Solar Remote Monitoring of Trough Water Level

Final Report

Team #28
Alina Ampeh
Ajay S. Venkatraman
Letian Zhang

ECE445 FA' 23

Professor: Olga Mironenko

TA: Zicheng Ma

Abstract

The Solar Remote Monitoring of Trough Water Level project addresses a significant challenge faced by livestock owners in the United States, where the manual task of regularly filling water troughs poses a time-consuming burden, especially on large properties. The consequences of overlooking or forgetting this crucial chore can be devastating. To mitigate this issue, our team developed a remote water monitoring system that employs ultrasonic technology to accurately monitor water levels in troughs. This system liberates livestock owners from daily manual inspections by providing real-time insights, allowing them to optimize their time and resources efficiently.

The system architecture comprises three core components: the Power, the Sensor, and Base Station subsystems. Our solar capability, scalable model, and grid independence position us for success in revolutionizing the livestock industry. Despite successfully meeting high-level requirements, the project faced challenges, including limitations in the communication range and issues in the power subsystem. Future work could involve upgrading to the transmitters, exploring different voltage regulation methods, and considering advanced microcontrollers for improved performance. Overall, our device presents a robust, energy-efficient, and scalable solution for real-time water trough monitoring in livestock farming.

Table of Contents

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, checking each trough is a time-consuming task that must be performed daily. Many will use Kubotas for 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 through inspections. Our system includes sensors to be mounted to every trough across a property, using ultrasonic technology to monitor all water levels periodically and accurately. Livestock owners can gain real-time insights into water levels, enabling them to optimize their time and only deploy to fill low troughs. Figure 1.1 shows the layout of the system in the field. Note: The layout shows five devices, while the design has three.

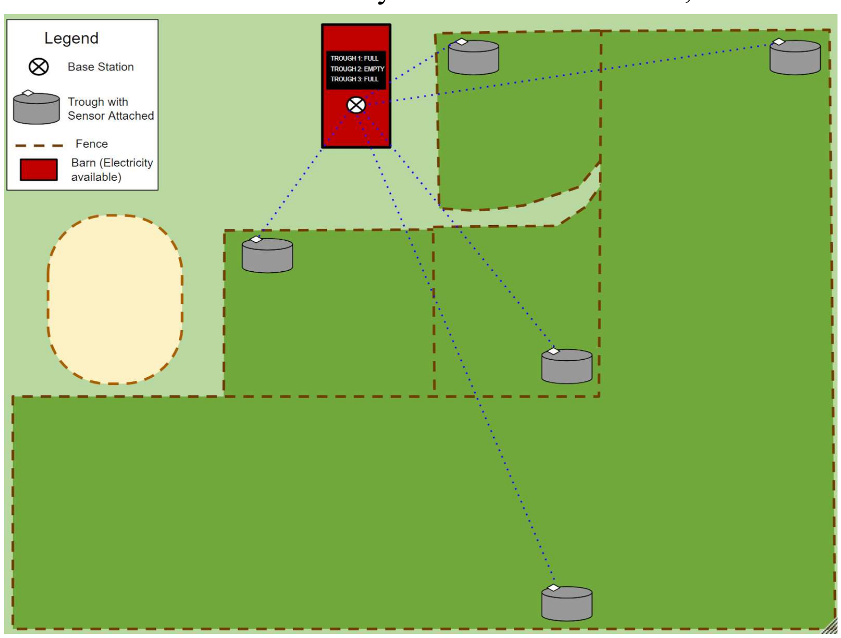

Figure 1.1: Visual Representation of Water Monitoring System Layout

1.3. High Level

1.3.1. Block Diagram

Figure 1.2 shows the final block diagram used for the system. There are two primary blocks: Sensor+Power and Base Station. The Sensor consists of an ultrasonic sensor, which sends data to a microprocessor, which relays it to the transmitter. The Power subsystem has a battery recharged by a 6V PV cell that supplies 5V to the ultrasonic sensor and the microprocessor and 12V to the transmitter. The Base Station receives the data via the receiver and relays it to the microprocessor to send data to the LCD. This station would generally be located in a barn (or any central building) and powered by a 5V DC supply. An AC to DC conversion must be made if a DC supply is unavailable.

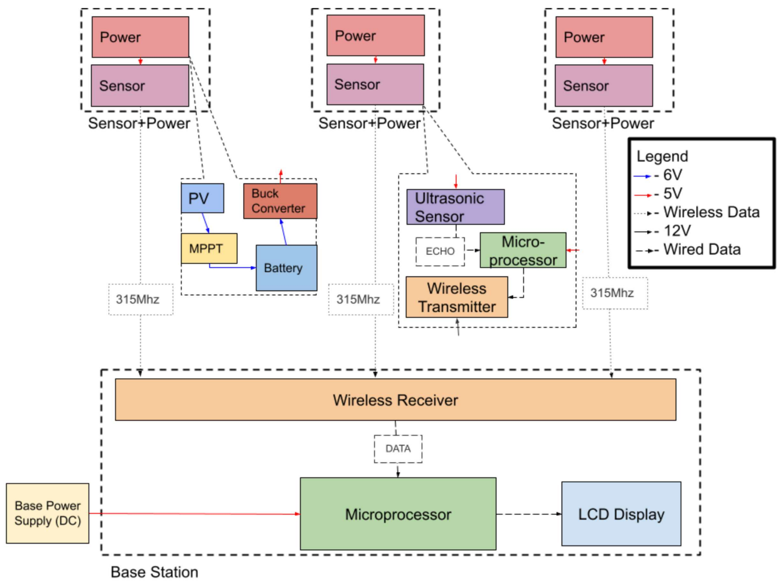

Figure 1.2: Final Block Diagram

This high-level design for the system has undergone multiple phases and changes. Initially, the thought was the microprocessor in the Base Station would also be powered by a source similar to the Power block. Still, it was decided unnecessary as the Base Station would be located near a power supply anyway. It was also thought that this microprocessor would relay the data to a computer, but the team thought it would be best to display that locally at the station.

1.3.2. Requirements

Our High-Level Requirements are as follows.

- Our system must allow the monitoring of 3 troughs simultaneously, no more than 200 m away from the central base station.
- The sensors must relay the trough's status at least once per hour during light conditions.
- We must relay HIGH, MED, and LOW conditions with an accuracy of +/- 4".

2. Design

The water monitoring system is designed to provide a robust and energy-efficient solution for real-time monitoring of water trough levels in agricultural settings. The design encompasses three core subsystems: the solar-powered rechargeable battery, the transmitter-sensor combination, and the base station with the receiver. The solar subsystem harnesses solar energy through solar panels, charging a rechargeable battery that powers the system. Wireless transmission at 315MHz facilitates communication between remote sensors and the central base station, allowing for remote monitoring. The ultrasonic sensor, coded on the ATTiny85 microcontroller, ensures precise water level measurements.

2.1. Design Procedure

KiCAD is used for designing the PCB in the base station, and the PCBs with ATTiny85 in the sensor-transmitter combination are the reused design from a previous assignment in the same course.

2.1.2. Sensor-Transmitter Combination

This part of the system was thought to be done without a microcontroller. A clock generator was supposed to send a pulse to the ultrasonic sensor, as seen in Figure 2.2, and the ultrasonic sensor sends the pulse back to the base station through the transmitter. This approach was not possible later because it is hard for the base station to decode a pulse from the transmission, and the clock generator can generate 8KHz at minimum.

Figure 2.2: Ultrasonic Sensor

Due to the factors above, the final design of the combination includes an ATTiny85 (the pinouts for which can be seen in Figure 2.3) as the microcontroller for timing the echo from the ultrasonic sensor and sending the delta back. The sensor for the water level is HC-SR04, an ultrasonic sensor that accepts low voltage and ranges from 2cm to 400cm. The transmitters and receivers are the 315MHz ASK pair due to their pin requirement (only one pin for data). The Virtualwire library [19] is considered for providing the drivers, but the Radiohead library [20] is used instead due to a timer problem.

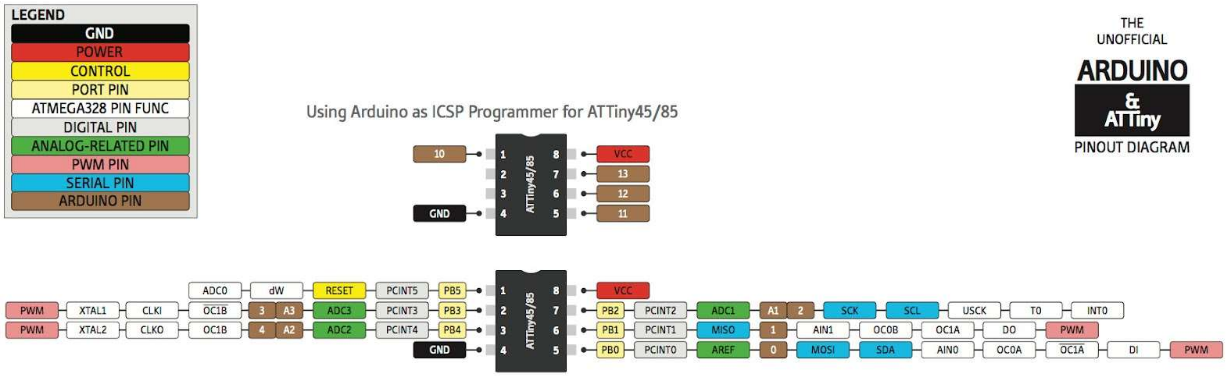

Figure 2.3: ATTiny85 PinOut

2.1.3. Base Station

The base station was initially assigned an ATMega328P microcontroller, seen in Figure 2.4 (left), in DIP packaging, which is responsible for processing and displaying the data on a computer. The microcontroller remains unchanged, but a 16x2 LCDs the processed data, eliminating the need for a computer and making the design more compact. The LCD comes with a PCF8574 from TI for interfacing via I2C, as seen on the right side of Figure 2.4. The base station was designed for direct interfacing with the LCD, but the I2C module on the LCD rendered that impossible, and two wires are soldered for SCL and SDA for the LCD.

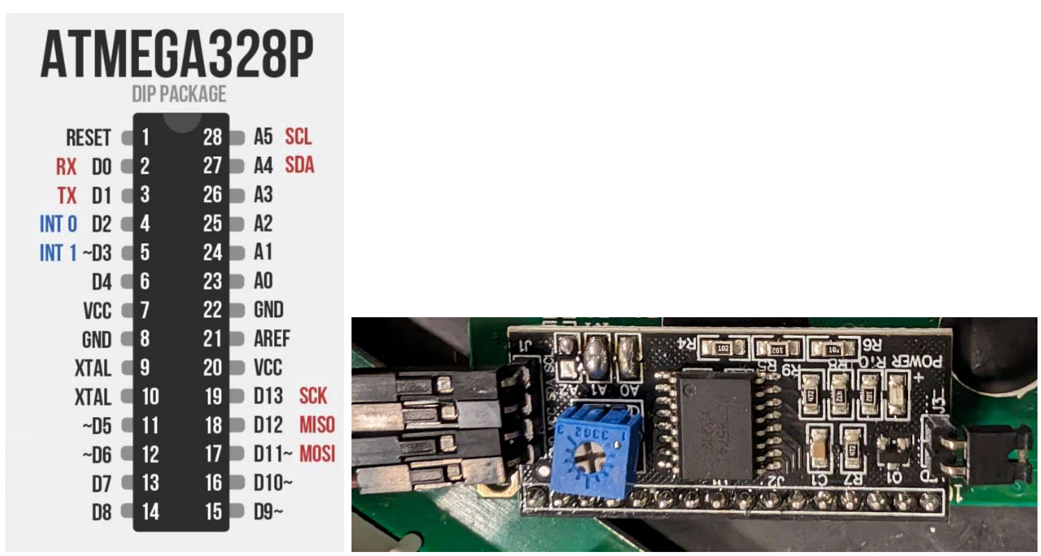

Figure 2.4: ATmega328P Pinout (left) I2C Module and A2, A1, A0 (right)

2.2. Design Details

2.2.1. Solar-Powered Rechargeable Battery

The solar subsystem, pictured in Figure 2.5, integrates high-efficiency solar panels with a Maximum Power Point Tracking (MPPT) controller to optimize power extraction from varying light conditions. Two rechargeable 3.7V Lithium Ion batteries, carefully selected for capacity and voltage compatibility, store excess energy during peak sunlight hours.. Using the perturb-and-observe method, the MPPT controller dynamically adjusts the electrical load to ensure the solar panels operate at their maximum power point.

Ideally, to satisfy our different power needs, we could have implemented 12V solar panels and used buck converters to bring the voltage for our sensor subsystem to 5V. However, our MPPTs were only compatible with 3.7 Li-Ion batteries, so we added two such batteries in series and a voltage divider to achieve 5V. We then used a 12V battery to support our data transmission.

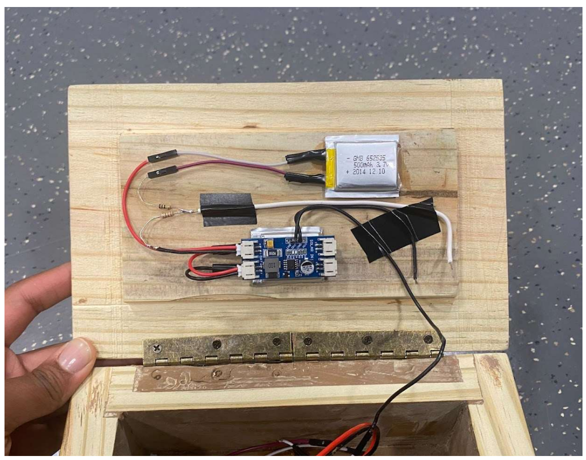

Figure 2.5: Power subsystem implementation

2.2.2. Wireless Transmitter-Sensor Combination

The wireless communication subsystem operates at 315MHz, providing an optimal balance between communication range and power efficiency. The central base station has a 315MHz receiver, while each remote transmitter-sensor combination equips one 315MHz transmitter. The wireless transmitters send the data through ASK, a type of amplitude modulation that encodes 1 to high amplitude and 0 to low, as shown in Figure 2.6. Theoretically, this transmission protocol ensures reliable data exchange, allowing the sensors to efficiently communicate water level measurements to the base station. The system prioritizes low-power operation to extend battery life, a crucial consideration for remote and off-grid deployments where energy conservation is paramount.

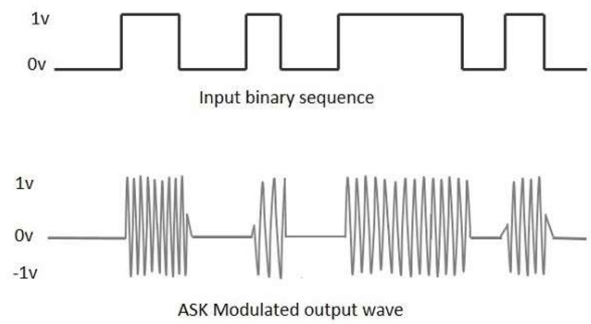

Figure 2.6: Amplitude Shift Keying

The heart of the water level measurement system lies in the HC-SR04 sensor, implemented on the ATTiny85 microcontroller. The ATTiny85 is programmed to execute precise and efficient ultrasonic ranging. The microcontroller times the duration from the echo pin of the sensor after sending out a 10us pulse. This solution enables low-power operation, making it well-suited for remote deployments with limited energy resources. The coded algorithms on the ATTiny85 ensure real-time measurement, contributing to the overall responsiveness and reliability of the water monitoring system.

ATTiny85 has two timers, Timer0 and Timer1. Timer0 is found to be the basis of several functions, including millis(), delay(), and delayMicroseconds(). These functions were critical for measuring the duration of a pulse, but since the VirtualWire library takes over Timer0's interrupts [19], any time unit on the chip feels around 100 times shorter. Despite occupying most of the chip's 8KB program memory and 512B dynamic memory, the Radiohead library's stripped-down Tinyhead version is used instead due to its ability to use Timer1. This releases Timer0 for accurate and reliable measurements. TinySnore library ensures the chip sleeps for the requested interval by setting the SE bit in the MCUSR register for sleep mode and wakes the device up through the watchdog timer by setting the WDTCR register's WDCE bit and WDE bit [21][22].

The measured time delta (an unsigned 16-bit integer) was encoded before converting to a char array by itoa(). As shown in Equation (2.1), the encoding takes the station number, T, time delta, t, and sends data, D, to the transmitter.

$$(2.1) \quad D = (T - 1) * 10,000 + t$$

2.2.3. Base Station

The base station consists of the custom PCB, whose schematic and design are in Figure 2.7, with ATMega328P DIP as the microcontroller and a 16x2 LCD module with I2C. Figure 2.8 pictures the physical PCB with all the connections. According to the datasheet of PCF8574 in Figure 2.4, the address of the slave device is 0x24 because A1 and A0 are grounded, while A2 is not (means 0b100, or 0x4). Together with the upper 3 bits (0b010, or 0x2) is where the 0x24 is derived from. The base station decodes data through a cascading if statement. It checks if the number is larger than 20,000, then 10,000, then 0. That corresponds to sensors 3, 2, and 1, respectively. Equation (2.2) calculates the distance between the water level and the device, x, in cm, where t is the time interval in µs.

$$(2.2) \quad x = 0.0343 * t/2$$

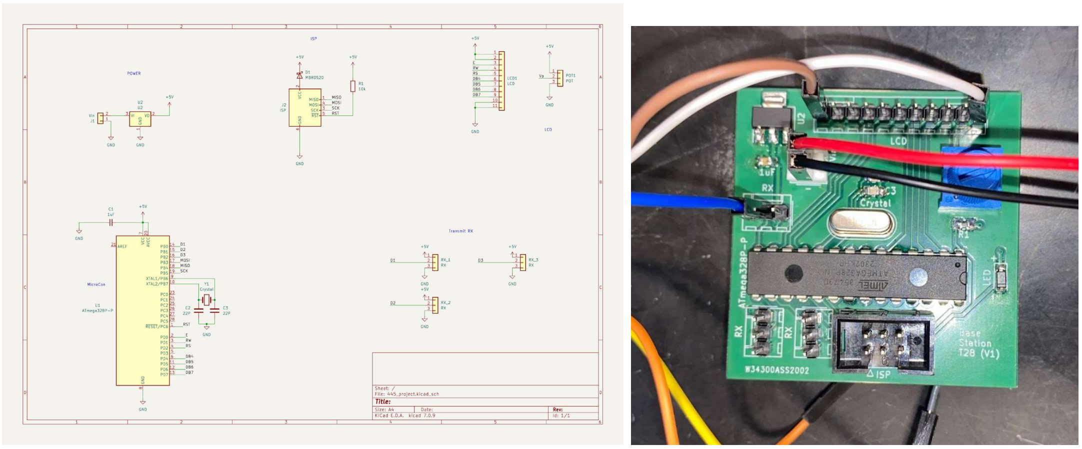

Figure 2.7: The PCB schematic (left) and the PCB upon arrival (right)

2.2.4. Casing Design

Figure 2.9 shows the draft of the design of the case. This design was modeled on 3D modeling software, and the drawing was based on the model. As seen in Figure 2.10, the final product featured a wooden case with a front plate/lid hinge and metal hook/rail on the back to secure it to the troughs. It has holes on the bottom for the ultrasonic sensor to make its reading and a hole at the top to allow for the wire for the PV cell. The side has a slot for the transmitter to be attached.

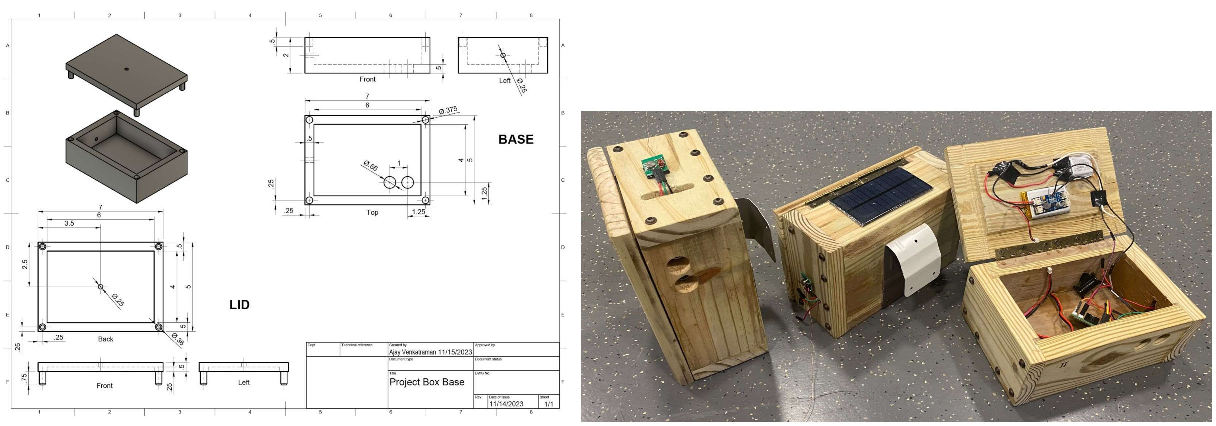

Figure 2.8: First Draft of Casing Design (left) and Final Casing Design (right)

3. Verification

3.1 Sensor Subsystem

Table 3.1 shows the verification and results from the tests run on the Sensor subsystem.

Verification	Results	Satisfied?
With a sensor under 5V and 18mA, place the sensor 24 inches above water level. Record the sensor reading and verify it is within 24 +/- 4”. Repeat that for 12 and 6 inches.	A trash can and several pieces of paper boxes were used for the simulation. One piece is placed at a level deeper than 24 inches, and the second is between 12 and 24 inches. The base station is programmed to display a length greater than 24 inches as “low,” a length between 12 and 24 inches as “med,” and a length below 12 inches as “high.” Given only the deeper cardboard is present, the base station reports “high” every 30 seconds. Given the less deep one is present, the base station reports “med.”	Yes
Program transmission at a rate of once per minute and verify validity. Repeat for a frequency of once per 10 minutes.	For 20 minutes, the sensor-transmitter combination sends a time delta averaged at 240.8 us, translating to 4.12972 cm given room temperature. The actual distance is 5 cm. A random sample of 5 intervals averaged at 63.8s per interval.	Yes
Measure power consumption during idle periods and ensure power consumption is <10mW.	The idle power consumption of the microcontroller and the ultrasonic sensor is around 30mW to 35mW (7mA at 5V)	No
The sensor must transmit water level	The sensor transfers data within	No

data wirelessly to the central base station with a range of ⅛ mi from the base station to the sensor and ¼ mi from the furthest sensors within line of sight.	4 meters indoors. And it is unable to transfer data at night.	

Table 3.1: Sensor Verification

3.2 Power Subsystem

Table 3.2 shows the verification and results from the tests run on the Power subsystem.

Verification	Result	Satisfied?
After implementing MPPT, verify constant voltage output in varying sunlight.	constant at 3.887V	Yes
Provide an overvoltage of 10V to Buck step down and verify step down.	Buck converter not implemented	No
Verify the actual efficiency of the installed solar panel array and MPPT under standard test conditions (STC) is greater than 10% by dividing the total power output by the panel surface area and then by the solar irradiance value.	efficiency = $(1W)/(0.006m^2 * 1380)$ efficiency = 0.125	Yes
Test Buck converter in the lab with voltage generators set at 6V.	Buck converter not implemented	No
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 following 5 transmissions are successful.	All shaded transmissions are successful.	Yes

Table 3.2: Power Verification

3.3 Base Station Subsystem

Verification	Results	Satisfied?
With a Sensor under 5V and 18mA, place the sensor 24 inches above water level. Record sensor reading and verify is within 24 in +/- 4 inch range. Repeat for 12 and 6 inches.	At 24 inches, the sensor reads: At 12 inches, the sensor reads: At 6 inches, the sensor reads:	Yes
Program transmission at a rate of once per minute and verify validity. Repeat for a frequency of once per 10 minutes.	Fails with frequency of more than once per 30 seconds, success at any frequency less than once per 30 seconds. success at once per minute and once per 10 minutes.	Yes
Set the sensor frequency to one chirp per minute while changing the water level from empty to full. Verify LCD reflects change by the minute.	Reflects change within one minute.	Yes

4. Costs

Overall, we used many parts, big and small, to complete our system. Table 4.1 lists the parts and the costs for the components used in the Base Station. Most of the parts we had to order from external vendors, but a few were readily available to us in the lab. Table 4.2 lists the parts and costs for the components used in the Sensor subsystem. These costs/quantities were tripled (except for the ultrasonic sensors, which came in a pack of 3). We only had to buy the Transmitter/Receivers and the Ultrasonic sensors and order the PCBs. Everything else was found in the lab. Table 4.3 details the parts and costs we had for the Power subsystem. For this, we had to buy all the components. Table 4.4 details our miscellaneous costs. This includes the parts for the three device casings and any wires that may have been used. As seen at the bottom of Table 4.6, the total paid was $181.67.
Outside the lab setting, there are other considerations to factor into costs. The labor cost breakdown is detailed in Table 4.5. For a team of 3, making an average engineer salary working about 15 hours per week for eight weeks, labor would cost $12,000 per person or $36,000. Table 6 shows the consideration in total manufacturing for this system if we were to make it from scratch without the lab's help. The projected cost of the system would be $36,219.

Part	**Cost**	**Quantity**	**Total**	**Paid**
ATMega Microchip	$9.98	1	$9.98	$9.98
Blue LCD	$3.66	1	$3.66	$3.66
PCB	$5.25	1	$5.25	$5.25
1uF SMD Capacitor	$0.30	3	$0.90	$0.00
SMD Resistor	$0.10	1	$0.10	$0.00
Regulator	$2.30	1	$2.30	$0.00
ISP Programmer Connector	$0.95	1	$0.95	$0.95
1x3 Connector	$0.51	3	$1.53	$1.53
1x2 Connector	$0.51	1	$0.51	$0.51
1x11 Connector	$0.82	1	$0.82	$0.82
Schottky Diode	$0.43	1	$0.43	$0.00
Crystal	$0.60	1	$0.60	$0.60
Potentiometer	$0.64	1	$0.64	$0.00
Total			$27.67	$23.30

Table 4.1 Base Station Costs

Part	Cost	Quantity	Total	Paid
RF Transmitter and Receiver	$5.89	3	$17.67	$17.67
Ultrasonic Sensor (x3)	$5.40	1	$5.40	$5.40
PCB	$2.70	3	$8.10	$8.10
1uF SMD Capacitor	$0.30	9	$2.70	$0.00
SMD Resistor	$0.10	3	$0.30	$0.00
Regulator	$2.30	3	$6.90	$0.00
ISP Programmer Connector	$0.95	3	$2.85	$0.00
1x3 Connector	$0.51	9	$4.59	$0.00
1x2 Connector	$0.51	3	$1.53	$0.00
ATTiny Microchip	$1.66	3	$4.98	$0.00
Total			$55.02	$31.17

Table 4.2: Sensor Costs

Part	Cost	Quantity	Total	Paid
3.7V Rechargeable Battery	$5.50	6	$33.00	$33.00
Solar Chargers MPPT	$10.54	4	$42.16	$42.16
6V Polysilicon Solar Cell (x3)	$14.88	1	$14.88	$14.88
100 Ohm Resistor	$0.16	1	$0.16	$0.00
220 Ohm Resistor	$0.16	1	$0.16	$0.00
Total			$90.36	$90.04

Table 4.3: Power Costs

Part	Cost	Quantity	Total	Paid
Wood For Casing	$7.20	3	$21.60	$21.60
Screws for Casing	$0.24	9	$2.16	$2.16
Hinges for Casing	$1.79	3	$5.37	$5.37
Rail For Casing	$0.78	3	$2.34	$2.34
ISP Programmer	$8.98	1	$8.98	$0.00
Wires (x40)	$5.69	1	$5.69	$5.69
Total			$46.14	$37.16

Table 4.4: Miscellaneous Costs

Per Hour Salary	Weeks Left	Average Hours Worked/Week	Work Hours	Labor Cost Per Member	Total Labor Cost
$40	8	15	120	$12,000	$36,000

Table 4.5: Labor Costs

Total Labor		$36,000
Total Cost		$219.19
Total Projected Cost		**$36,219**
Total Paid		**$181.67**

Table 4.6: Total Costs

5. Conclusions

Our team is set on revolutionizing the livestock industry with our water level monitoring system. Our solar capability, scalable model, and grid independence all position us for success in achieving our solution to our problem. Our product can have implementations that go beyond our scope. It can be the grassroots of a wider system that monitors the water level of lakes, ponds, or other bodies of water. Its implications can extend beyond farming to a wide-scale environmental impact.

5.1. Accomplishments

Overall, we delivered our project satisfactorily, meeting all of the high-level requirements we specified. Our system successfully allowed the monitoring of 3 troughs simultaneously. The sensors relayed the trough's status at least once per the specified interval. The LCD displayed HIGH, MED, and LOW conditions. We could package and hang our device and make a polished product.

5.2. Uncertainties

Unfortunately, we were not able to extend our range to 200m. Future work could consider upgrading to the nRF24L01 2.4GHz transceiver to fix this range issue rather than using transmitters/receivers. We hit a snag along the way in our Power subsystem, which caused us to have low output to our ATTiny Microcontrollers. To overcome this, future work could examine how linear regulators may or may not be more beneficial than the buck converters we initially planned to use. The microcontroller on the sensor side could be upgraded to a more performant chip, like the ATTiny1614, for better performance.

5.3. Ethical considerations

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 must be applied to the packaging and the inner components. Also, each group member respected the others within and outside the group. No dangerous equipment (e.g., the heated-up soldering iron or the bitter chemical mentioned above) was used to harm others. As part II of the IEEE Code of Ethics stated, discrimination or micro-aggressions were made.

References

[1] ACM Code of Ethics and Professional Conduct. Code of Ethics. (n.d.). https://www.acm.org/code-of-ethics

[2] Adafruit Si5351A Clock Generator Breakout Board - 8KHz to 160MHz https://www.adafruit.com/product/2045

[3] Amplitude shift keying https://www.tutorialspoint.com/digital_communication/digital_communication_amplitude_shift_keying.htm

[4] ATTiny85 Datasheet https://ww1.microchip.com/downloads/en/devicedoc/atmel-2586-avr-8-bit-microcontroller-attiny25-attiny45-attiny85_datasheet.pdf

[5] Fenderson, Edward. “RoHS vs Non-ROHS Soldering.” DigiKey, Maker.io, 26 Aug. 2015, www.digikey.com/en/maker/blogs/rohs-vs-non-rohs-soldering.

[6] Gates, Ashley. “What Is Maximum Power Point Tracking (MPPT).” NAZ Solar Electric, 12 June 2019, www.solar-electric.com/learning-center/mppt-solar-charge-controllers.html/.

[7] Hansen, S. R., Janssen, C., & Beasley, V. R. (1993). Denatonium benzoate as a deterrent to ingestion of toxic substances: toxicity and efficacy. Veterinary and human toxicology, 35(3), 234–236.

[8] HC-SR04 ultrasonic sonar distance sensor + 2 x 10K resistors. Adafruit. (n.d.).
IEEE code of Ethics. IEEE. (n.d.).

[9] https://www.ieee.org/about/corporate/governance/p7-8.html

[10] Interface an I2C LCD with Arduino https://lastminuteengineers.com/i2c-lcd-arduino-tutorial/

[11] Last Minute Engineers. (2023, May 10). Insight into how 433MHz RF TX-RX Modules Work & Interface with Arduino.

[12] “Lead and Lead Compounds.” P65warnings.ca.Gov, www.p65warnings.ca.gov/fact-sheets/lead-and-lead-compounds. Accessed 28 Sept. 2023.

[13] Mybotic, & Instructables. (2017, September 25). How to interface with RF transmitter and receiver. Instructables.

[14] Pendergast, R. L., Santos, R., Dragon, Anderson, J. R., Javier, Dark, Iain, Kent, Louis, Marc, Trung, Ankit, Adekoya, S., Ramesh, Charley, Pawar, S., Rafi, Firas, Lance, … Dierickx. (2021, September 22 RF 433mhz transmitter/receiver module with Arduino. Random Nerd Tutorials.

[15] Pule, Mompoloki, et al. "Wireless Sensor Networks: A Survey on Monitoring Water Quality." Journal of Applied Research and Technology, Elsevier, 3 Jan. 2018, www.sciencedirect.com/science/article/pii/S1665642317301037.

[16] Radiohead Library
https://www.airspayce.com/mikem/arduino/RadioHead/

[17] TI PCF8574 Datasheet
https://www.ti.com/product/PCF8574#tech-docs

[18] TinySnore Library
https://github.com/connornishijima/TinySnore

[19] TPS82140 17-V input 2-a step-down converter microsip module with ... Texas Instruments. (n.d.).

[20] Ultrasonic Ranging Module HC - SR04
https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf

[21] United States Environmental Protection Agency 1EPA. (n.d.).
https://archive.epa.gov/epawaste/hazard/web/pdf/battery.pdf

[22] VirtualWire Library
https://www.airspayce.com/mikem/arduino/VirtualWire/

Appendix A Symbols and Abbreviations

Unit or Term	Symbol or Abbreviation
alternating current	AC
amperes	A
amplitude shift keying	ASK
binary form	0b
centimeter	cm
direct current	DC
hexadecimal form	0x
inch	in
inter-integrated circuit	I2C
liquid crystal display	LCD
maximum power point tracking	MPPT
megahertz	MHz
meter	m
microseconds	µs
mile	mi
milliamp	mA
milliwatt	mW
photovoltaic	PV
printed circuit board	PCB
serial clock	SCL
serial data	SDA
station/device 1	T1
station/device 2	T2
station/device 3	T3
surface mounted device	SMD
volts	V
watts	W