Solar Water Filtration and Vending System

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Abstract

This report outlines the design and implementation of a solar-powered water filtration and vending system for use in off-grid rural communities in countries like Indonesia. The system is explained in detail and its components are listed. Verification checks are outlined and the costs associated are presented. Lastly, ethical considerations and future steps are elaborated upon.

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1 Introduction

1.1 Objective

Our objective is to create an effective solar-powered water purification and dispensing system to be deployed in remote rural environments. Our system will be powered using solar energy to allow for use in environments without stable or reliable electric grids. Energy generated from a photovoltaic cell will be stored in a lead-acid battery, which in turn will be used to power water pumps, electric valves, sensors, a display, and input buttons. Purified water will then be stored and dispensed based on button inputs. A system of sensors and electric valves will monitor and control water water levels in the tanks, and the correct dispensing.

Many people in rural areas in developing countries do not have access to clean water. They have to walk several miles a day to obtain it from the closest water source. Additionally, this water cannot be consumed without further treatment. In the absence of electric infrastructure, water is boiled on burning firewood. As result, considerable amount of smoke is inhaled, causing long-term lung issues. One of our member's non-profit organization is building solar water pumps in East Nusa Terengganu, Indonesia. To complement this, we have decided to design a water filtration system using solar energy.

1.2 Functionality

Based on one of our member's personal observations in Indonesia, villagers may need to spend at least two hours a day to purify water by distillation on firewood. Besides the inefficiency, this process presents environmental issues and health issues associated with the smoke generated. Therefore, we propose reverse-osmosis filtration as an alternative. To avoid an unstable, and occasionally even non-existent, electric grid, we use a solar power module. This provides an output voltage within a range of 13.5 - 13.8 V to power a control module and the user interface module.

For our control module, we want to maintain a water level between 5% and 90% of storage tank volume. The first constraint allows for enough water to always offer some quantity to dispense to the user. The second is used to prevent overflow and allow for effective use. This water level will be monitored using a pressure sensor. Finally, we want to make our final system compatible with a vending system-style setup. We believe this method can help create a sustainable business plan, with revenues partially offsetting initial costs and fully funding all maintenance.

1.3 System Overview

Our system is composed of three modules - a power module, a control module, and a user interface module. The power module consists of a lead-acid battery charged using solar panels. It will provide the energy required to power the whole system whenever the solar panels are not generating enough power. Since the output voltage of solar panels is unsteady, a dc-dc converter is required to maintain a desirable charging voltage.

The control module will manage the input and output of water valve in the filtration/dispensing system. Pressure sensors will signal the microcontroller the level of water in the containers. With this information, the microcontroller can turn on the electric valves and pump to allow the flow of water in or out of the system. There are two conditions boundary for our water tank. If the water height is below 11 cm, the output water valve will be closed. On the other hand, if the water height is above 33 cm, the pump and input water valve will be closed to overcome overflow.

The user interface module consists of 4 input buttons and an LCD display. If the water height is below 11 cm, an error message ("Please wait") will be presented while the tank fills. The LCD will always display the temperature and the height of the water when no button is pressed. There are three buttons corresponding to 3 different dispensing option - 1, 2, and 32 liters respectively. The other button is a "Yes" button, allowing for the user to confirm their selection and trigger a water dispense.

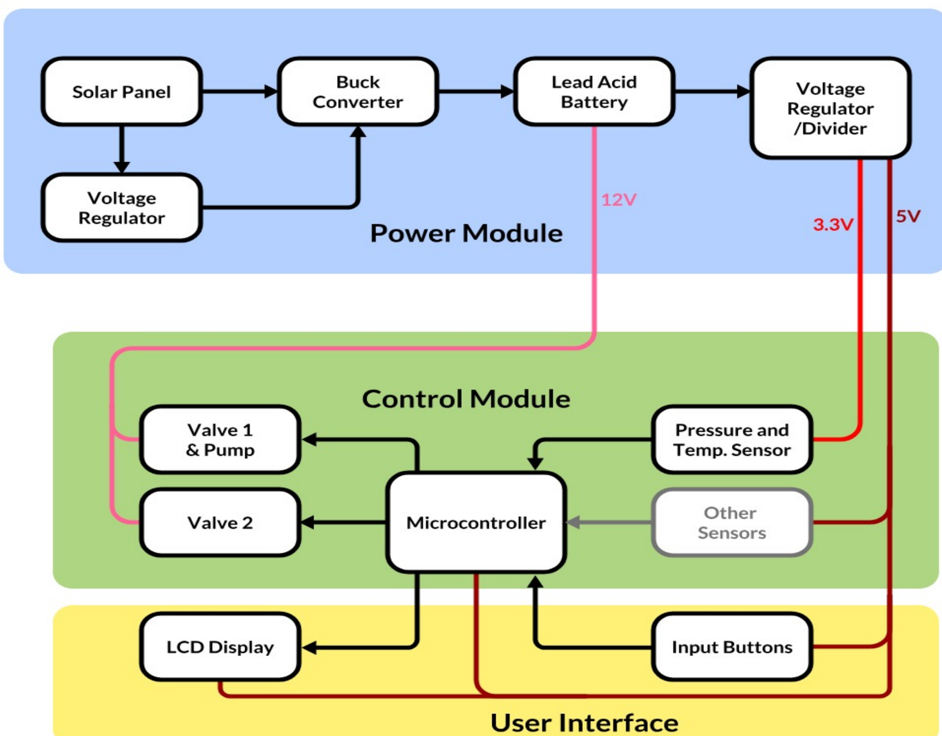


Figure 1. High Level Block Diagram

1.3.1 Power Module

- Solar Panel
Our project is to be deployed in rural areas where electricity is not an stable commodity; as a result, we are using solar energy as our main energy source. The average power rating of a booster pump and an electric valve are approximately 24 W and 36 W respectively. Additionally, the power rating of a 12V/12Ah lead-acid battery is 36 W considering that its maximum allowed charge current is 3 A. Hence, the maximum wattage consumption of the whole system would be roughly 96 W. Therefore, we will use a 100 W solar panel to power our system.

- 12V Lead-Acid Battery
We will use a lead-acid battery because it is cheaper than its counterparts. It will power the water pump as well as the control unit. To improve lifespan of the battery, it must be charged at the floating charge point. A 12 V lead-acid battery floating point ranges from 13.5-13.8 V [1]. This is because it is composed of six cells, where each cell measures on average 2.25 V during float charge.

- Buck Converter
The output from the solar panel is dependent on weather conditions and positioning relative to the sun. Therefore, a dc-dc converter is required to maintain a stable voltage to charge the battery. When receiving enough solar radiation, the output voltage from the solar panel is greater than battery voltage; a buck converter is required to step down the higher voltages to a suitable level. The dc-dc conversion should be as efficient as possible, so we can obtain the most energy from the solar panel. We decided as a result that our buck converter must have an efficiency greater than 80%.

- PWM controller & Voltage Regulator
The PWM controller will adjust the duty ratio required for the buck converter to keep the desired output. It will be an analog implementation. It consists of an error generator, PI control, comparator, triangular wave generator. Moreover, A voltage regulator IC will be used to step down the battery voltage to 5 V to power the control module.

1.3.2 Control Module

- Microcontroller
This serves as the primary component of the control module. It takes inputs from the pressure and temperature sensors, as well as user inputs from the input buttons. It then generates outputs to send to the electric valves, booster pump and the LCD display. These outputs are generated using a control logic that ensures that a certain water level is maintained throughout operation, complying with the high-level requirements for water quantity.
For the purposes of this project, we used an ATMega328-PU chip to perform this functionality. This chip was bootloaded as an Arduino Uno microcontroller, allowing us to replicate a standard platform used for such control units. Code was written on the Arduino IDE, and was uploaded to the chip using an Arduino as an in-serial programmer. Doing so allowed us to debug and modify functionality efficiently.

- Electric Valves

We have 2 electric valves in out project - an input valve leading into the storage tank, and an output valve leading out of the storage tank. These valves are used to moderate the flow of water, implementing an effective water management system. Both of these valves are controlled by a simple 12V power signal; when the power is supplied, the valve opens and water can flow through. This signal is in turn controlled by an output from the microcontroller, which is used through a transistor.

- Pressure and Temperature Sensor
The pressure sensor is used to calculate the volume of water inside the tank. By translating the pressure reading into an equivalent height and volume, the sensor can accurately monitor the water level. This data is used both to maintain the water level, and track it for water dispensing. For this project, we used the MS5803 Sensor with Breakout Board from Sparkfun Electronics.

This sensor has the additional functionality of being a Temperature Sensor, which we also used as a salient data point. The sensor was placed in a waterproof case and setup, to ensure safety and use while immersed in water. The data was transferred through the I2C bus to the microcontroller, which utilizes analog communication in order to reduce the number of pins required.

- Booster Pump
In our final implementation, we intend to use a reverse-osmosis filter to provide the purification component for our final project. While we did not purchase and include this pump in our physical design, we established all the surrounding components such that the additional of the filter would be easy and modular. The booster pump is used to increase the pressure of the water flowing through the reverse-osmosis filter to allow for effective operation. The booster pump operates very similarly to the input electric valve. It too requires a 12V signal when in operation, and the same output from the microcontroller is used to verify its use.

1.3.3 User Interface Module

-Input Buttons
There are four different input buttons, one each corresponding to 3 different outputs and one used as a “Yes” button to confirm an action. Each input will trigger a “dispense” signal, asking the system to dispense a required discrete amount of water - 1L, 2L, and 3L respectively. The microcontroller will receive the signal, which triggers the valves to open for a certain amount of time based on the input signal.

-1602 Serial LCD Display with I2C Breakout Board
We used an 16x2 LCD display - 2 lines of output with 16 characters on each line. When there is no user interaction, the LCD displays the height and total water that have been dispensed. When the user presses input buttons, an interaction based on the input signal is displayed. For instance, if the user presses the 1L input, the LCD will confirm this and ask the user to press “Yes". Lastly, the LCD will display an error message if the water level is too low for a dispense.

Figure 2. LCD Operations

2 Design

2.1 Buck Converter

2.1.1 Power Loss

We decided that the converter must have an efficiency greater than 80 %. The losses produced in the converter are due to the switching and conduction of MOSFET and diode.

The MOSFET losses can be calculated with equations (2.1, 2.2):

$$P_{sw} = \frac{1}{2} \bullet V_{in} \bullet I_L \bullet (t_f + t_r) \bullet f_{sw} \quad (2.1)[2]$$

$$P_{c,mosfet} = I_L^2 \bullet D \bullet R_{ds,on} \quad (2.2)[2]$$

While the diode losses can be obtained with equations (2.3, 2.4):

$$P_{rr} = f_{sw} \bullet V_{in} \bullet Q_{rr} \quad (2.3)[2]$$

$$P_{c,diode} = V_F \bullet I_d \quad (2.4)[2]$$

Where P_{sw} is the switching loss, P_c the conduction loss, and P_{rr} the reverse recovery loss.

To obtain these values, it is necessary to specify some initial assumptions:

- The highest output voltage from the solar panel is about 20 V. The switching loss is proportional to V_{in}. Hence, to find the highest loss, we will assume $V_{in} = 20$ V.
- The average current I_L through the inductor will be the equal to the average current into the load. The maximum current that a 100 W solar panel can supply is around 5 A. The maximum charging current of 12 V-12 Ah battery is about 3 A.
- We will use the available IRF510 N-MOSFET in the lab for testing. It has the following characteristics:

$$t_f + t_r = 87 \text{ ns}[3]$$

$$R_{ds,\,on} = 0.077\ \Omega[3]$$

- f_{sw} is the switching frequency. The sizes of inductance and capacitor are inversely proportional to frequency. We will assume a frequency of 50 kHz.
- D is the duty ratio. In a buck converter, $D = V_{out}/V_{in}$. A bigger duty ratio would incur bigger losses.
- As for the diode, we will use a Schottky diode because they have a small forward voltage and no reverse recovery. We will use DSSK 80-0025 with $I_F = 40$ A and $V_F =$ 0.39 V[4].

With these assumptions, we obtain:

$$P_{sw} = 0.1305 \text{ W}$$

$$P_{c,mosfet} = 0.6237 \text{ W}$$

$$P_{rr} = 0 \text{ W}$$

$$P_{c,diode} = 1.17 \text{ W}$$

We can see that the most significant losses come from the conduction loss. Hence, the efficiency can be further improved by choosing MOSFET with lower $R_{ds,on}$ value, and diode with smaller forward voltage.

The total power loss must account for the copper loss from the inductor. The ESR loss from the capacitor is negligible considering how small the ripple current is.The size of inductor and capacitor will depend on the switching frequency of the MOSFET and the current and voltage ripple.

Assuming our buck converter is working at 50 kHz with a ripple of 1% of the average output current and voltage, we can determine their values with the following equations:

$$v_L = L\frac{di_L}{dt} \qquad (2.5)[2]$$

$$V_L = L\frac{\Delta i_L}{\Delta t} \qquad (2.6)[2]$$

When Mosfet is on; $V_L = V_{in} - V_{out}$, $\Delta t = DT$. Considering that ripple must be within 1%, $\Delta i_L = 0.01 I_L$. Hence, L>0.75 mH.

$$i_c = C\frac{dv_c}{dt} \quad (2.7)[2]$$

$$i_{cmax} = C\frac{\Delta v_c}{\Delta t} \quad (2.8)[2]$$

When Mosfet is on; $i_{cmax} = \frac{\Delta i_L}{2}$, $\Delta t = DT$. Considering that ripple must be within 1%, $\Delta v_c = 0.01V_{out}$. Hence $C > 6$ μF. This value of capacitor does not take into account the ESR resistance of the component, which increases the voltage ripple.

In order to ensure that our buck converter will work within the proposed specifications, we will select a 1.5 mH inductor and 10 μF capacitor.

Considering that the inductor must withstand at least a current of 3 A, we will be using B82726S2163N0. It has a resistance of 7.1 mΩ [5], which will result in loss of 0.0639 W.

Considering all the calculated losses, the approximate power loss in the dc-dc conversion is less than 5 W. Assuming that input power is 100 W, it gives us an efficiency greater than 95 %.

2.1.2 PWM Generator

A PWM signal with a specific duty ratio can be generated by comparing a constant voltage with a triangular wave as shown in Figure 4. The triangular wave is obtained by integrating a square wave generated using a Schmitt trigger.

When v2 is greater than Vtri, the output voltage from the comparator will be 5 V, and 0 V if smaller. Knowing that the output voltage from the solar panel varies somewhere between 15 and 20 V, Vcomp has to change accordingly to generate a PWM signal with duty ratio ranging from 0.68 to 0.91 if we want to maintain a charging voltage of 13.6 V.

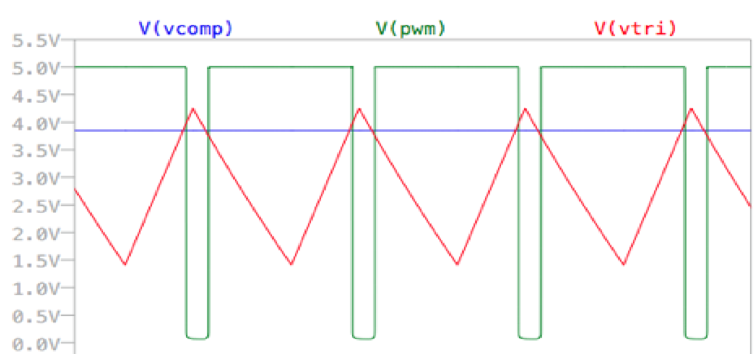


Figure 3. PWM signal of amplitude 5 V

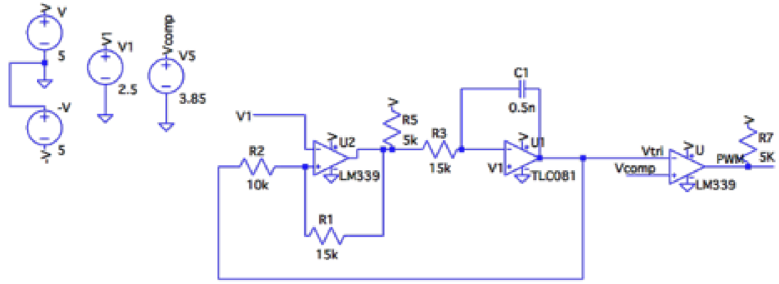


Figure 4. PWM Circuit

2.1.3 Feedback PI control

In order to control the output voltage of our buck converter, the duty ratio of the PWM signal has to change accordingly for different input voltages. To do so, we will use a PI control as shown in Figure 5. We will feedback the voltage output and subtract it from the desired reference voltage, which will be between 13.5 and 13.8 V. The resulting error will be corrected using a PI control. In a steady state, the output voltage should be equal to reference voltage.

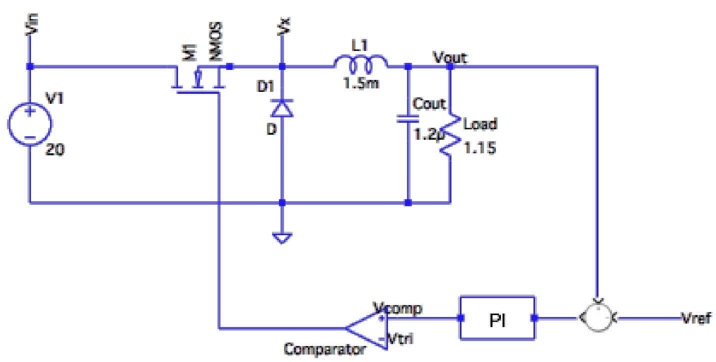
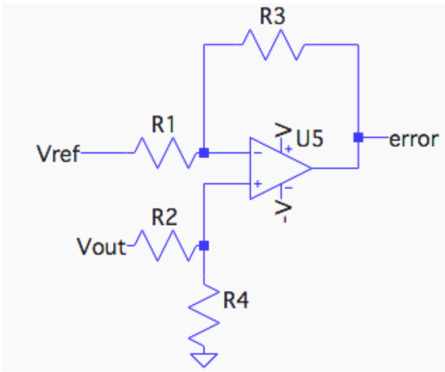


Figure 5. Control Concept

To subtract the output voltage from the reference voltage, we will use a differential amplifier as shown in Figure 6. The output of a differential amplifier can be found using equation (2.9). When $R_1 = R_2 = R_3 = R_4$, $error = V_{ref} - V_{out}$. The resulting error will be fed into the PI control (Figure 7). In Figure 8 we can see the response of output voltage with a reference of 13.8 V and a 12 V voltage load.

$$error = V_2 * \frac{R_4}{(R_2+R_4)} * \frac{(R_1+R_3)}{R_1} - V_1 * \frac{V_3}{R_1} \quad (2.9)\ [6]$$



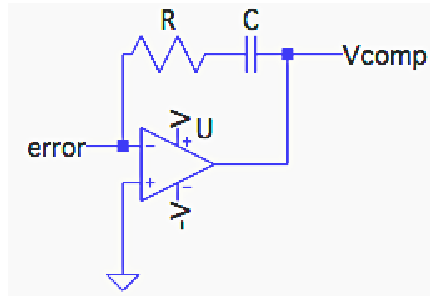


Figure 6. Differential amplifier

Figure 7. Proportional + Integral

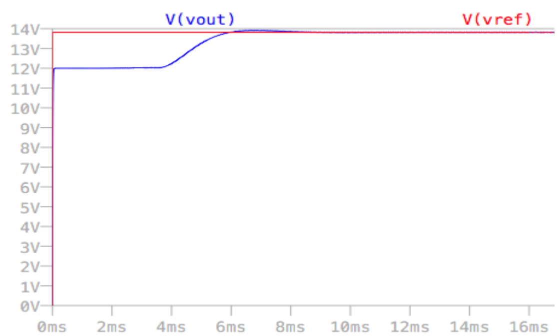
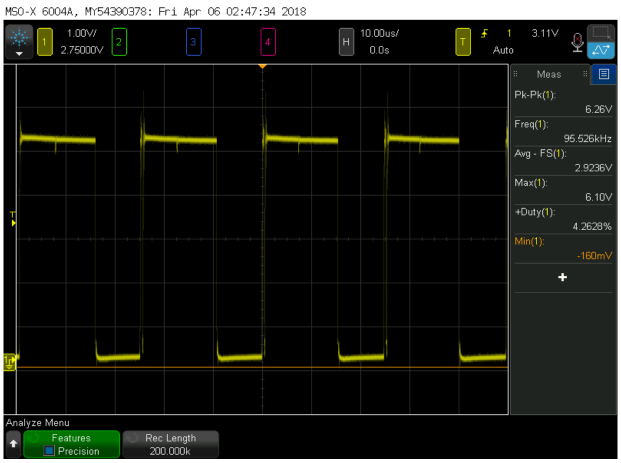


Figure 8. Simulation result with 12 V Battery load and 13.8 V reference

2.1.4 Breadboard testing and modifications

During breadboard testing, the designed buck converter did not work as expected. The output voltage was capped at 13 V, which means that for any reference voltage above 13 V, the output will always stay at 13 V, instead of reaching the desired reference voltage. We took several steps to solve this issue.

At first, we thought that the problem was caused by the PWM signal due to comparator instabilities. In Figure 9 we can see how the PWM experiences a double transition due to noise, resulting in a wrong measurement of the duty ratio. This problem was solved by adding hysteresis to our comparator. However, the 13 V cap issue persisted.



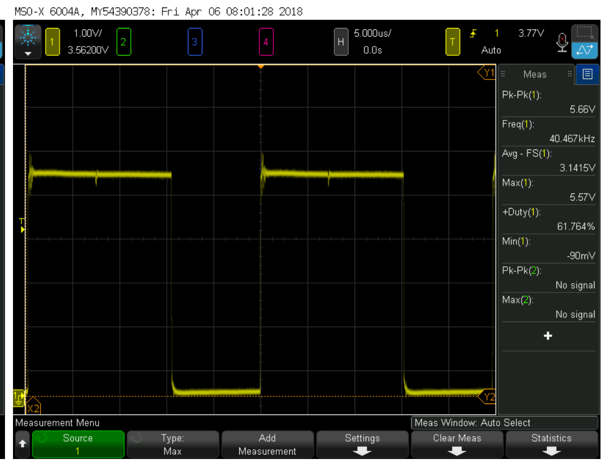
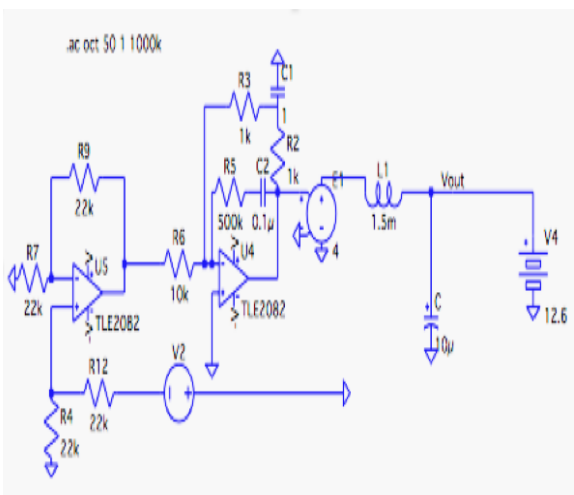


Figure 9. PWM signal double transition   Figure 10. PWM with Hysteresis comparator

The next plausible reason was an unstable feedback loop. So, we decided to analyze the loop stability by doing AC frequency-domain simulation (Figure 11) to obtain the bode diagram of the close loop system. The resulting bode plot (Figure 12) shows a phase margin of 90º at unite gain. Considering the stability margins of power supply design, any positive phase margin at unite gain will result in a stable system [7].



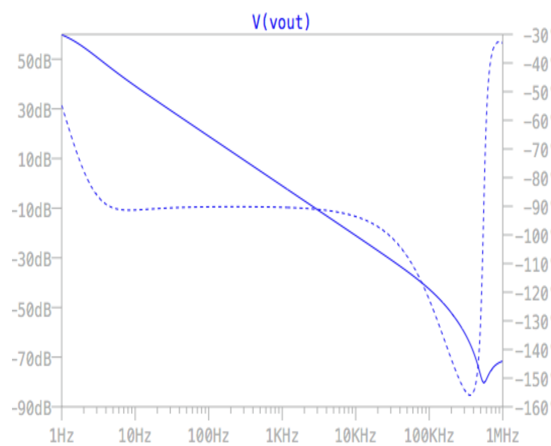


Figure 11. AC frequency domain simulation   Figure 12. Closed loop analysis

The issue was resolved by introducing a voltage divider at the output, so we could feedback the voltage divider output instead of the actual buck converter output and compare it with a lower reference voltage as shown in Figure 13. In Figure 14, we can observe a steady output voltage of 13.6 V when supplied with 15 V and 20 V respectively.

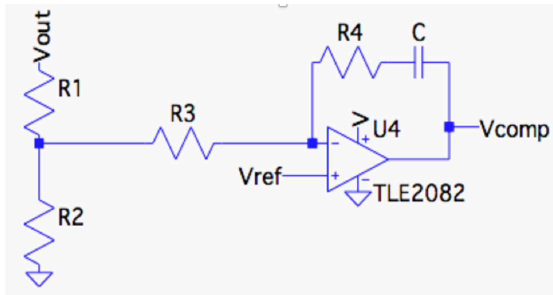


Figure 13. Modified FeedBack Loop

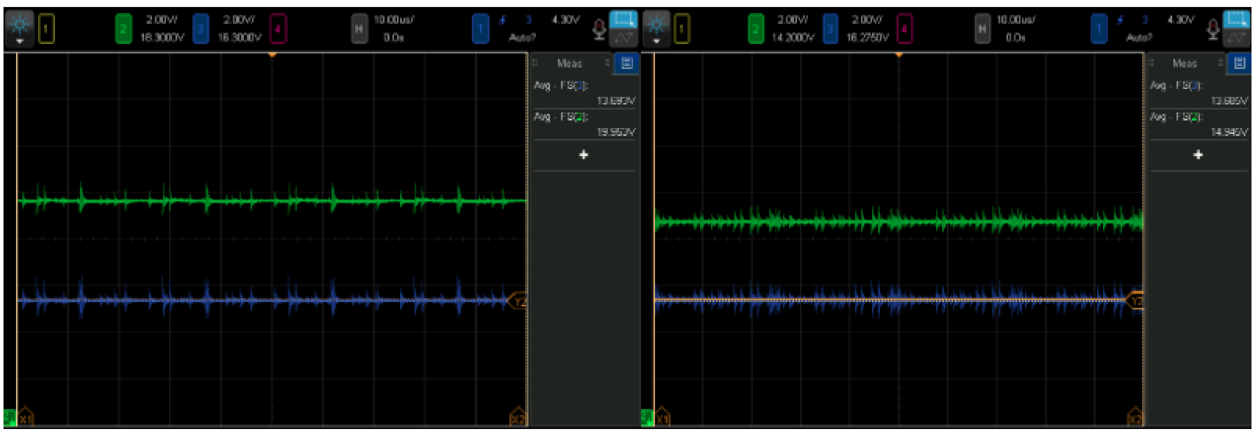


Figure 14. Output voltage (Blue) at different Supply voltages (Green)

2.2 Control Module

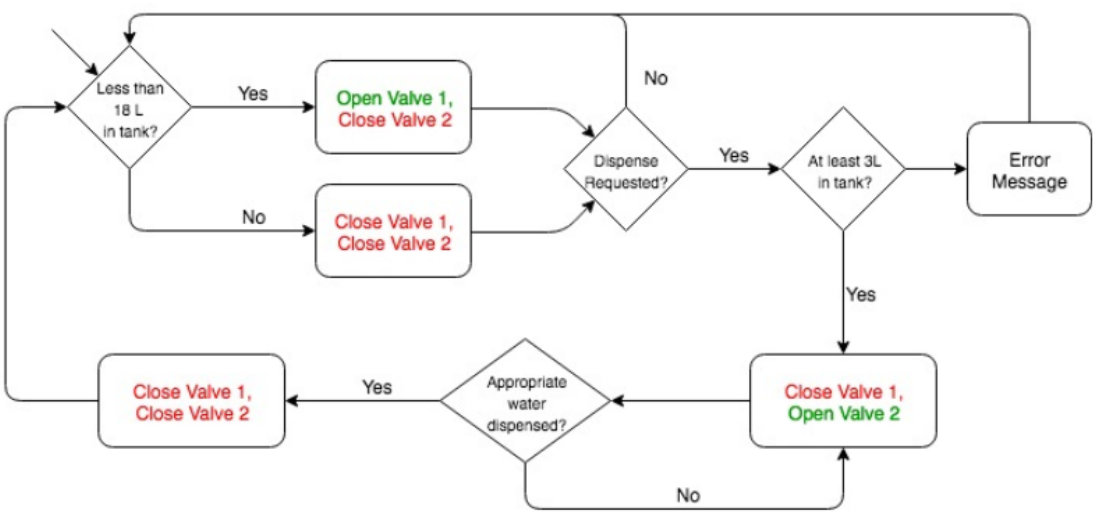


Figure 15. Control Logic Flowchart

We made some significant design choices over the course of our project. We were asked to consider other options for measuring water levels, including flow meters. This was in an effort to eliminate any other data required for operation besides the reading from the meters. We determined that pressure sensors were still the most viable option, because flow meters would not be able to provide an accurate reading for distilled water, which often flows in small quantities. Moreover, we would still require the volume of the container for the second high-level requirement. Lastly, we believe this product would be shipped as a coherent package, including standardized water container sizes.

2.3 Physical Design

The bucket used as a storage tank is cylindrical and has volume of 5 gallons. It connected to a output valve that has no minimum pressure requirement to operate. The bucket is inside the case that is slightly bigger than it. The purpose of the case is to separate the water with the power module and control module, thereby preventing hazards. On the top of the clean water tank, there should be a reverse-osmosis filtration module. However, we did not buy it because of cost constraints - we believe this would be a simple modular addition to our project. The filtration module is connected to the pump and the plastic input valve that has minimum operating pressure of 3 PSI.

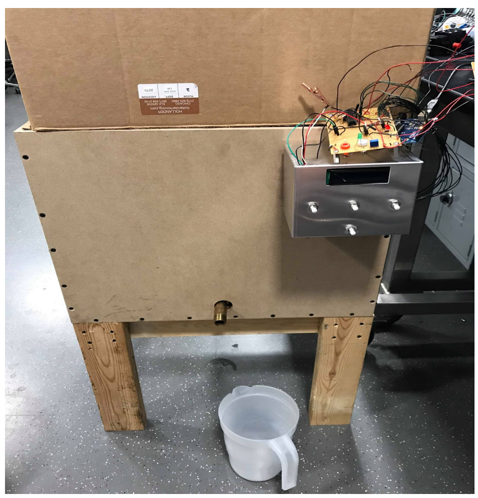


Figure 16. Final Product

We had issues operating our electric valves. Our earlier models had a minimum pressure requirement of 3PSI. While this is not an issue for the input valve owing to the booster pump, the output valve did not function as expected. We ultimately resolved this issue with another valve with no such requirement.

We also considered implementing various purification mechanisms. We wanted to implement a distillation system, but quickly realized this would be not be feasible or efficient. We ultimately chose a reverse osmosis system as an effective alternative.

2.4 Dispensing System

We decided to just use an electric valve to minimize our cost. We take the advantage of our pressure sensor that is always showing the height of the water in the tank. Deriving bernoulli equation, we get the equation for the time to open the valve given the water height, area of the bucket, and area of the hole shown in the following equation:

$$t = \frac{2A}{a\sqrt{2g}}(\sqrt{h_1} - \sqrt{h_2}) \quad (2.10)[8]$$

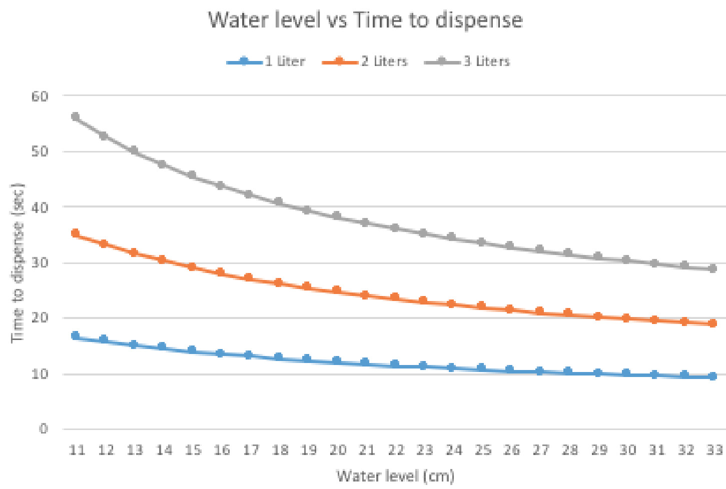


Figure 17. Water Level VS Time to Dispense

Using this method, we are able to get an accurate amount of water that is dispensed. However, since our bucket does not have a constant radius, above 22 cm water level, we get the amount of water from the input value with up to 5% uncertainty.

Table 1: Power Consumption

Parts	Voltage (V)	Current (A)	Power(W)
1602 Serial LCD Display	5	0.0448	0.224
Booster Pump	12	1	12
Atmega328 Microcontroller	5	0.0448	0.224
Brass Electric Valve	12	3	36
Plastic Electric Valve	12	0.2	2.4

3 Requirements and Verification

We presented three high-level requirements in our initial document, all of which we believe we adequately fulfilled.

The solar charging should be able to maintain output within range of 13.5 - 13.8 V
As we noted in our demonstration, this requirement was clearly fulfilled. At a varying input voltages, the output voltage was maintained at approximately 13.68V. This was our expectation for the power module, and is a clear measure of its primary functionality.

Both water tank should never go below 5 % and surpass 90% of its capacity
In our demonstrations, we presented a set of checks whereby the error message was displayed when the water dropped below the minimum, and above a prescribed maximum. While the final design did not use the precise values of 5% and 90%, this is because of the reduced size of our storage tank (5 gal). Any change to those values is trivial and would require changing a line of our code, so we consider this requirement fulfilled.

End user will get the amount of water from the input value with 2% uncertainty
This was also demonstrated clearly through a video in our final presentation. This required a few trial-and-error calculations to perfect, but after establishing the time relationship outlined in section 2.4, the amount of water was within a reasonable bound. This accuracy can be improved by use of a fully cylindrical tank, as opposed to one with a slight slope.

Further verification is presented in Appendix A.

4 Cost

An extensive accounting of the part costs can be found in Appendix C.

By researching annual average salary for entry level electrical and computer engineer based, it comes out to be around $40/ hour. We decided to choose $40/hour for hour labor cost. Our team consists of three people, we estimate to work around 7 hours/week for each member. We also assume that we work start from week 4 to week 14 because the first four weeks are about the introduction of the course. After discussing our design with the machine shop, we come up the idea to buy the water tanks. Therefore, the machine shop only needs to create the pyramid, case for the clean water bottle, and connect everything together. It will take them one week which is around 20 hours. Moreover, the average salary for machinists is 20.25/hour. Therefore, using the labor cost calculation formula, the labor cost for our project is as presented below.

Table 2. Labor Cost

Team Member	Hourly Rate	Total Hours	Expense Multiplier	Total Cost
Lixiang Dong	$40	70	2.5	$7000
Mustika Wijaya	$40	70	2.5	$7000
Rahul Raju	$40	70	2.5	$7000
Machine Shop	$20.25	20	2.5	$1012.5
			LABOR TOTAL	**$22012.5**

Table 3. Total Cost

Type	
Part Cost	$534.04
Labor Cost	$22012.50
Total Cost	**$22546.55**

5 Conclusion

5.1 Accomplishments

Over the course of the semester, we built a functioning water management system that can be used as a based for an extensive purification and vending system. We successfully demonstrated full functionality of our core components. We built a power module designed to work with a solar panel and lead-acid battery that would harness that power and distribute it across a complex circuit. We built a control module which used an array of sensors to generate salient data, and translated that into a water management system operated by electric valves. Finally, the system facilitates user interaction through input buttons and provides feedback and data through an LCD display.

5.2 Uncertainties

In our implementation, we faced certain setbacks. We had issues operating our electric valves that were not rectified by the time of our scheduled demonstrations; they were, however, subsequently cleared. Additionally, we had issues with integration in our project and in transferring the final design to a solder board - these too were eventually overcome with the addition of simple electric components to the circuit.

5.3 Future Work

Our modular design is built to be easily customizable and allow for the addition of further components to enhance functionality. One proposed addition would be a cloud-based monitoring system, whereby the same data transferred to the LCD display module is also transmitted for processing. This data is then stored on the cloud to provide useful data analytics. Such analysis can also be used to iteratively improve the design for future implementations, taking into account patterns of use.

Another design idea discussed at length is that of a purity feedback loop. First, an intermediate tank would be placed between the storage tank and the filter-pump setup. This tank would be used to test purity using a pH and a turbidity sensor. If the water was sufficiently pure, it would be passed on to the storage tank. If not, it will be recycled through the filter to increase its purity. This would be particularly useful later in the usage life of a reverse-osmosis filter. Such a setup would also require at least 2 additional valves, and some further code.

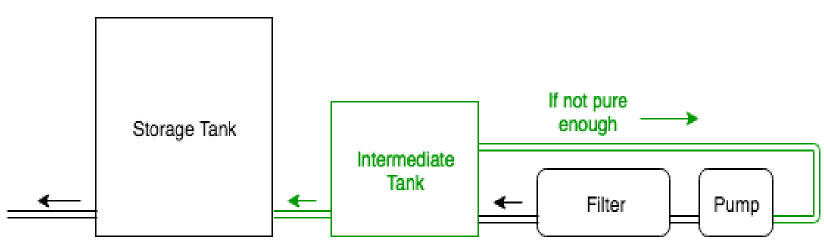


Figure 18. Purity Feedback Loop

5.4 Ethical Considerations

As a project that actively seeks to present a solution to a pressing real-world problem, we take the ethical dimensions of our system seriously. We believe that our project demonstrates good environmental stewardship through the use of green and sustainable energy. This, combined with our established partnership with local stakeholders in communities draws us to IEEE Code of Ethics #7 ("To improve the understanding by individuals and society…."). Additionally, in order to present transparency to comply with IEEE Code of Ethics #3, our data panel will provide public access to the statistics derived from our sensors.

Safety is a critical element in this consideration; indeed, IEEE Code of Ethics #1 (": "To hold paramount the safety...") highlights this expectation [10]. Because of the use of water in our project in particular, we have taken additional precautions to preserve insulation.
Pressure sensors will be placed in the water tank to make sure that it will not overflow. Our solar charging system is also placed outside the vending machine so that it will never be in contact with water.

6 References

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Appendix A: Verification Tables

Requirement and Verification for Control Module (20 Points)

Requirements	Verifications	Result
• Accuracy of pressure sensor to within 100 ml of water	**Equipment:** Tank, Measuring cup, Water Pressure sensor, Arduino **Procedure:** 1. Connect Pressure sensor to Arduino 2. Pour water into tank and measure reading 3. Add incremental measured amounts of water to change the amount **Expected Output:** The reading is accurate to within equivalent pressure to 100 ml of water	**Y**
• Less than 1 s between consecutive pressure sensor and temperature sensor readings	**Equipment:** Tank, Measuring cup, Water Pressure sensor, Arduino **Procedure:** 1. Connect Pressure sensor to Arduino 2. Pour water into tank and measure reading 3. Add incremental measured amounts of water to change the amount **Expected Output:** The reading changes within 1 s	**Y**
• Microcontroller data must be processed within 0.25 s for each set of inputs.	**Equipment:** Microcontroller, Pressure Sensor, Input Buttons, Temperature Sensor, Oscilloscope **Procedure:** 1. Connect Sensors and Input Buttons to Oscilloscope through Microcontroller 2. Perform any combination of operations expected during operation of project, routing outputs through Oscilloscope **Expected Output:** • Each cycle of outputs is displayed every 0.25 s	**Y**
• Low power requirement for efficient operation, ideally within 1W	**Equipment:** Microcontroller, Pressure Sensor, Input Buttons, Temperature Sensor, Multimeter, electric valve **Procedure:**	**Y**

	1. Connect Sensors and Input Buttons to Microcontroller 2. Measure voltage and current across pin that powered the chip **Expected Output:** Total power is below 1 W	
• Must close the valve within 1 s with a reliable constant open/close time.	**Equipment:** Microcontroller, Electric Valve, stopwatch **Procedure:** 1. Connect Valve to Microcontroller 2. Turn the valve on and off repeatedly, for at least 10 times **Expected Output:** Valve closes each time within 1s, and deviations between times are less than 0.2 s	**Y**
• Electric Valve between the distillation tank and clean water tank should be closed if the tank has 90 % of its capacity volume • Electric Valve for dispensing the water should be closed if the tank only has 5 % of its capacity volume	**Equipment:** Microcontroller, Electric Valves, Pressure Sensors, Tank **Procedure:** • Connect Valve to Microcontroller, and Microcontroller to pressure sensor as in final setup • Pour the water to the tank lower than 5 % and greater than 90 % of its capacity respectively **Expected Output:** Electric Valves should be closed based on the conditions in the high-level requirements	**Y**

Requirement and Verification for Power Module (20 Points)

Requirements	Verifications	Result
• The solar panel must be able to provide a voltage of 13.5 V and above to charge 12 V battery	**Equipment:** Solar panel, Voltmeter, Ammeter. **Procedure:** 1. Expose the Solar Panel under direct the sunlight. 2. Measure open circuit voltage with voltmeter. **Expected Output:** • Output voltage must be above 13.5 V when exposed to enough sunlight.	**Y**
• Charging voltage of a 12 V lead-acid battery	**Equipment:** Battery, Buck converter, Oscilloscope, Ammeter, Power supply. **Procedure:**	**Y**

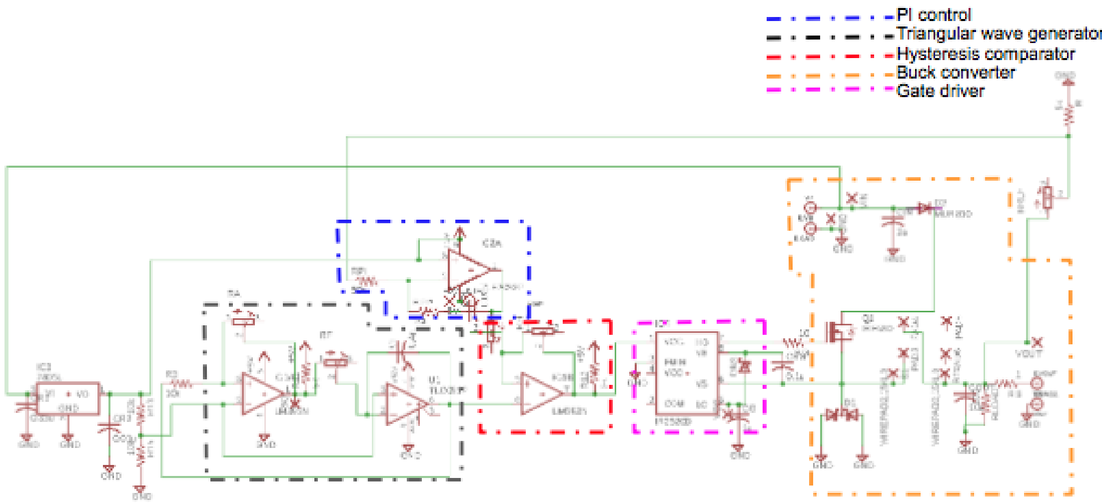
ranges from 13.5-13.8 V.	1. Connect the Lead-Acid battery to the buck converter. Supply voltage ranging from 15-20V. 2. Use oscilloscope to measure the voltage of the output. **Expected Output:** ● Measured output voltage should be within range 13.65 ± 0.15 V	
● Maintains the component thermal stability below 125 °C	**Equipment:** Buck, PWM, IR Thermometer **Procedure:** 1. During all verifications, use IR thermometer to check the thermal stability across the component of the circuit **Expected Output:** ● All the component should be below 125°C	**Y**
● PWM generator must provide square wave what goes from 0.5±0.5 V to 4.5±0.5 V	**Equipment:** PWM generator, Oscilloscope **Procedure:** 1. Measure PWM output with oscilloscope. **Expected Output:** ● Square output signal ranging from 0.5±0.5 V to 4.5±0.5 V	**Y**
● Buck Converter must keep an average output voltage between 13.5-13.8 V ● Voltage ripple must be less than 1 % of the average output voltage.	**Equipment:** Power Supply, Buck Converter, PWM Generator, Oscilloscope. **Procedure:** 1. Connect resistive load of 1 Ω to buck converter output. 2. Supply 15 to 20 V to buck converter 3. Measure output with oscilloscope **Expected Output:** ● Average voltage within 13.5-13.8 V range. ● Ripple voltage <1 % average output voltage.	**Y**

<u>Requirement and Verification for Display Module (10 Points)</u>

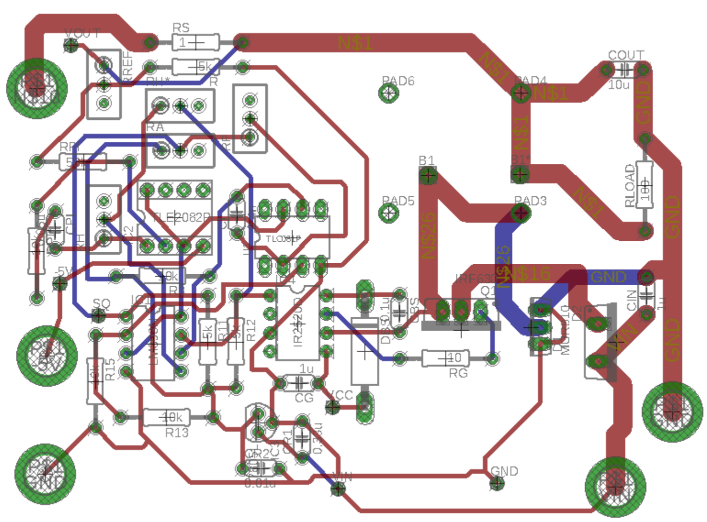
Requirements	Verifications	Result
● Low power requirement for efficient operation ideally within 1W.	**Equipment:** Microcontroller, LED Display, Multimeter **Procedure:** 1. Connect LED Display to Microcontroller 2. Measure voltage and current across	**Y**

	Display during operation **Expected Output:** Total power is below 1W	
• Error Display	**Equipment:** Microcontroller, Electric Valve, Pressure Sensors, Tank **Procedure:** 1. Connect Valve to Microcontroller, and Microcontroller to Sensors as in final setup 2. Vary water level in tank, testing minimum bound as in high-level requirements. **Expected Output:** Display error message if there is too little water to dispense.	**Y**

Appendix B: Circuit Diagrams



Buck Converter Circuit Schematics



Buck Converter PCB Layout

Appendix C: Part Costs

	Part	Quantity	Unit Cost
Power Module	100 W Solar Panel	1	$109.95
	LM7805 Voltage Regulator	1	$0.70
	DSSK 48-0025B Schottky Diode	1	$2.56
	B82726S2163N0 1.5mH Inductor	1	$9.80
	Various Capacitors	x	Free
	Various Resistors	x	Free
	12V 12AH Lead-Acid Battery Power Sonic	1	$28.99
	IRF2125 Gate driver	1	$6.24
	TLC081 Op-Amp	3	$1.60
	TLE2082 Op-Amp	2	$3.35
	IRF630 Mosfet	1	$0.94
Control Module	ATMega328p Microcontroller	1	$2.01
	Plastic Water Solenoid Valve	1	$6.95
	Brass Water Solenoid Valve	1	$29.99
	SparkFun Pressure Sensor Breakout - MS5803-14BA	1	$59.95
Filtration Unit	iSpring RCC7 High Capacity Under Sink 5-Stage Reverse Osmosis with booster pump	1	$249.99
I/O	16x2 LCD display	1	$6.48

	Input Buttons	4	$2.00
		Total Cost	$534.05