Automated Cleaning System for Solar Panels

ECE 445, Spring 2022

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Team 10

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1. Introduction

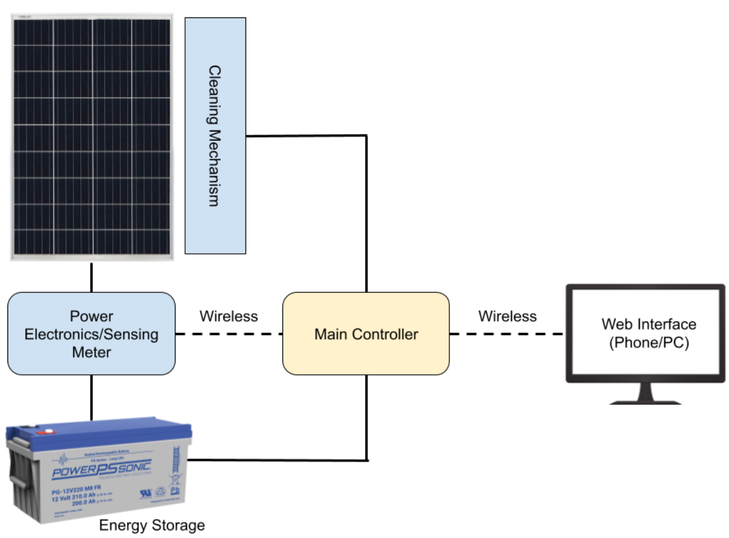
a. Problem

As solar panels are constantly exposed to the outdoor elements to achieve maximum efficiency and performance, the natural dust in air or pollutants from nearby settlements can cover the surface of the photovoltaic arrays with particulate matter that negatively affects their power output.[1] Current methods to remove this contamination are laborious and require human intervention to physically remove the dirt and dust which increases operation costs of solar farms. In applications where solar panels are installed on rooftops, cleaning can also be difficult as it will be left to the homeowner who may not be able to easily access the panels without specialized equipment.

b. Solution

An automated system which can detect decreased power output due to dirt coverage will be able to deploy a cleaning spray followed by a wiper to remove contaminants from the solar panels. This system can also be utilized to clear snow in cold climates by activation of just the wiper. Remote control of the wiper mechanism will also be possible for manual cleaning if needed in spite of the output readings being tracked by the system itself.

c. Visual Aid



d. High-Level Requirements

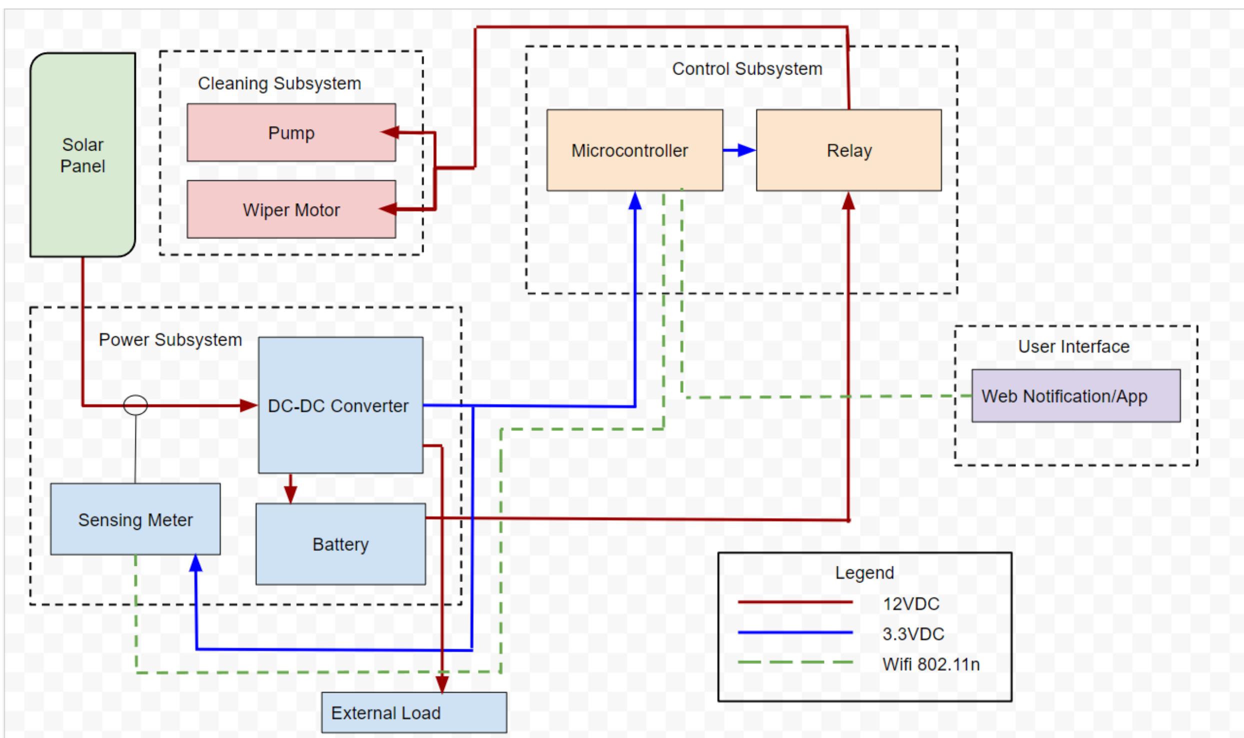
i. The system will be able to clean the solar panel from all debris and coverings.

ii. The cleaning of the solar panel with wiper and sprayer will happen when the power output reaches to 65%-75%[1] of the max output for a period of at least 7 days. The cleaning will return the solar panel back to 90+% power output.

iii. The system will be self-sustaining as it will use less power to clean than it will gain from cleaning.

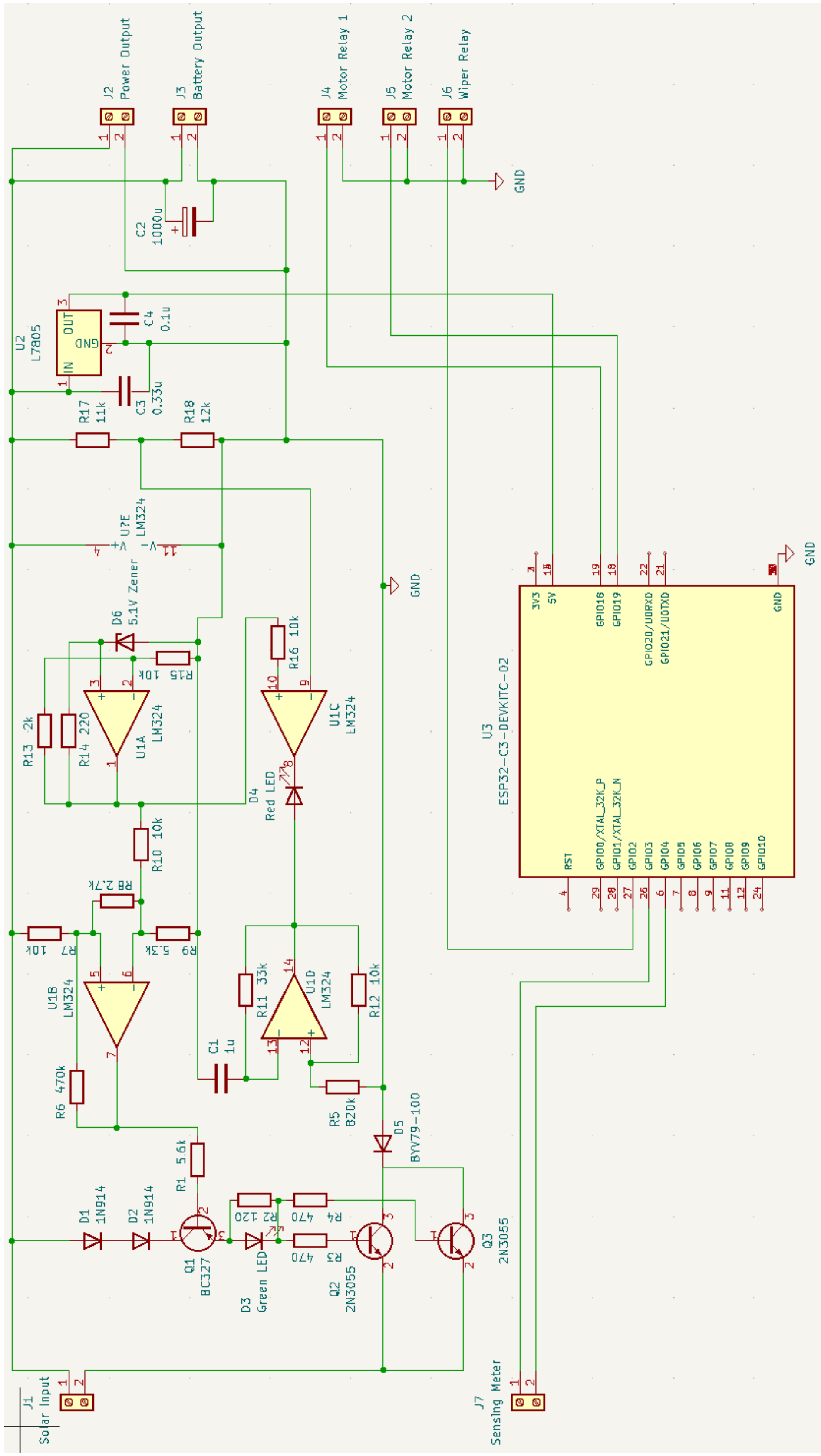
2. Design

a. Block Diagram



The power subsystem will take power from the solar panel (with V_{oc} = 21.6VDC and optimal operating voltage V_{mp} = 18VDC) and have it go through a LM324 op amp-based buck converter which steps the voltage down to 12V to be used to charge the source battery. This battery will also be utilized to power the pump and wiper motors once full charge has been reached. The 12V will be stepped down through a second buck converter within a regulator to have the voltage step down to 3.3V that will be used to power the current sensor of the power subsystem. It also will power the microcontroller which is used to control a relay that controls the pump and motor of the cleaning subsystem powered by the source battery. It will also receive data from the current sensor and keep track over a period of days to determine if time and power loss threshold is met. The data will then be available on a web-based interface. The pump and motor will wait for the relay to allow for a voltage input and have them run for a period of time for cleaning.

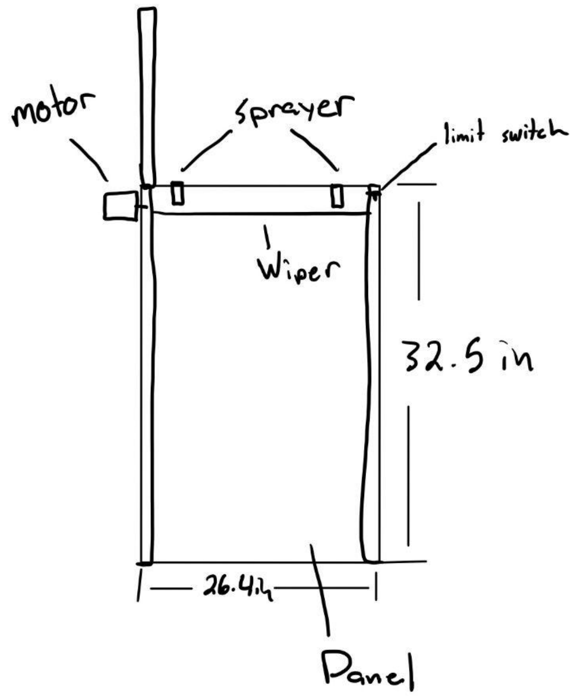
b. Physical Design



The above schematic shows the circuit with terminal connections to the peripherals necessary for this project. J1 connects the solar panel output to the input of the battery charging circuit, output power, and supply for the microcontroller. J7 is a connection for the sensing meter to debug software wired in case the wireless connection is either too far or is for some reason not responsive. J2 outputs the power from the solar panel/battery to the cleaning subsystem. An L7805 regulator also provides the microcontroller with supply voltage in the specified range. J3 will be the connection point for the batteries to receive charge from the stabilized solar panel voltage. A filter capacitor (C2) will be added across the terminals to further minimize the ripple from the charging circuit. J4, J5, and J6 are terminals to which the relay modules will be connected for controlling the sprayer and wiper from the microcontroller. J5 is an extra connection in case the intended return mechanism is not sufficient in returning the wiper to its initial state.

A few other points of interest are the green and red indicator LEDs which will indicate the charging status of the batteries with the green one showing charging is occurring and the red that the solar panel voltage is too low and the connected battery is still needing charge. The red LED blinks at 2Hz from the oscillator created with the U1D op amp. Capacitors C3 and C4 are filter capacitors to ensure the microcontroller supply regulator output is highly stable.

As for the connections to the relay modules, the outputs from J4 and J6 connect to the low side of a relay for both the wiper and sprayer. The voltage from J2 will be connected to the NO contacts of the sprayer (it will only run when the microcontroller gives a command) and to both the NC and NO contacts for the wiper motor in reverse polarity. To return the wiper to a resting state, we intend to have the microcontroller run the wiper for a set period of time before switching off. This will then cause the motor to run in reverse to a limit switch which will break the circuit and leave the wiper ready for the next cleaning cycle.



We will have our sprayers placed at two locations 4.5inches away from the middle of the panel to get as best of coverage as we can with the cleaning solution. The motor will be placed on the side of the panel held in place to run a worm gear which will run the wiper up and down the panel to have the wiper that is 24 inches clean the panel. A limit switch will be placed by one side of the wiper so when the wiper reaches the top the motor will stop running and wait for an input from the microcontroller to start running again.

c. Cleaning Subsystem

Receives power input from the charged battery of the power subsystem which is controlled by the microcontroller relay. This is to trigger the liquid pump to spray cleaning solution on the solar panel if predetermined conditions are met. Motor will then be triggered and move the wiper down the solar panel to clean the dirt off to return the solar panel back to top efficiency.

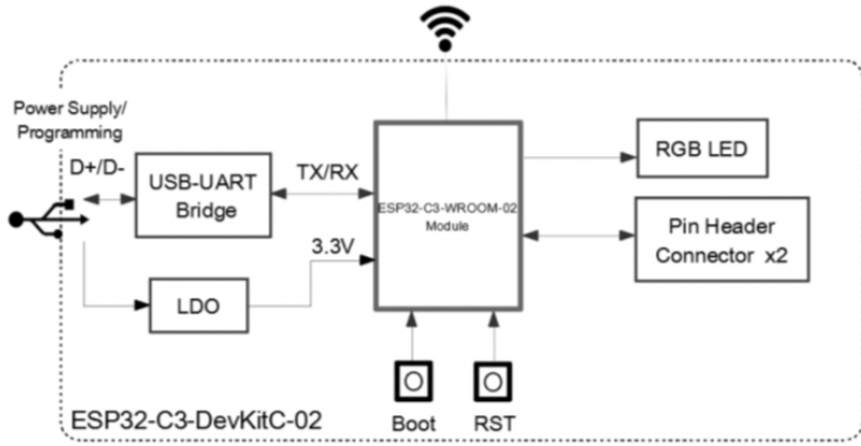
Requirements	Verification
1. Apply 12VDC and 1A through the relay that is connected to the pump and motor and be sure there is 0V and 0A reaching 2. Have 12VDC and 250mA run to the pump and motor for a 30sec to clean the system and make sure nothing goes wrong	1A. Measure with an Oscilloscope that no voltage and current is reaching the pump and motor when cleaning is not needed 2A. Measure that when 12VDC is supposed to be reaching the pump and motor it is and within a +/- 5% using an Oscilloscope. 2B. Read motor specs and determine how long it will need to run to reach the entire length of the solar panel 32.5 inches +/- 3 inches

d. Power Subsystem

DC-DC converter to extract steady power from the solar panel. Current meter and associated electronics to gather data for microcontroller to track power output. Charging circuitry for long-term storage batteries will also be included. The power of the source battery will be used to power the pump and motor of the cleaning system controlled by a set threshold from the microcontroller and relay input. The DC-DC converter will stabilize a 3.3V output which will be used to power the current sensor and microcontroller.

Requirements	Verification
1. Determine that the current meter is properly reading 5A of current and sending the correct data with +/- 1% accuracy	1A. Send 12V and 5A through the sensor with a power source in lab to test the ability and accuracy of the current reading of the current sensor +/- 1% accuracy 1B. When the current sensor is correct and the ability is there send the data to the microcontroller and determine if the output remains the same through data transmission

2. Output of DC-DC Converter is able to supply 12VDC at rated current for cleaning subsystem	2A. Apply steady voltage (18VDC) to input of converter and measure output voltage. 2B. Introduce known load to reach desired rated current (~2A) 2C. Activate all cleaning subsystem components manually and observe supply components with oscilloscope and multimeters to ensure minimal drop
3. Output of DC-DC converter supplies 5VDC at rated current for microcontroller and relay trigger contacts.	3A. Apply 12VDC to the specified regulator and measure output voltage. 3B. Provide load at minimum of 0.5A to ensure microcontroller will be able to operate 3C: Increase load to max of both relay contacts to ensure the system will not push the regulator into shut-down.
4. Battery charging is stopped when rated voltage is reached	4A. Place a properly charged 12V battery to output terminals which should not activate the charging circuit. 4B. Place a discharged battery at terminals to activate the charging circuit which will draw a maximum of 3A +/- 1%. 4C. Circuit will turn off green LED and turn on Red LED to signify batteries are fully charged.



This is the developed chip that we will be using to have with our current sensor that will transmit the current readings to our microcontroller. The reason that we did this was that this has built in wifi and bluetooth that will guarantee us easy communication between our microcontroller and our current sensor.

e. Control Subsystem

Microcontroller and associated interconnections to provide wireless data to the communication subsystem, obtain power output data from the sensing subsystem, and signals to activate the cleaning mechanism through relays. This is powered from the DC-DC converter 3.3V output, which then will allow us to control a relay that will stop power from reaching the cleaning subsystem until requirements are met.

Requirements	Verification
1. Receives the current readings from current sensor system on the solar panel cables 2. Controls relay and doesn't allow power through when power is not	1A. When we have both the sensor and microcontroller have the sensor read a known current from a known power source at 6A. 2A. Measure current and voltage, with an oscilloscope, across a

needed in pump and motor 3. Controls relay and allows power to pump and motor when cleaning is wanted 4. Wirelessly transmit message to App or E-mail	resistive load from the output of the relay to be 12V +/- 5% 3A. Measure current and voltage, using an Oscilloscope, across resistive load from the output of the relay to be 0.25A amps and 12V for the motor. 4A. Check if message is received by App or E-mail notification within a period of 3 minutes from when the data was processed on microcontroller

f. Tolerance Analysis

i. A point of potential risk in the project is differentiating between cloud cover and dirt build up as cloudy days may appear as a dirtied panel to the program triggering a false cleaning which would waste stored energy and resources.

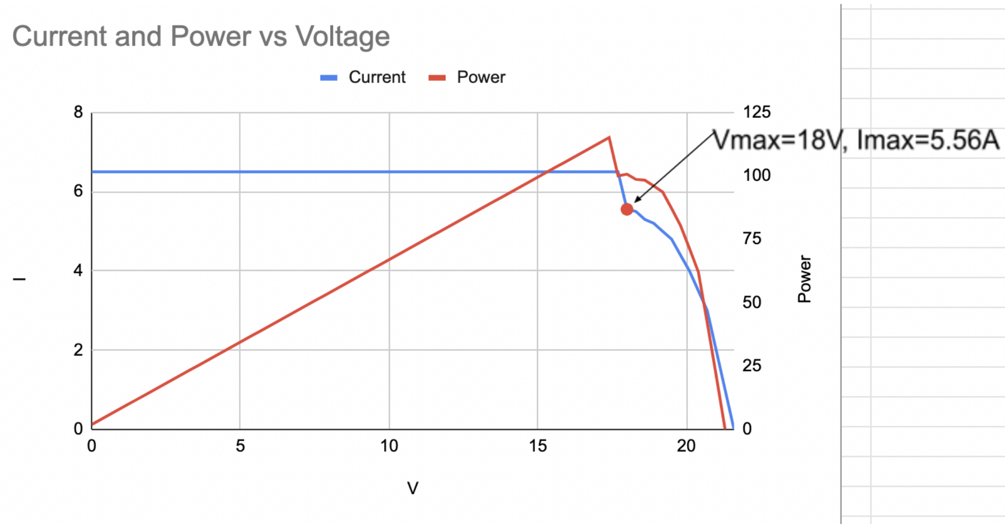
ii. While our system strives to be self-sufficient in power via batteries, we may find that excess energy could be sent to a larger bank or load to prevent damage to the DC-DC converter operating at no load.

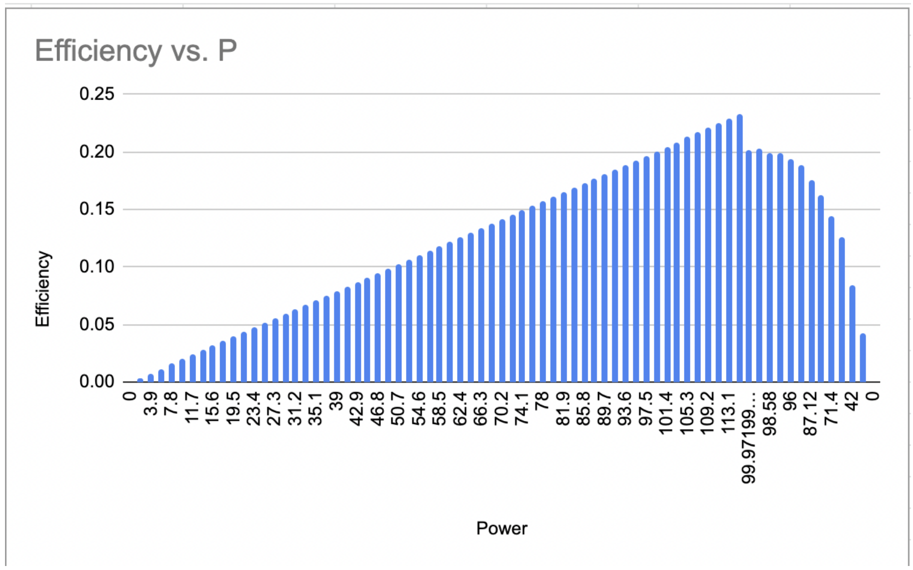
iii. Calculation for percentage loss of solar panel:

To determine the Current vs Voltage part of the graph I use the solar equation

$$J = Jsc - Jo\,(e^{qV/kT} - 1)[4].$$

Which is the equation that allows us to see where the max power is reached with the perfect current and voltage to attain it. This will also be where the highest efficiency of the solar panel is allowing us to use it to the best of its ability.





As the power drops by 25% you can see that, since it is a 100W rated solar panel, the power output drops by 25W. With this solar panel you can also see that the efficiency drops to around 7% and with devices where efficiency is very important you begin to lose out on a lot of what the panel has to offer. This was calculated with the test conditions provided by the panel of 1000W/m^2 of incident power and multiplying this by the area of the panel to get P_s=495W of incident power and then using the equation

$$\eta = JmVm/Ps \text{ [4].}$$

iv. As we saw from the previous tolerance analysis of the solar panel with a decrease in 25% power output you will begin to lose 25W of power and if held over a long period of time you will begin losing

25W * hours

that the power loss remains. To be sure that the device meets up to standards we will need to be sure the watt-hours used by the pump and motor to clean the device is less than

watt-hours gained from cleaning > watt-hours used for cleaning

3. **Cost Analysis and Schedule**
    a. Cost of Labor
        i. The average salary (in the 2019-2019 academic year) for an Electrical Engineer graduate from UIUC is $79,714, and the average salary for a Computer Engineer graduate is $96,992. We will use the average of those two values in our calculations which is $88,353.
        ii. $88,353 / (50 weeks*40 hours per week) = $44.18 per hour
        iii. Overhead inclusion: $44.18 per hour * 2.5 = $110.45
        iv. $110.45 * 15 hours per week * 11 weeks = $18,224.25 per Student
        v. $18,224.25 * 3 students = $54,672.75 for student labor
        vi. Machine Shop Estimated Labor = *15 hours * $59*
        vii. Total Cost = Student Labor + Machine Shop Labor = *$83,336.63*

    b. Cost of Parts

Description	Part Number	Quantity	Cost
Microcontroller	ESP32	1	$4.00
Windshield Wiper	RX30224	1	$9.00
Battery	ML5-12	1	$15.99
Sprayer Module	CMXCAFG190640	1	$8.98
Current Sensor	BYT-VAM-033	1	$18.98
MCU Board (2nd Board)	ESP32-C3-DevKitC-02	1	$9.00
Relay Module	B00LW15A4W	1	$6.79

Limit Switch	ZMSH03130T10SSC	1	$3.53
Solar Panel	HSP100D-L	1	$89.14
Quad Op Amp IC	LM324DR2G	1	$0.55
12v to 5v Regulator	L7805ABV	1	$0.70
5.1V Zener Diode	BZX79C5V1-T50A	1	$0.16
Rectifier Diode	BYV79E-200,127	1	$1.25
Switching BJT	2N3055	2 (Min 5 order)	$9.85
LED BJT	BC32740BU	1	$0.38
Battery Filter Cap	25PX1000MEFCT810X16	1	$0.64
Lighting Ckt Diode	1N914MS-ND	2	$1.68
0.1μF Capacitor	FA28X8R1E104KNU06	1	$0.34
0.33μF Capacitor	FA14X8R1E334KNU06	1	$0.48
1μF Capacitor	FA18X8R1E104KNU06	1	$0.38
120Ω Resistor	CFR-12JB-52-120R	1	$0.10
220Ω Resistor	CFR-12JB-52-220R	1	$0.10
470Ω Resistor	CF14JT470R	2	$0.20
2kΩ Resistor	CFR-25JB-52-2K	1	$0.10
2.7kΩ Resistor	CFR-25JB-52-2K7	1	$0.10
5.3kΩ Resistor	CMF555K3000BHEB	1	$0.08
5.6kΩ Resistor	CF14JT5K60	1	$0.10
10kΩ Resistor	CF14JT10K0	5	$0.50
11kΩ Resistor	CFR-25JB-52-11K	1	$0.10
12kΩ Resistor	CF14JT12K0	1	$0.10
33kΩ Resistor	CF14JT33K0	1	$0.10
470kΩ Resistor	CFM14JT470K	1	$0.10

820kΩ Resistor	RNV14FAL820K	1	$0.24
Red LED	UR502DC	1	Already Own
Green LED	UR502DC	1	Already Own
Terminal Block	TB007-508-02BE	7	$5.95

c. Schedule

Week	Austin	Alex	Prudhvie
Week 7	Help with PCB design/ Go in and finalize design with machine shop	Finalize PCB design	Help with PCB and understand how to program ESP Chips
Week 8	Get PV characteristics of the solar panel	Characterize cleaning subsystem components (sprayer, wiper motors) with waveforms.	Test if current sensor is outputting correct readings to secondary board (Use arduino test kit)
Week 9 (Spring Break)	Document Check	Document check (datasheets)	Document Check
Week 10	Helping with prototyping/ Working on solar output threshold for data transmission	Prototyping for circuit design	Work on setting up web interface; Get current sensor interfacing with secondary board
Week 11	Work with known power source and check outputs of power subsystem	Prototyping for circuit design	Work on interfacing main board with secondary board
Week 12	Start connections with main microcontroller	Finalize testing of cleaning system interactions	Work on processing data and activating relay from microcontroller
Week 13	Connect solar panel with power subsystem and test	Extreme testing for operation conditions	Work on sending data and notification to web

			application

4. Discussion of Ethics and Safety

a. IEEE 802.11 - Wireless communication standards [5]

   i. As our sensing meter and microcontroller rely on wireless communication, we must follow regulations set forth by IEEE and the FCC to prevent interference with networks of equipment nearby.
   ii. Preferably, our project will use WiFi for the communication standard.

b. IEEE 1013 - Lead-acid battery selection, charging, testing, and evaluation of batteries for PV systems [6]

   i. Sealed lead-acid batteries will be used to store energy for the project and possibly for a demonstration of connections to larger storage systems. We will need to size our components in the power subsystem as well as the batteries themselves to ensure safe and efficient operation of the project.

c. IEEE 1562 - Solar array and battery sizing for stand-alone PV systems [7]

   i. This standard concerns systems where solar panels are connected to batteries in a stand-alone system much like our project. If this cleaning system were to be utilized on a solar farm which is grid connected, we would have to slightly modify some components concerning the charging and conversion sections of the power subsystem.

d. IEEE Code of Ethics Implications

   i. Our project looks “to strive to comply with ethical design and sustainable development practices” [8] and “to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems” [8].
   ii. As out project involves moving components that are able to produce significant force, we will need to ensure that there are sensors which monitor equipment status and stop movement if resistance is detected as we need “to hold paramount the safety, health, and welfare of the public” [8]
      1. This will be addressed by monitoring motor current and note that a sustained current draw for more than a second can

stop the wiper motion and send an alert to the web application.

iii. In developing technology which is new and innovative, there is an obligation that one serves to the community to ensure it is beneficial for all those involved and aims to improve current situations.

5. References

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[6] *Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems*, IEEE 1013-2019, 2019

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