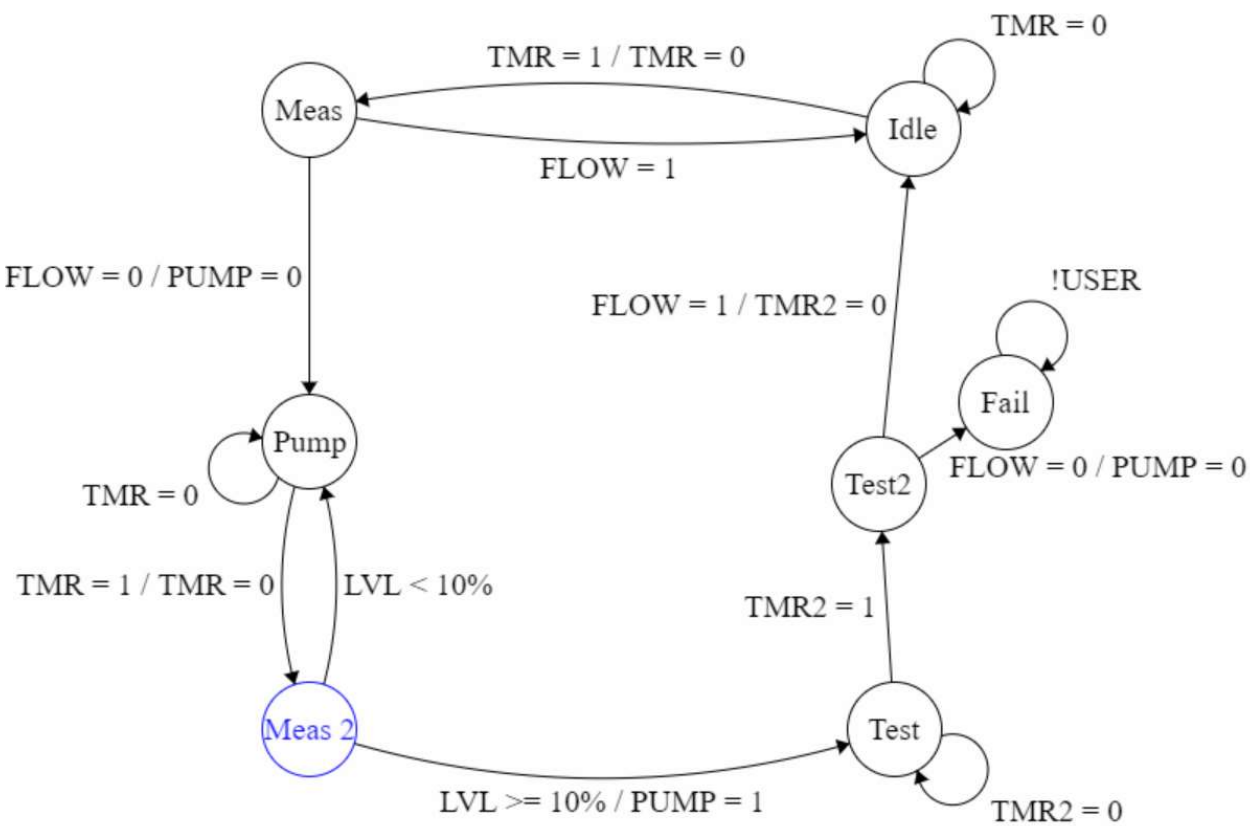
6. Conductive Presence sensor

The state machine below specifies the programmatic operation of the sensor used for detecting water through the overflow outlet. The **poll** state is the microcontroller sampling the sensor every second for status of the reservoir. This sensor is used in conjunction with the ultrasonic transducer to determine if the reservoir is full; the ultrasonic transducer becomes unreliable at distances closer than 6 inches. This sensor is put in place for the case where the overflow outlet is less than 6 inches from the ultrasonic transducer. The **wd** state is the water detected state, which indicates the reservoir is full.



7. Flow Sensor / Pump Control

The state machine below describes the pump system's behavior in the case of a flow failure being detected. In normal operation, the system is in the idle state, and the flow sensor is polled every second. If the system detects zero flow, it waits until the level is above a safe threshold before turning the pump on briefly. After this brief period, the system checks for water flow, then enters the fail state if none is detected. If flow is detected, then the system returns to the idle state as the reservoir has returned to normal operation.



States:

Idle: The system waits for the polling timer before moving to the measure state.

Meas: The flow sensor is tested for any flow.

Pump: The flow is found to be zero.

Meas 2: The system waits until the reservoir level is greater than 10 percent before moving on to the Test state.

Test: The system turns on the pump and waits a short time to allow the pump to Pull a water current.

Test 2: The system checks the flow sensor to see if there is flow. If there is none, then The system has an issue, and transitions to the fail state.

Fail: The reservoir is clogged, or the pump has failed. The user is alerted, and the System will not return to idle state until the user intercedes.

Inputs:

TMR: The polling timer, interrupting at a frequency ~ 10 hz.

TMR2: Times the pump test. The pump runs for less than a second.

FLOW: Water flow between reservoir and pump.

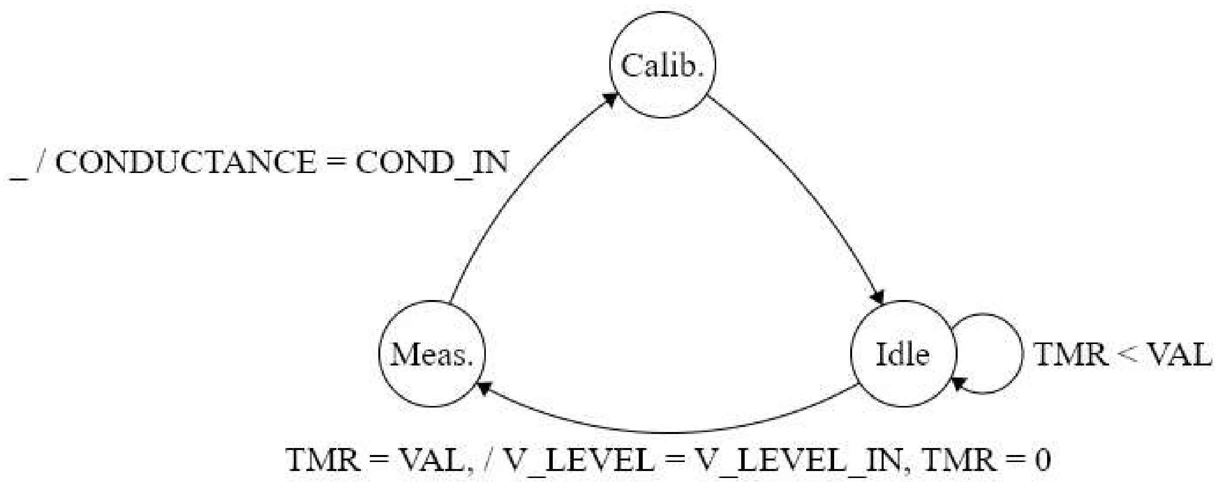
LEVEL: Reservoir water level.

USER: Some user interaction on the interface unit, after the fail state alert is sounded.

Outputs:

PUMP: The pump controlled by a relay, 0 is off, 1 is on.

8. Conductive Staff Gauge



The staff gauge only needs to be measured around one time per day. For this reason, the counter may be implemented with clock dividers in order to slow it's count speed. When the timer 'TMR' reaches the desired value, the system transitions to the measurement state. In this state, the system polls the V_LEVEL_IN input, which is the voltage across the conductive sensor. In the calibration state, the voltage across the calibration sensor, which is fully submerged, is polled and stored in CONDUCTANCE variable. This information is then used to derive the actual conductance in Mohs of the water. After this, the water level of the source can be determined using the conductance formula R = Mho * L / A, as well as the known area and separation of the conductive plates.

Individual Member Roles

Kyle

The LCD display, touch screen, and LCD SD card will be developed and primarily tested by Kyle. He will also help with integration of the LCD module into the interface unit.

Peter

As the software specialist, Peter will manage the code repository on Github and facilitate the usage of Software IDE's and coding structure pertaining to product development. Additionally, Peter will audit code used for implementation adapted from outside sources to ensure copyright, licensing and plagiarism stipulations are abided. Peter will also manage software and hardware development for the transceiver modules and conductive presence sensor.

Colin

Colin is assigned the Conductive Staff Gauge, Flow Sensor, Pump Control, and Piezo-Electric Buzzer modules. Extensive testing on the conductive staff gauge will be his largest contribution to the team.

Shaun

As a embedded system specialist, Shaun will work toward integrating parts and developing code that will allow them to communicate properly. This role will require Shaun to be in contact with other team members and facilitate communication and overall design. His efforts will be toward the Ultrasonic Transducer testing and integration toward the sensor module. He will also be responsible for the testing of the buttons to make sure they will work and writing the debounce sequence.

Appendix

[1] Microchip. “PIC32MZ Family Reference Manual” Datasheet.

Terminology

Table. 3 Terminology

Sensor Unit	At-Source microcontroller unit which polls sensor data, performs basic emergency operations, and transmits data to the Control Panel.

Interface Unit	In-home / on-site microcontroller unit which has a GUI capable of monitoring sensor data, controlling the state of the system, and adjusting sensor unit parameters.
Sampling Frequency	Frequency at which sensor unit polls sensor output and records the value
Transmission Frequency	Frequency at which sensor unit sends a packet to the control panel
Storage Frequency	Frequency at which data-points are stored permanently in memory.
Reservoir	Holding Tank used to hold water in a buffer before it reaches the pump.
Overflow Outlet	Piping which directs water back to the source when the reservoir is at maximum capacity.
Staff Gauge	Long measuring stick which indicates the level of a body of water.
Water Source	Body of water from which water is being diverted into the reservoir.