Solar Remote Monitoring of Trough Water Level

ECE445 Project Proposal - FA23

Project # 28

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1. Introduction

1.1 Problem

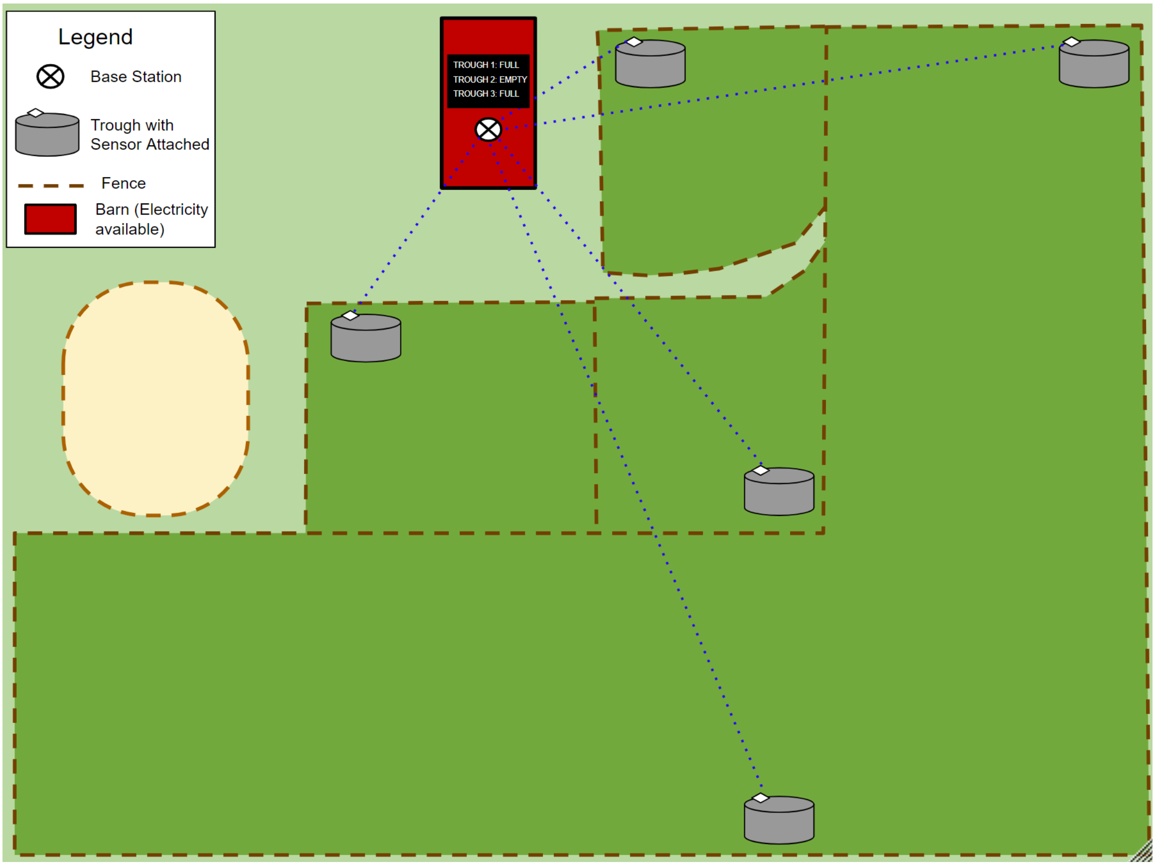
For the millions of Americans who rear livestock- whether it be recreational, amateur farming, or commercial production- filling water troughs several times per week all year round is one of the most important chores to be performed. For those with multiple large pastures, the process of checking each trough is a time-consuming task and one that must be performed daily. Many will use Kabotas or tractors to make quick work of the task, but without such tools, the process can be grueling. This is a task that has devastating consequences if overlooked or forgotten.

1.2 Solution

Our remote water monitoring system solution is designed to liberate livestock owners from this burdensome task of daily manual water trough inspections. Our system includes sensors to be mounted to every trough across a property, using ultrasonic technology to accurately monitor all water levels periodically. Livestock owners can gain real-time insights into water levels, enabling them to optimize their time and only deploy to fill troughs that have low-levels.

Since troughs are in remote off-grid locations, our devices will be solar-powered, and since water levels are fairly consistent over short periods of time we will transmit data hourly to substantially reduce power consumption. The collected data is transmitted to a central base station, located in a barn (or any central building) and powered by AC electricity. From there, users can access water level information on their smartphones or computers.

1.3 Visual Aid

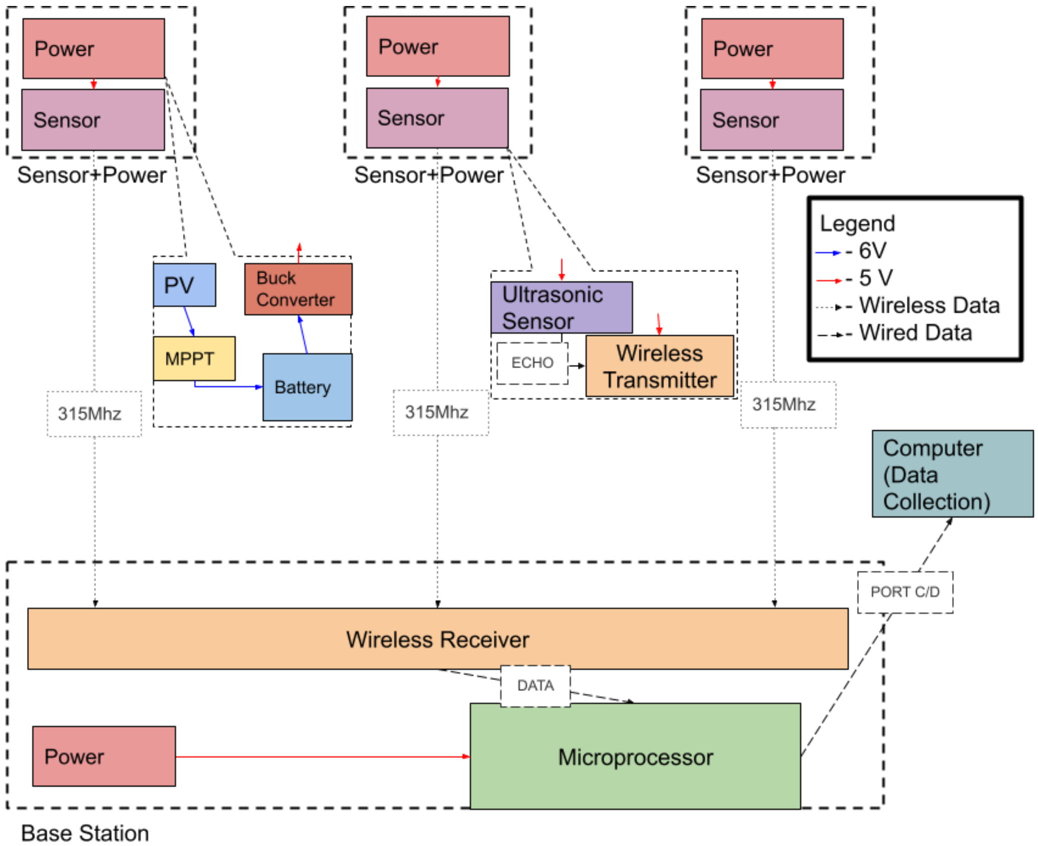


1.4 High-Level Requirements

- Our system must interface with a minimum of 3 troughs simultaneously. We will demonstrate a close range of 5 meters +/- 1 meter in our demonstration, and we will include video of functioning at ⅛ mile (200 meters +/- 50 meters).
- The sensors need to relay the trough's status at least once an hour during the day-time.
- We must provide accurate water level readings with a resolution of < 4 inches. This will be sufficient to calculate FULL, MEDIUM, and EMPTY conditions.

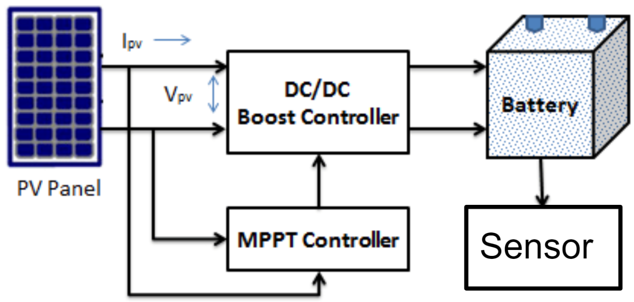
2. Design

2.1 Block Diagram



2.2 Subsystem 1: Power

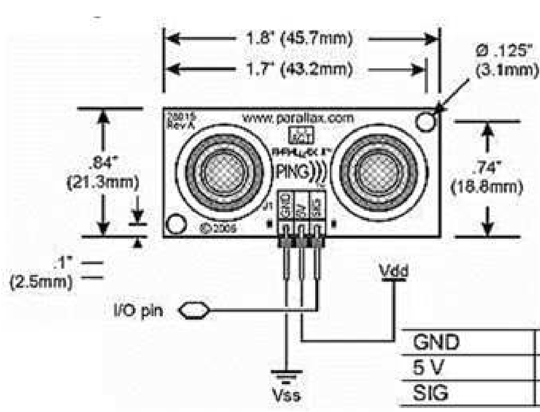
In our power subsystem, Si solar panels capture sunlight and convert it into electrical energy. The MPPT controller optimizes the energy output of the solar panels. Excess energy is stored in the rechargeable Nickel-Cadmium battery for use during cloudy or dark conditions. We will need a voltage step-down converter to regulate the power to match the requirements of the sensor subsystem. The power system will need to facilitate the wireless transfer of data from the sensor to our base station subsystem. We found that the power necessary to power a typical ultrasonic sensor (5V and a max operating current of 18mA) to be 90mW.



Requirements	Verification
The solar subsystem must deliver 6 volts at a minimum of 18mA.	After implementing MPPT, verify power output in direct sunlight.
Waterproof Packaging (project boxes) must resist rain and splash conditions	Submerge the empty sealed project box in shallow water for 5 seconds and verify no leakage.
The solar subsystem must include safety mechanisms to prevent overcharging of the battery and overvoltage conditions	Provide an overvoltage of 10V to Buck step down and verify step down.
The solar panel array must have an efficiency of at least 15% after MPPT implementation	Measure the actual efficiency of the installed solar panel array and MPPT under standard test conditions (STC) by dividing the total power output by the panel surface area and then by the solar irradiance value.
Buck converter (voltage step-down) must make solar output compatible with ultrasonic sensor (5V)	Test Buck converter in lab with voltage generators set at 6V.
Nickel Cadmium Battery must provide sufficient energy storage for cloudy conditions and for at least a single transmission at night.	After several successful transmissions in direct sunlight, at a chirp frequency of one transmission per minute, provide partial shade (50% cover) to the panel and verify the next 5 transmissions are successful.

2.3 Subsystem 2: Sensor

This sensor employs ultrasonic technology to measure water levels accurately to within at least 4 inches. The system is optimized for low-power operation and transmits water-level data once every hour, making it an ideal choice for remote and off-grid locations. At the core of the subsystem is an ultrasonic sensor module. This module uses ultrasonic sound waves to measure the distance from the sensor to the water's surface. It emits an ultrasonic pulse and calculates the time it takes for the pulse to bounce back after hitting the water's surface. This data is then used to accurately determine the water level. The microcontroller is responsible for interfacing with the ultrasonic sensor, processing the distance measurements, and managing the timing and data transmission functions of the sensor subsystem. To minimize energy consumption and maximize the sensor's operational lifespan, the microcontroller is programmed for low-power operation. It enters a low-power sleep mode between measurements and data transmissions to conserve energy (less than 10mW). When active, the typical ultrasonic sensor will draw no more than 90 mW. The sensor module and electronics are housed within a waterproof enclosure to protect them from environmental elements, such as rain, dust, and humidity. This also ensures the safety of the animals using the troughs.

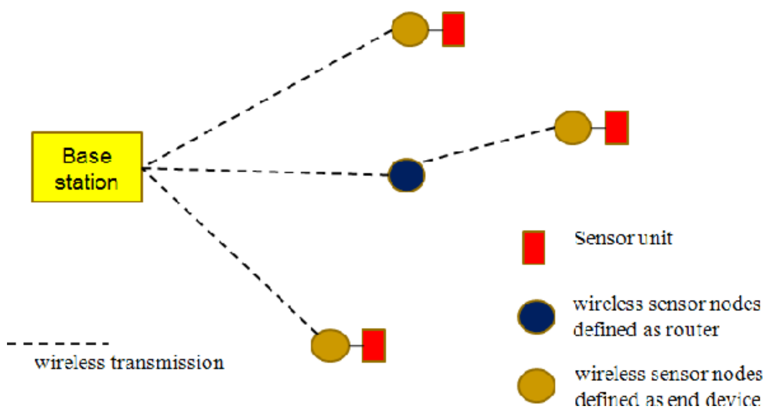


GND	Ground (Vss)
5 V	5 VDC (Vdd)
SIG	Signal (I/O pin)

Requirements	Verification
The ultrasonic water level sensor must provide measurements with an accuracy of at least ±4 inches.	With a sensor under 5V and 18mA, place the sensor 24 inches above water level. Record sensor reading, verify is within 24 inch +/- 4 inch range. Repeat for 12 and 6 inches.
The sensor must transmit water level data to the central base station on specified time intervals. (will be once per hour in real-world application)	Program transmission at rate of once per minute and verify validity. Repeat for a frequency of once per 10 minutes.
The sensor subsystem must operate in a low-power mode between measurements to conserve energy.	Measure power consumption during idle periods, ensure power consumption is < 10mW.
The sensor must transmit water level data wirelessly to the central base station with a range of ⅛ mile from base station to sensor and ¼ mile from furthest sensors within line of sight.	First verify at a 10 m, line of sight range. Then verify at 100m, then 200m.

2.4 Subsystem 3: Base Station

The Central Base Station Subsystem is the core hub of the remote water level monitoring system, serving as the centralized data collection and transmission point for water trough sensors deployed in the field. The **Zigbee protocol** is a promising method we found for our application. It was used in a study titled “Design of a Water Environment Monitoring System Based on Wireless Sensor Networks” by Peng Jiang et. al. Unlike the remote sensor subsystems, the central base station is housed in a barn and connected to AC power for continuous operation. This base station is equipped with a data receiver and processor responsible for receiving data from multiple ultrasonic water level sensors located in the field, and relays it to a liquid crystal display (LCD) which will show either FULL, MEDIUM, or EMPTY status.



Requirements	Verification
The base station must interface with 3 devices.	With a Sensor under 5V and 18mA, place the sensor 24 inches above water level. Record sensor reading, verify is within 24 in +/- 4 inch range. Repeat for 12 and 6 inches.
Must have a visible LCD display which can show FULL MEDIUM and EMPTY statuses.	Program transmission at rate of once per minute and verify validity. Repeat for a frequency of once per 10 minutes.
Must update every time the sensor system transmits data.	Set sensor frequency to one chirp per minute while changing the water level from empty to full. Verify LCD reflects change by the minute.

2.5 Tolerance Analysis

One aspect of the design that poses a potential risk to the successful completion of the project is the wireless communication link between the central base station and the user's smartphone or central monitoring platform. Ensuring reliable and robust wireless communication, especially in remote or challenging environments, is critical for the project's success. To demonstrate the feasibility of this component, we can conduct a basic link budget analysis for the chosen communication technology, Wi-Fi, Bluetooth, and Zigbee Protocol, to determine if it can meet the project's requirements.

Assumptions:

Transmission Distance (D): Assume a maximum transmission distance of 100 meters (328 feet) between the sensor node and the central base station.

Frequency Bands:

a. *Wi-Fi: 2.4 GHz (IEEE 802.11b/g/n)*
b. *Zigbee: 2.4 GHz (IEEE 802.15.4)*
c. *Bluetooth: 2.4 GHz (Bluetooth Low Energy, BLE)*

Transmit Power (Pt): Assume a common transmit power level for all three technologies: 20 dBm (100 mW).

Receiver Sensitivity (Pr): Typical values:

a. *Wi-Fi: -70 dBm*
b. *Zigbee: -85 dBm*
c. *Bluetooth (BLE): -90 dBm*

Path Loss (L): Calculate the free-space path loss using the Friis transmission equation.

Link Margin (M) for all three technologies is calculated as the difference between transmit power (Pt) and received power (Pr) minus path loss (L).

Link Margin Results:

a. Wi-Fi: 195.68 dB
b. Zigbee: 210.68 dB
c. Bluetooth (BLE): 215.68 dB

According to the link margin analysis, both the Zigbee protocol and Bluetooth have slightly more potential as reliable options than Wi-fi. This confirms our initial assumption that Wi-fi may be unfeasible for this application, as it can fail to work over varied terrain.

3. Ethics and Safety

Safety: Since we will be putting electronic equipment in close proximity to water troughs, the highest safety concern will be the risk of electrocution. The monitoring device should have waterproof packaging. The design should not short-circuit. The batteries should be disposed properly through local recycling programs, as stated in EPA standards. Since the solder in the lab is an alloy of Lead and Tin, any PCB in this project should not be present in water as it is not P65 or RoHS compliant (due to presence of Lead).

Ethics: Since the device will be small and inevitably contain harmful chemicals (e.g. lead), it is likely to cause health problems if ingested by livestock. For prevention, a small amount of denatonium benzoate, the same chemical applied on Nintendo Switch game cards, will be applied on both the packaging and the inner components. According to a research conducted by Hansen,S.R., Janssen, C., & Beasley, V.R (1993), Denatonium Benzoate is a chemical that could make both children and animals less likely to ingest liquid while not toxic for the amount added (Hansen, S. R., Janssen, C., & Beasley, V. R., 1993).

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