ECE 445 Smart Pot Plant Design Document

Team 3

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Introduction

Growing indoor plants can help with the environment as well as provide a method to grow food quickly and sustainably. However, without the proper knowledge base and constant attention, plants can quickly die or become a burden to take care of. Our solution will use automated hydroponics. This is a water-based, environment-controlled technique [7]. Traditional, outdoor farming techniques require constant intervention for prolonged periods of time depending on the weather/soil conditions. This puts the weight of careful, hands-on plant care on the individual, whereas our system will not. Hydroponic plants can grow up to 25% faster, and our design takes advantage of this [29]. By using a controlled environment, i.e., with an automatic light, humidity, and temperature subsystem, our solution aims to remove the need for constant manual intervention and will allow for any individual to grow plants (with or without expertise). By removing the variability in the environment, it will be easier to take care of plants and keep track of everything the plant needs. However, there are new challenges posed with a hydroponics technique. These include taking care of the water reservoir temperature, root aeration, and water top off and purging. Without our system, these issues would require constant manual labor maintenance, but these processes can now be safely automated considering the controlled environmental conditions. Our solution will provide this controlled environment and automation based on different stimuli. While this is a small-scale solution meant for use at home, this is a proof of concept for expansion into general-purpose agriculture.

Solution

We want to create, what we are calling, The Smart Plant Pot. Our solution is based on the technique of hydroponics. We will be eliminating the meticulous caretaking that growing plants normally necessitates, such that little to no human intervention is needed. Our solution will monitor the temperature, humidity, light, and water levels concerning the plant and ensure that it is within the necessary range for a particular type. We will have a TFT LCD and an easy-to-use rotary encoder displaying hydroponic plant options that the user can easily peruse and pick from.

We will have a humidity control system with adjustable vents and a fan for careful air circulation to maintain the humidity levels necessary for the plant. Our device will automatically calibrate the settings based on the plant type and the humidity sensor that will be monitoring real-time data. We will also have a temperature system closely monitoring the temperature of the water along with a water-level sensor to track our Smart Plant Pot's water reservoirs, which will be filled/drained depending on when it is due for either. For the lights, we will be using grow lights, considering our solution focuses on houseplants. These grow lights and our device's adjustable shades will be tuned according to the data from the light sensor in concert with how much light a plant needs. All of the plant data will be recorded and displayed on the TFT LCD for the user. Lastly, we will also have a maintenance alert system in the case that manual intervention becomes necessary, but our sensors and our built-in automatic systems will be used to survey the plants/plant-growth at all times.

Visual Aid

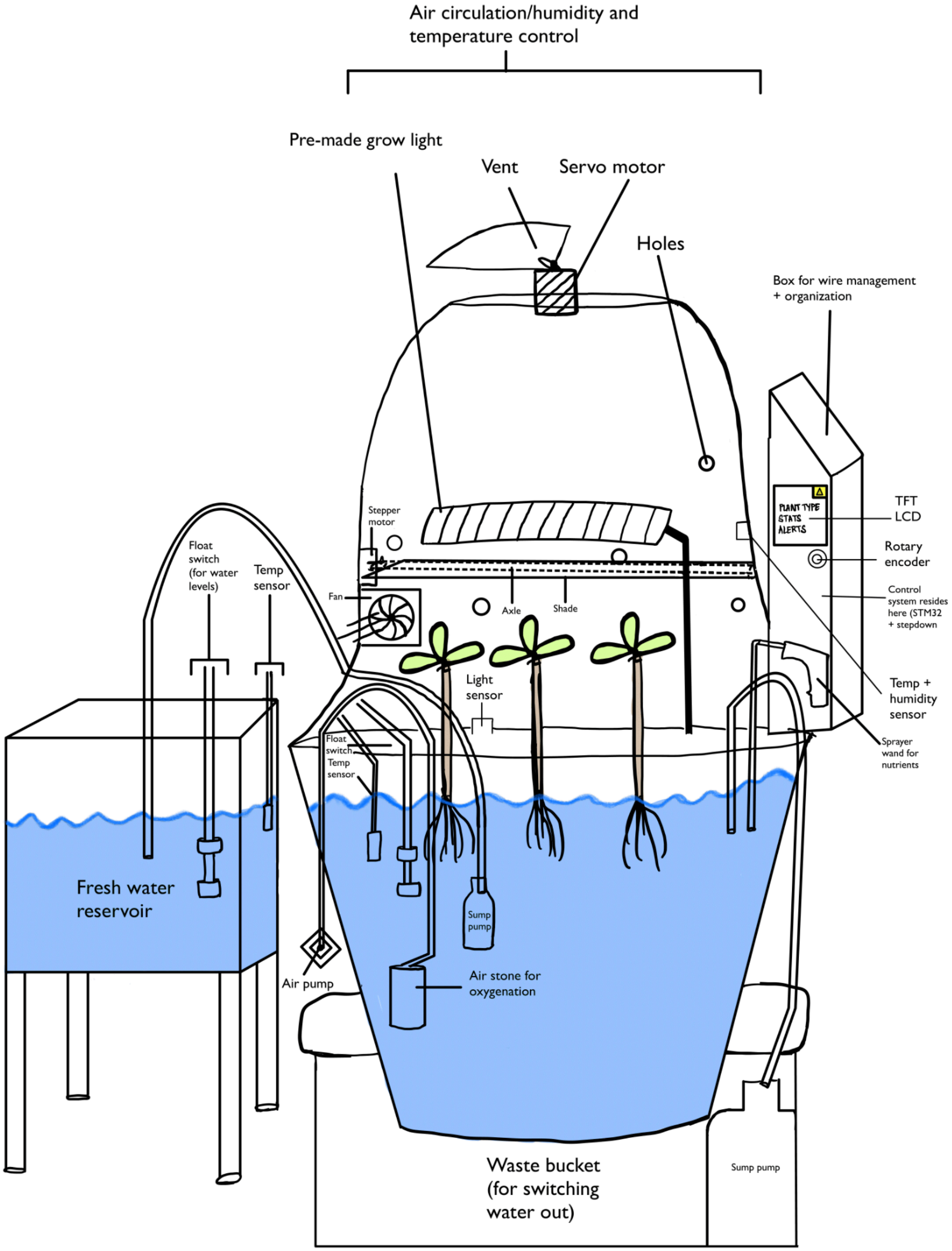
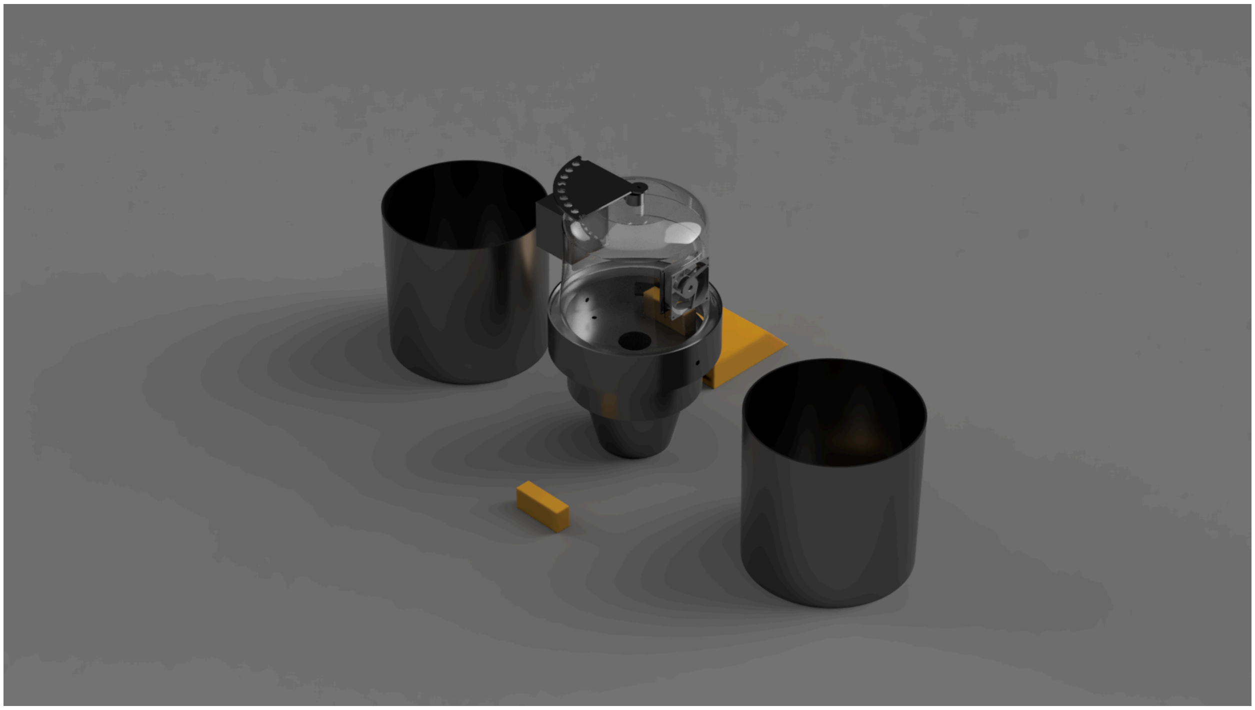
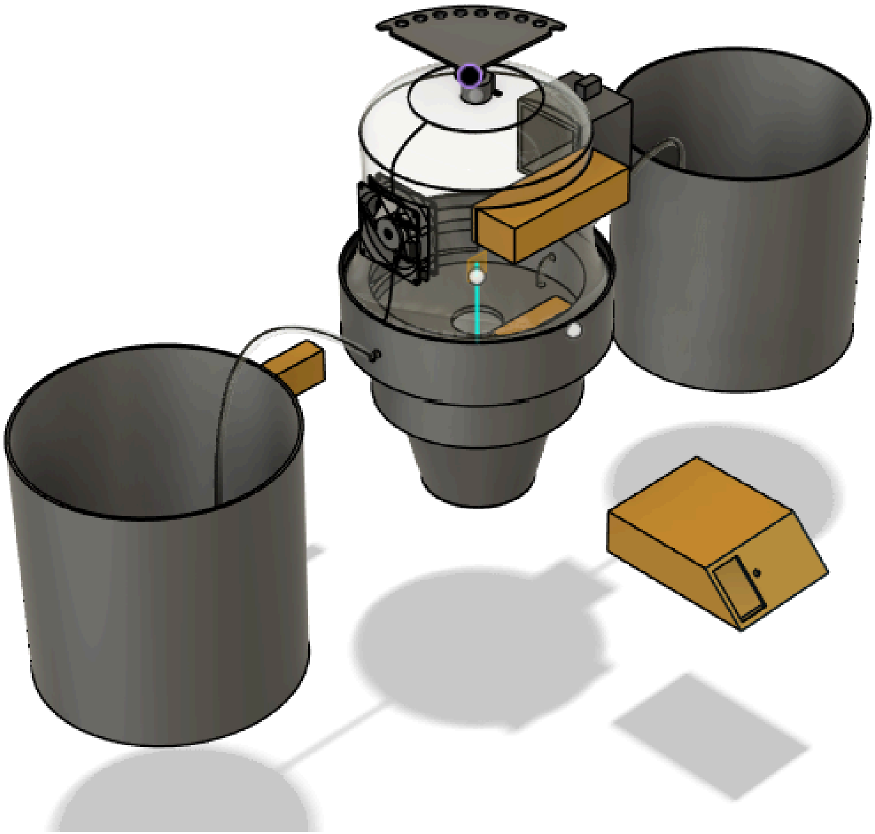
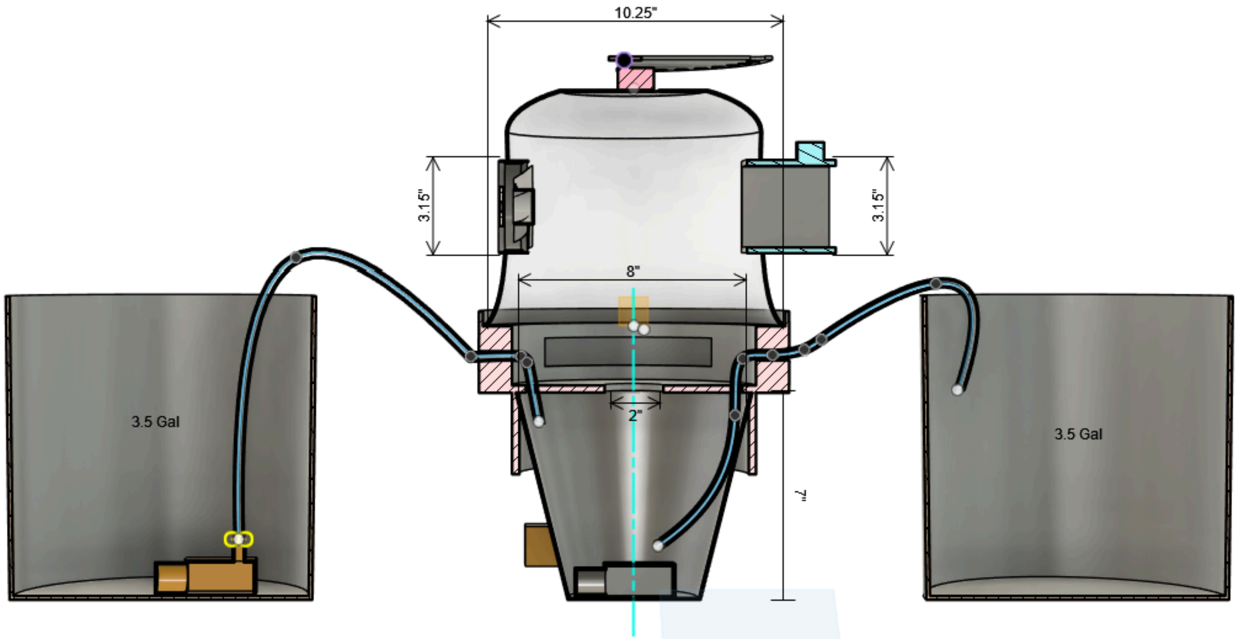


Figure 1: Pictorial representation of The Smart Plant Pot Design

CAD + Renders







Figures 2-4: CAD models and renders of the Smart Plant Pot design

The physical design comprises 3 reservoirs that hold water for different purposes. The first reservoir on the left holds clean fresh water that will be used to top off the main reservoir. The main reservoir is in the middle. Water from the reserve is sumped to the middle to do water changes and water top offs. Finally the third reservoir is the output of the sump in the main reservoir. This is where wastewater is drained into during a full water change.

Electronics for the water sensors and sprayer are placed within the lid unit as seen on Figure 3. The control unit will be housed in a box separate from these reservoirs in the trapezoid shaped box, this is where the motor control is also held. On the transparent dome of the reservoir, the orange box on the dome houses motor circuits, humidity, and light sensors. The motors will be placed around the dome. A stepper motor is placed at the top of the dome which holds the shade mount and the fan and vent are placed on the opposing sides of the dome.

High-level Requirements List

High Level Requirements	
1	The user can select from 5 different plant types to grow on the TFT LCD. Each type will have a set configuration which includes the optimal humidity level and amount of light exposure (during a 24hr period) the plant should experience.
2	All sensor measurements (humidity, water temperature, etc.) should be taken at a minimal rate of 1 measurement/second and be displayed on the LCD in real time.
3	The Smart Pot enclosure humidity level will be maintained as specified in the plant configuration with a tolerance of +/-5%.
4	Water temperature of the main reservoir must be within a range of 63-77 degrees F. If the temperature is outside of this range, corrective action will be taken.
5	The amount of nutrients injected into the main water reservoir during a refill should be the following: 1) 10ml +/- 5ml of Floragrow per gallon 2) 7.5ml +/- 2.5ml of Floramicro per gallon
6	Water will be topped off when the float sensor is tripped until the float sensor is restored to its nominal value.
7	The Smart Pot ensures that the plant receives the optimal amount of light exposure (6 hrs-16 hrs) during a 24 hour window. This is dependent on the configuration of the plant.
8	Main water reservoir water changes will be conducted every 3 weeks. Before doing so, the temperatures of the extra water reservoir and main water reservoir will need to be within the 63 degrees F - 77 degrees F range.
9	The Smart Pot actuators should respond to sensor stimuli within <1 minute.

Design Block Diagram

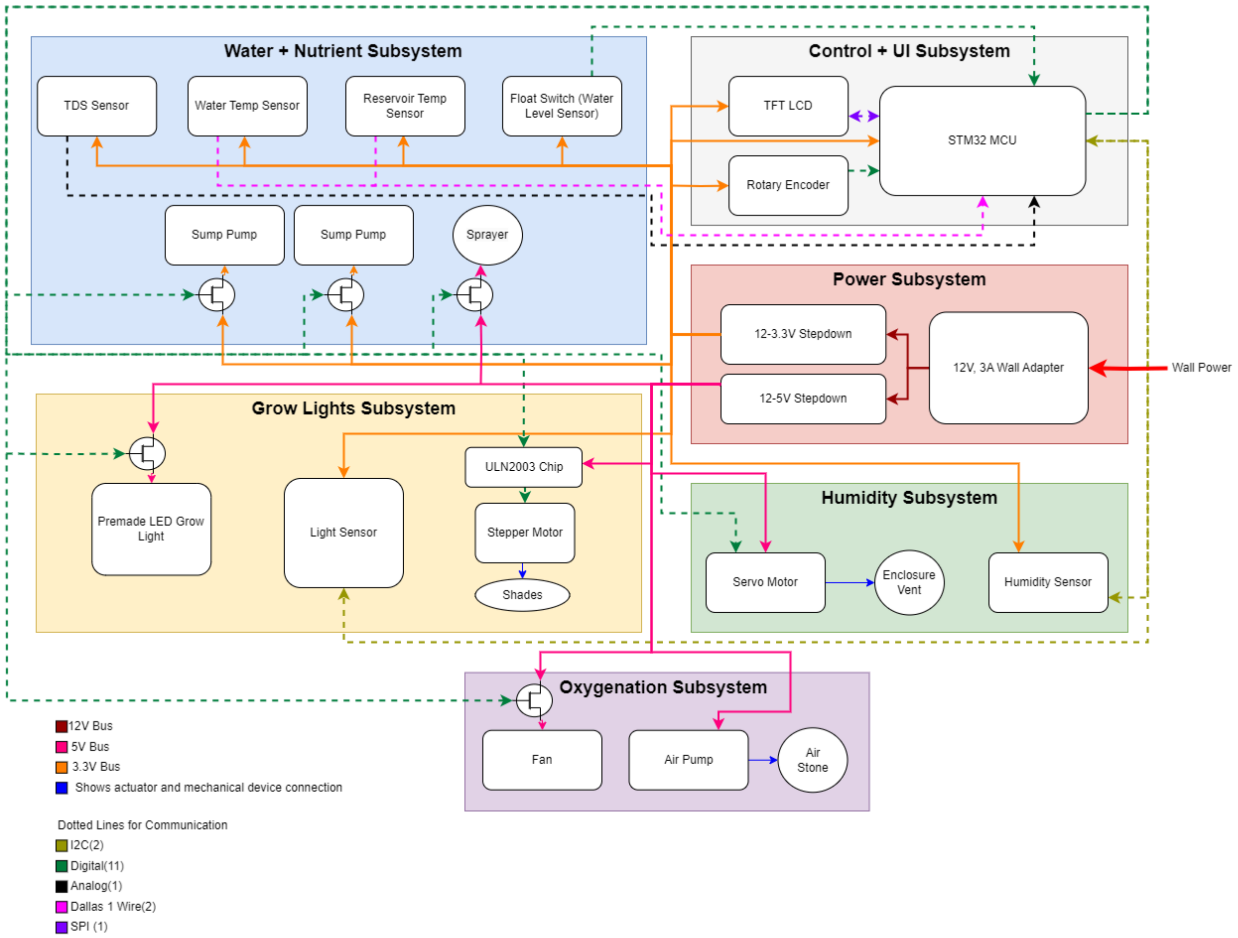


Figure 5: Smart Plant Pot Subsystem Block Diagram

The block diagram (Figure 5) details the different subsystems for The Smart Plant Pot. Our hydroponics solution/device can be split into 6 primary subsystems: power, control and UI, water and nutrients, humidity, grow lights, and oxygenation. The power subsystem will work with a 12V wall adapter. To power the parts particular to each subsystem, the appropriate voltage step-down/buck converter will be used, i.e., the 12V to 3.3V or the 12V to 5V. This will be based on each subsystem's individual supply voltage range and amperage.

The water and nutrient subsystem has a Total Dissolved Solids (TDS) sensor, providing us with the concentration of dissolved nutrients in the water. As shown in Figure 1, the nutrients will be supplied using a sprayer wand. The analog output from the TDS sensor feeds into the STM32, giving constant feedback on the current amount of dissolved solids in the water. If this number is too low (low amount of nutrients), the necessary 5V will power the sprayer wand to inject more nutrients. Along with the sprayer, there is a main water reservoir temperature sensor and extra water reservoir temperature sensor, and these simply communicate with the STM32 using the Dallas 1-wire protocol. The data from both sensors will be evaluated to ensure that they fall within a temperature range that would not cause damage to the plants. The float switch's digital output will feed into the microcontroller, ensuring that the water levels are not too low/high. If it is too low/high, the primary hydroponics tank/pot will be refilled/pumped out with the help of the sump pump controlled via digital output from the STM32. These sump pumps along with water level and water temperature sensors will be powered using the 3.3V step-down converter and turned on/off with MOSFET switches.

The grow lights subsystem has a light sensor (powered by 3.3V) to measure the amount of light received by the plant in a 24 hour period. This data is sent to the STM32 via I2C protocol. If the light received is too little, a signal from the STM32 will feed into the stepper motor driver chip (powered with 5V), which will drive the stepper motor to open the shades (and vice versa if it's above the range). To prevent damage to the plants, the pre-made grow lights (powered with 5V) will also be turned on or off if the amount of light exposure is considerably out of the range.

The humidity subsystem uses a humidity sensor (powered with 3.3V) to track the humidity levels within the Smart Pot enclosure. Using I2C communication protocol, the STM32 receives and interprets data from this sensor. This data will be used to actuate the servo motor (powered with 5V) to adjust the vents or the fan to ventilate the enclosure.

The oxygenation subsystem ensures healthy air circulation for the plant. A 5V-powered air pump is used to power the air stone, which oxygenates and agitates the water in the hydroponics pot setup to prevent bacteria/algae growth. The air pump/stone will be run continuously, while the fan will be controlled using a MOSFET switch (similar to the other subsystems).

Finally, the Control and UI subsystem has the STM32 microcontroller, which as detailed, is the heart of the Smart Pot. It interprets all sensor data and provides the digital signals to specify actuator control in each subsystem. To increase the ease-of-use of this product, a TFT LCD will be used to show all real time sensor data and maintenance alerts in the case of any necessary manual intervention. Communication between the LCD and STM32 will be done via SPI protocol. A rotary encoder will allow the user to look through a preset list of plants that can be grown in the pot and specify the type to be grown. This will output a digital signal to the microcontroller.

Subsystems Overview

Power

The power subsystem ensures that every other subsystem receives a uniform supply voltage and current to function desirably. Due to the fact that multiple PCBs are required for this design, a power solution is necessary to supply adequate amperage and voltage. A step down regulator will be used on each PCB in order to achieve this. Our current configuration for these devices is to have a 12-5V buck converter (LM2575/76) to a 5-3.3V LDO regulator. Two different regulators are used to better fit the current requirements of each subsystem. The LM2575 is rated for 1A maximum output while the LM2576 is rated for 3A. Our 3.3V line for any of the boards will never exceed 1A draw, thus it was decided to use a TLV75733 which has a max rated current of 1A. This decision is detailed more in the Tolerance Analysis section.

Depending on the current needs of each board, the correct network of LM2575s, LM2576s and TLV75733s will need to be used. These calculations and design decisions can also be found in the Tolerance Analysis section.

Requirements	**Verifications**
Wall adapter must output 12V +/-0.5V and be able to draw 6A +/- 0.5A without malfunctions	Connect the wall adapter to a 5.5A load and check if the wall adapter malfunctions or maxes out at a lower level.
Power adapter regulators must support the maximum current draw of each subsystem	Connect the regulator system to a load that would induce the maximum current draw. Energize the system and see if there are any malfunctions or voltage variances
3.3V line must output a sustained voltage of 3.3V +/-0.3V	An oscilloscope will be connected to the 3.3V line of each component and voltage will be tracked continuously to detect any significant variances. Determine if the RMS voltage is within the acceptable range.
5V line must output a sustained voltage of 5V +/-0.5V	An oscilloscope will be connected to the 5V line of each component and voltage will be tracked continuously to detect any significant variances. Determine if the RMS voltage is within the acceptable range.
Protection diodes should be used to protect all actuators and n-channel MOSFETs from spontaneous reverse voltages/voltage spikes.	The switches which control a majority of the actuators (sump pumps, motors, etc.) contain diodes which protect the n-channel MOSFET and the actuator. More information on the functionality of this switch and diode specifications/requirements can be found in the Special Note: The 5V/12V Switch section. To verify that this diode works as intended, a basic test circuit can be created where this diode can be placed in series with a 10K ohm resistor. A 5V (and then, a 12V) power supply will then be attached to the circuit, such that current flows through the diode. Observe the circuit to verify that the diode is able to handle the current coming from a 5V and 12V source. Measure the amount of amps passing through the diode with an ammeter, and

	compare this to the maximum forward current the diode can handle. Then use sight, smell and feel to identify if the diode is stable during testing. If the diode's temperature during testing is less than 110*C, and the circuit does not smell burnt, then the diode passes the verification test.

Control/UI

The Control and UI subsystem houses the microcontroller (STM32U545CET6Q), TFT LCD (358), and rotary encoder (PEC11R-4115F-S0018). The STM32 will communicate with a TFT LCD to display a UI which will allow the user to specify the type of plant they desire to grow, and to monitor the Smart Pot's current conditions (humidity level, water temperature, amount of sunlight the plant has received in a 24 hour window, etc.). It will also handle communication with all system sensors and actuators, and will use inherent logic to ensure that the Smart Pot can sustain the prespecified plant.

To start, the UI will consist of a series of pages, where page one will be dedicated to plant selection and page two will be for sensor data monitoring. Below is an example of what the UI will look like from the user's perspective. Note that there will be only one LCD; the diagram below shows an approximate layout of pages one and two.

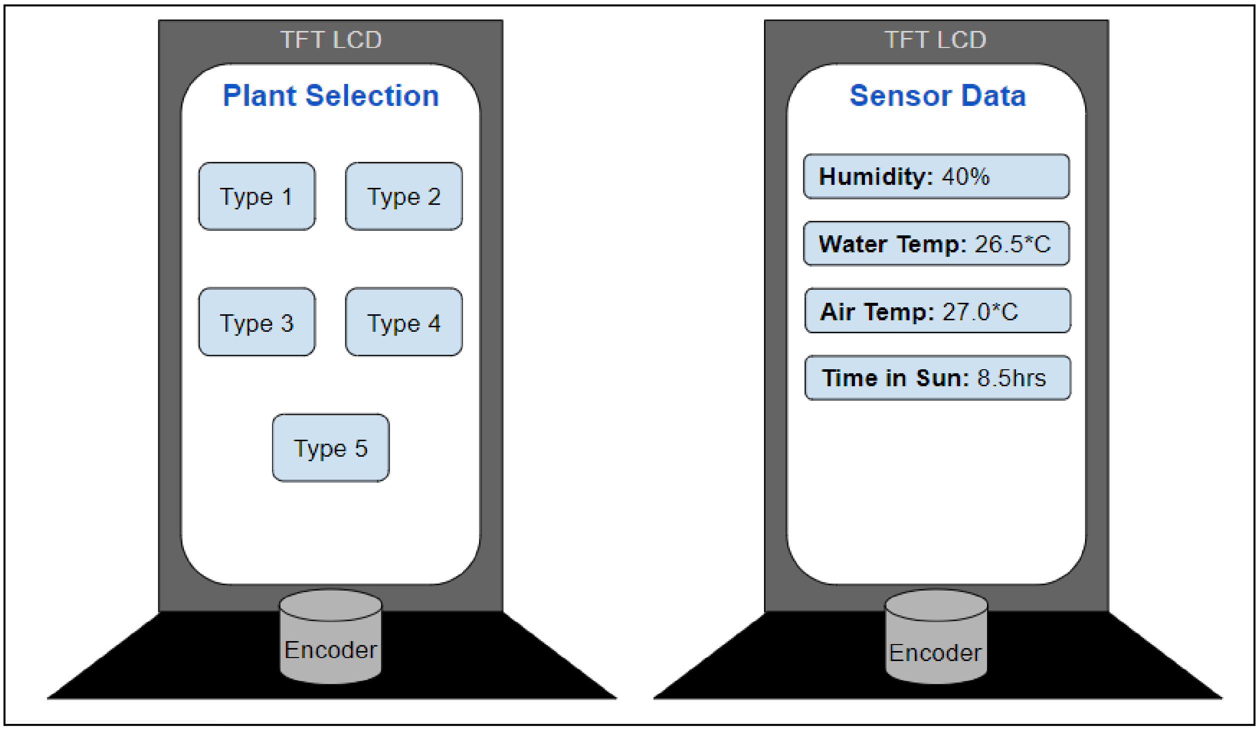


Figure 6: TFT LCD display design

On page one, there will be 5 plants that the user can choose from. All of which will have preset configurations stored in the STM32's flash memory. These configurations include the optimal humidity level, water temperature, and amount of sunlight within a 24 hour period for the specified plant. The user will be able to make this selection via a rotary encoder, and the Smart Pot will handle maintaining the desired humidity/temperature/light parameters.

To maintain homeostasis of the desired growth environment, the Smart Pot will monitor four sensors: the enclosure humidity sensor, the light sensor, the main reservoir water temperature sensor, and the main reservoir TDS sensor. The following logic will be used which takes each sensor's data as an input, while actuator manipulation is the output.

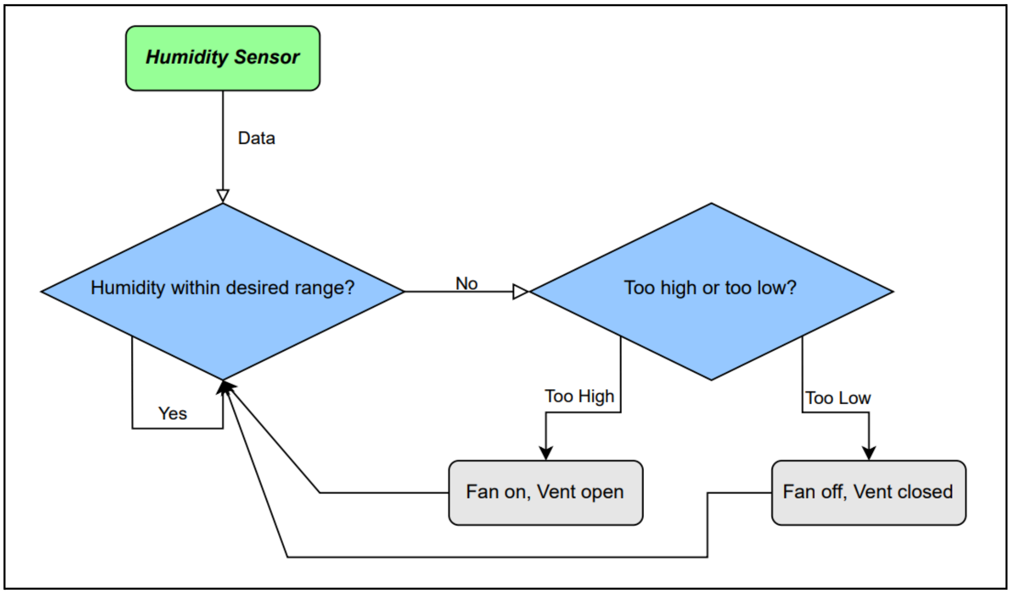


Figure 7: Control system logic for humidity subsystem

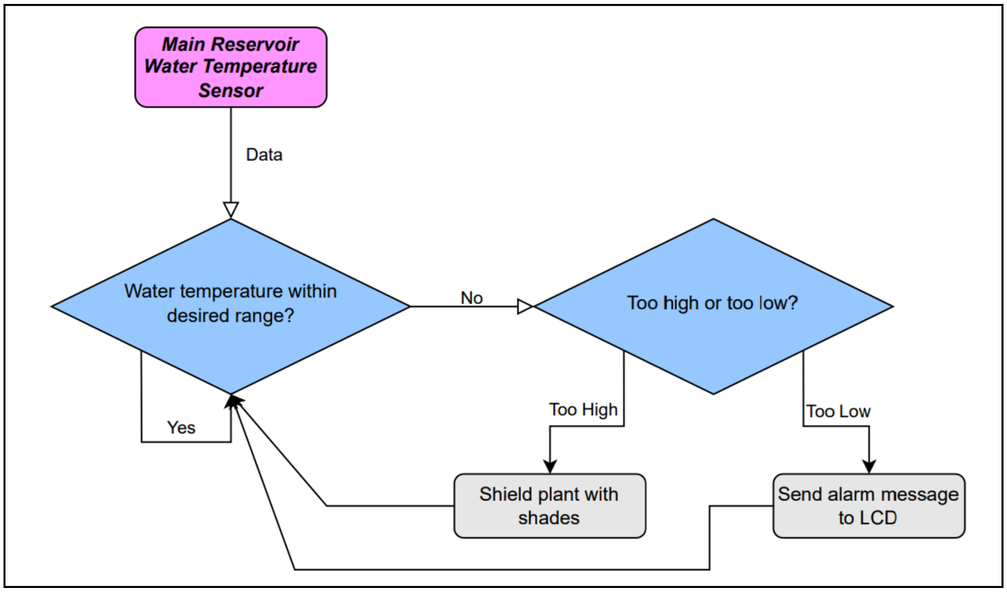


Figure 8: Control system logic for water subsystem

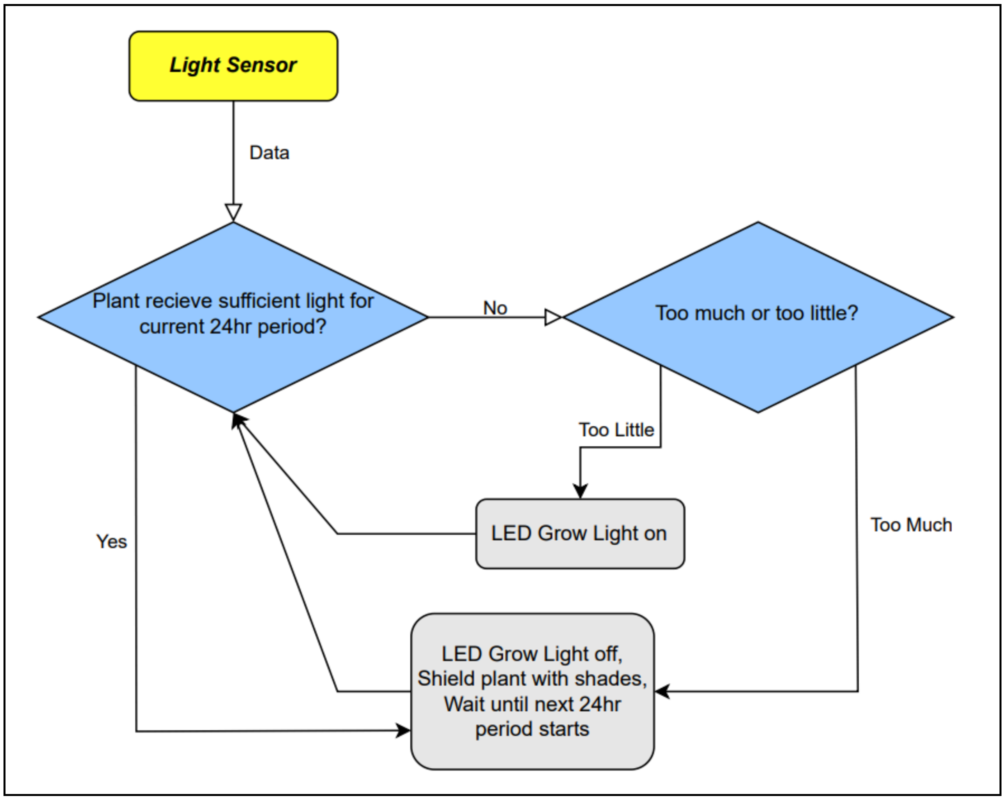


Figure 9: Control system logic for grow lights subsystem

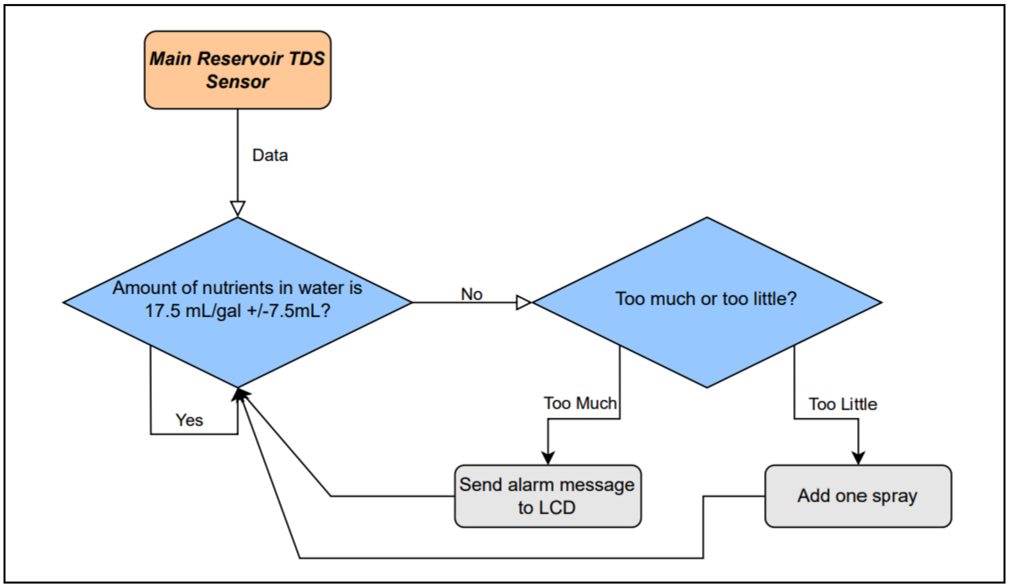


Figure 10: Control system logic for nutrient subsystem

While the logic for maintaining control of each parameter is more complicated than detailed above, the diagrams give a good representation on the feedback loops necessary for the Smart Pot to function. While the Smart Pot is on, all four sensors listed above will be continuously read. Knowing whether or not a certain parameter (humidity, temperature, etc.) is out of bounds is based on the preset configuration of the plant being grown. These parameters are initialized in memory once the user selects the plant to grow on the UI, and they specify the optimal humidity, water temperature, light exposure and TDS levels for the plant.

Hydroponically sustaining a plant is not as simple as monitoring light levels and humidity. Main reservoir water changes are also needed to sustain plant life to refresh the minerals and nutrients in the main reservoir water. Water changes will occur every three weeks, and they will also be controlled via the STM32. The amount of time since the last water change will be stored in the STM32's flash memory, and once the two week mark is hit, a water change will occur. Refer to the logic diagram below for a full picture of this process. Note that a "suitable" water temperature is specified in the plants configuration settings.

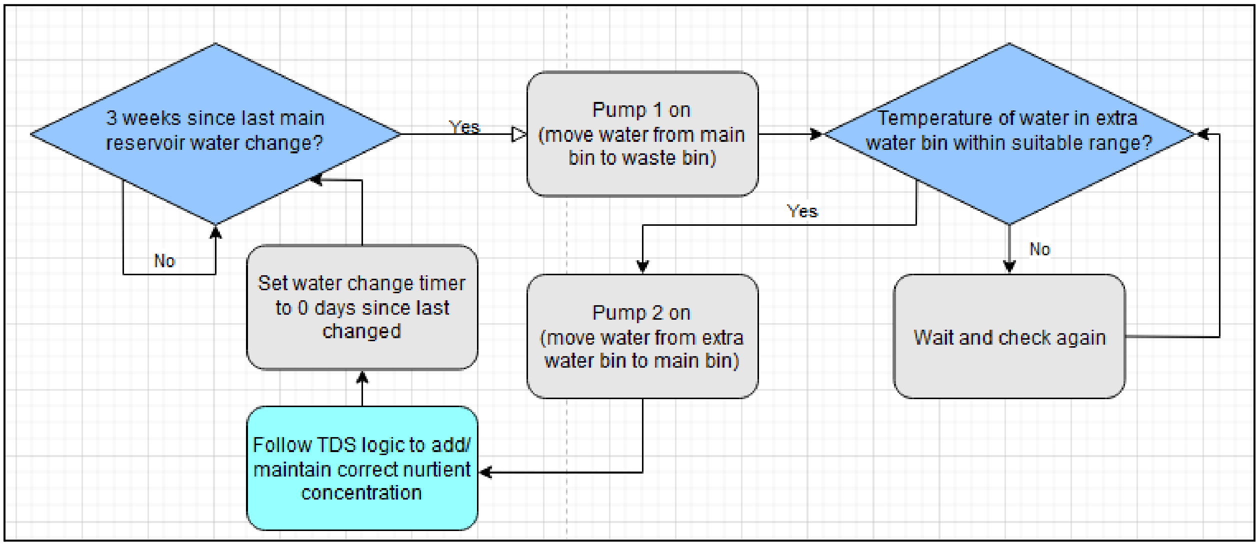


Figure 11: Control system logic for usage of sump pump [water exchange] with the TDS sensor

Overall, the logic diagrams above give a small glimpse into the control this subsystem will have; every sensor will be continuously monitored and every actuator will eventually be triggered. Sustaining a plant in the Smart Pot can only be done when all logic works together and in parallel. Although it is not explicit, every logic diagram associated with a specific sensor is intertwined. Achieving a sense of synchronization and unity in the firmware is imperative to the success of this project.

Focusing now on the hardware portion of this subsystem, the STM32U545CET6Q will need to receive input from the light, humidity, and water/nutrient subsystems' sensors. These sensors and their communication protocols are listed below.

STM32 Input Communication				
Digital	*Analog*	*I2C*	*SPI*	*Dallas 1 Wire*
Float switch (water level sensor)	TDS sensor	Humidity sensor	TFT LCD	
		Light sensor		

The STM32 will also need to be able to send output signals to all actuators and some of the sensors (to prompt the sensor to send data). The communication protocols needed to do so are listed below, and correspond to specific sensors/actuators in the Smart Pot system.

STM32 Output Communication				
Digital	*Analog*	*I2C*	*SPI*	*Dallas 1 Wire*
Sump pump 1 Switch		Humidity sensor	TFT LCD	Water temp sensor
Sump pump 2 Switch		Light sensor		Reservoir temp sensor
Sprayer				
Servo Motor				
Grow light switch				
Fan switch				

On a hardware level, the STM32U545CET6Q was specifically chosen for its ability to communicate through a plethora of protocols to both sensors/actuators and its purchasability. The model that was chosen comes with SMPS (Switched-Mode Power Supply), however this will not be utilized because power consumption of the STM32 is not of concern in this design [19].

According to its datasheet, the STM32U545CET6Q can support 4 I2Cs, 3 SPIs, 2 USARTs, 2 UARTs, and 1 USB host and device. Pins corresponding to these protocols can also be used for general IO [19].

Below is a diagram of the STM32U545CET6Q pinout. All pins labeled PA#, PB# or PC# are GPIO, while Vss, Vdd, VssA, VddA, etc. are power supply pins. In the Control/UI schematic, all

GPIO pins are directly connected to a specific sensor/actuator depending on communication protocol, while the power supply pins are either ground or powered [19].

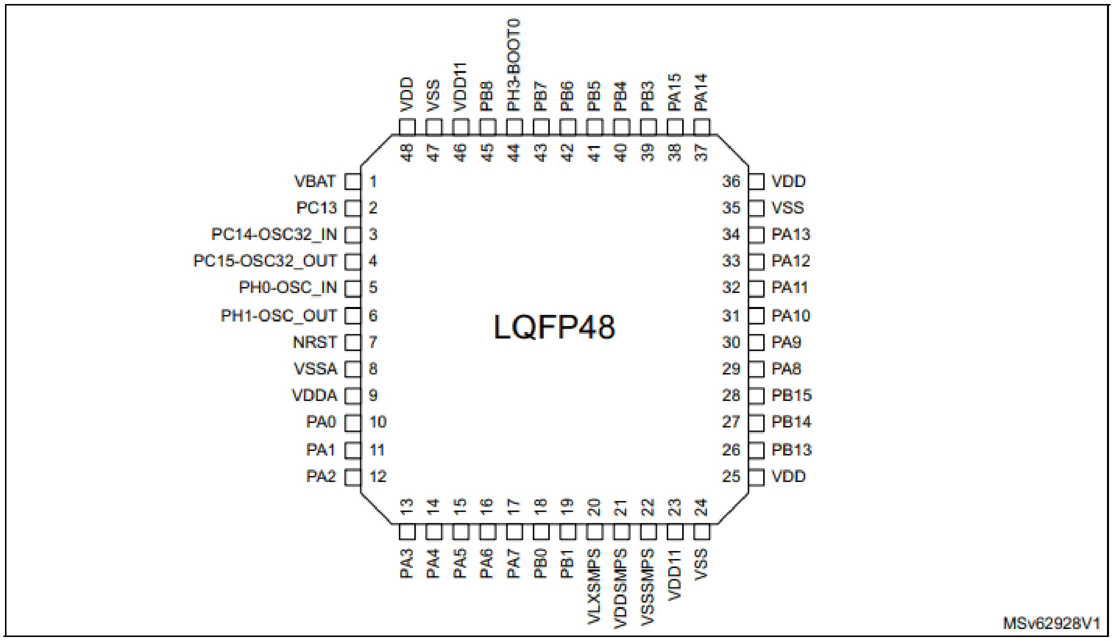


Figure 12: STM32U545CET6Q pinout

Following the STM32 pinout diagram is the Control/UI subsystem circuit schematic. Design choices for this layout are later detailed.

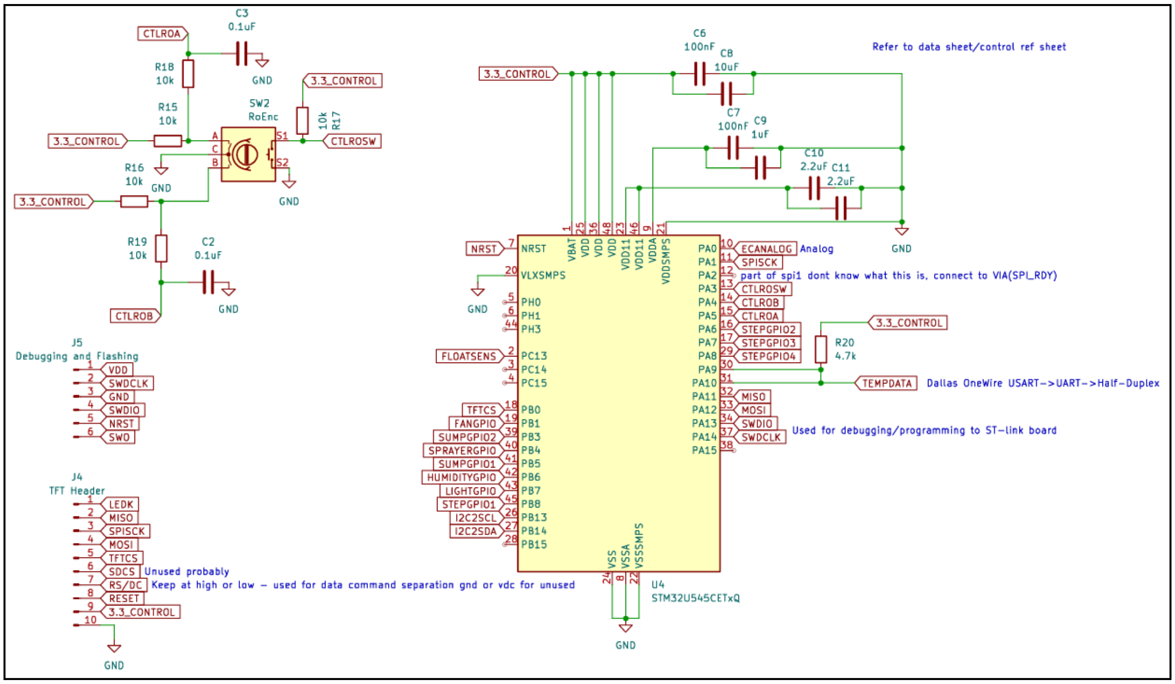


Figure 13: Control/UI subsystem circuit schematic

Since SMPS is not employed, the VlxSMPS, VddSMPS and VssSMPS pins (which correspond to SMPS internal step down converter output, power supply and ground respectively) will be tied directly to ground (Vss) as recommended by the STM32's datasheet. Both Vdd11 pins (power pins for the SMPS step down converter), will be connected to ground via 2.2uF capacitors as recommended by "Getting Started with STM32U5 MCU Hardware Development" guide. Due to the fact that the Vdd11 pins have internal ties to many circuits within the STM32, the 2.2uF capacitors serve to prevent noise transmission from ground [19].

Decoupling capacitors connect Vdd, VddA, and Vbat to the 3.3V source from the power subsystem. This is seen with Vdd being connected in series with a 100nF + 10uF capacitor and VddA to a 100nF + 1uF capacitor. The STM32U545CET6Q;s datasheet suggested these capacitances to filter any noise from the power supply that could be attributed to other parts of the circuit [19].

While the layout of the discrete components needed for the STM32 is simplistic, the UI subsystem expands upon this. The UI consists of the rotary encoder and the TFT LCD. As highlighted previously (in the STM32 Output Communication table), the LCD communicates with the STM32 via SPI [13]. Pins PA1, PA2, PA11, PA12 correspond to SPI1, however note that PA2 is unused. PA2 corresponds to the SPI1_RDY signal, which is sent when the slave (LCD) is ready to receive a message from the master (STM32) [19]. This signal is primarily used when there are multiple slaves, however for the current design this is unnecessary. As such, it was recommended that this pin remain floating by the STM32's manufacturers because it does not have an impact on any internal STM32 hardware.

The rotary encoder has three terminals (A, B, and C), and voltage pulses at the A and B terminals identify what direction the encoder is being turned, as well as how much it is turned. In our schematic, terminals A and B are connected to the STM32 via PA5 and PA4 respectively. Do note, however, that they are connected via an RC filter. Below is an image of a suggested filter circuit from the rotary encoder's manufacturer. This circuit is utilized in the Control/UI subsystems design.

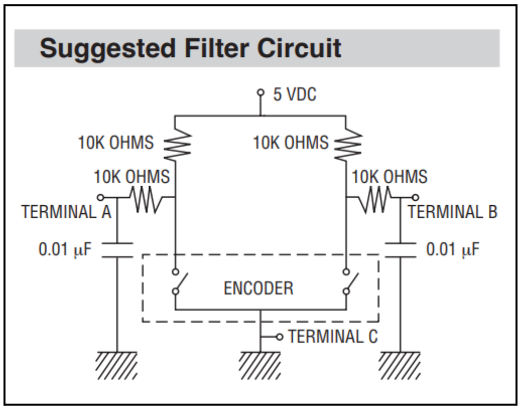


Figure 14: Suggested rotary encoder filter circuit

The most crucial part of this RC filter is its RC time constant. Observe the calculation below:

$$RC = (10,000 + 10,000)(0.01 \times 10^{-6}) = 0.0002s$$

0.0002 seconds is the amount of time it takes the capacitor to rise to 63.2% of the applied voltage. Compared to how the rotary encoder functions, this time constant is plenty large enough to filter out any random noise coming from power or ground. However, it is small enough to allow for the terminal A and B pulses to be sensed.

To verify that the Control/UI subsystem is functioning at the highest standard, a requirements and verification table is given below.

Requirements	**Verifications**
5 different plant options will be displayed on the LCD for the user to choose from. Each plant option will have preset configurations stored in memory.	This can be seen on the LCD when the user wants to specify the plant they want to grow. To ensure that the configuration settings are correct/properly stored, these can also be displayed on the LCD on page one. If a configuration is loaded, we will test the sensors to see if different sensor threshold values actuate the actuators.
Sensor measurements are taken at a rate of minimum 1 sample/sec	All sensor data will be displayed on the LCD. Every time new data comes in, this will be displayed on page two of the LCD. The second page can be continuously monitored and timed to verify that the data there is updated at a minimum of once per second.
Humidity level is maintained as specified by the current plant configuration with a tolerance of +/-5%.	A humidity sensor will be located inside of the Smart Pot enclosure. To test that a constant desired humidity is maintained, we can test two conditions: if the humidity is too high, and if it is too low. To make the humidity high, we can use a humidifier. After some time, the humidity sensor should pick up on the high humidity. In reaction to this, the Smart Pot enclosure vent should open and the fan should turn on. These should not be closed/turned off until the humidity is back within normal range. To lower the humidity for testing, a dehumidifier can be used. When the humidity falls below the desired threshold, then the vent should be

	closed and the fan be off. This will allow for any water that evaporates out of the main reservoir to remain in the Smart Pot enclosure air. 5 hours after these are actuated, the humidity inside the enclosure should be within the desired range.
Warning appears on TFT LCD when main water reservoir temperature is outside of acceptable bounds given by the current plant configuration (63 degrees F-77 degrees F)	To verify this, the Smart Pot can be manually filled with very cold water (the temperature below 63 degrees F). After 5 minutes, the main reservoir temperature sensor should detect the cold water, and a warning will be displayed on the LCD. This warning will go away once the water temperature falls back into the desired range. Warm/hot water will also be tested, and this will be done in the same format as with the cold water.
If the water level in the main reservoir is low, it will be “topped off” until it reaches a suitable depth.	To test this, the water in the main reservoir can be filled to varying heights (specifically heights that are lower than the desired water depth). Once this triggers the float switch, we can see if the sump pump connecting the extra water reservoir to the main reservoir is activated. If so, we can see if it fills the main reservoir up to the desired height based on float switch feedback.

Nutrient/Water

The water and nutrient subsystem allows for water monitoring and maintenance to be automated, and provides a number of functionalities to promote healthy plant growth. To start is the topping off/water change system. Electronically, the nutrient and water subsystem contains a EC/TDS sensor, 2 temperature sensors, a sprayer, and 2 sump pumps. Below is an image of the PCB schematic for this subsystem. A more in depth description of this is given beneath.

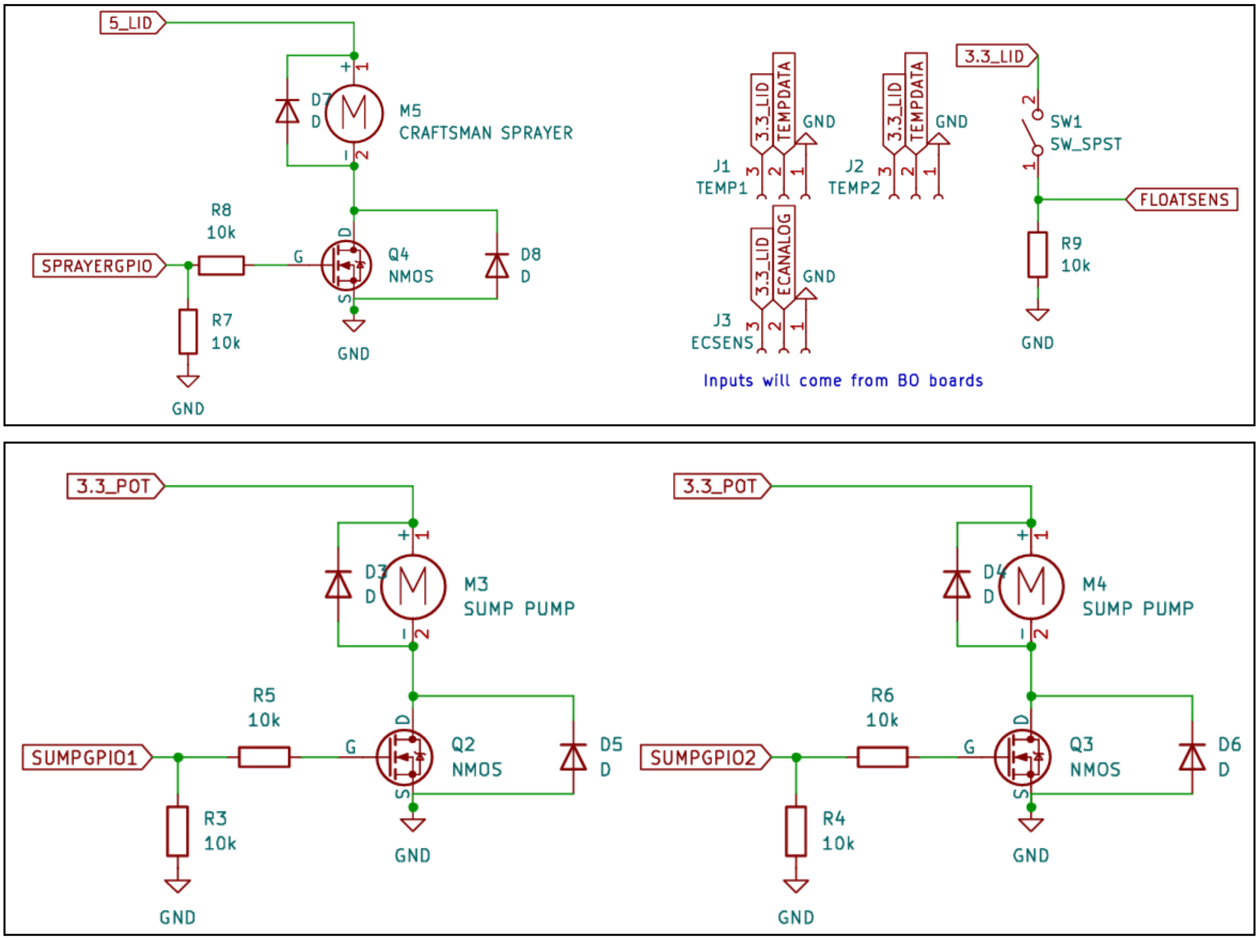


Figure 15-16: Water/Nutrient subsystem circuit schematic

Room temperature water will be used to initially fill the main reservoir. A nutrient solution (Floragrow and Floramicro) will then be injected according to the following quantities. Note that these quantities were derived via research [11].

10ml +/- 5ml of Floragrow per gallon
7.5ml +/- 2.5ml of Floramicro per gallon

A reserve reservoir will be kept alongside the main reservoir that the plant sits atop of. On start up, a TDS (total dissolved solids) reading will be taken by the SEN0244. This will be communicated to the STM32 via an analog signal. This initially saved value will be used as a guideline for the amount of total dissolved solids which should be in the Smart Pot's main reservoir at any given time. If the nutrients are below this threshold, more nutrients will be injected. This logic will be controlled by the STM32 in the control subsystem. Refer to the control/UI subsystem documentation for the logic diagram of this operation.

Not only will nutrients be monitored and maintained, but this subsystem will also maintain the Smart Pot's water level and water changes. To do so, temperature readings from both reservoirs will be continuously taken with two DFR0198s and will be used to determine the temperature differential. If the temperatures are within the range of 63-75 degrees F and a water top-off is necessary (for the main reservoir), water from the extra reservoir will be added to the main reservoir. Note that water changes for the main reservoir will be conducted every 3 weeks, and an internal timer in the STM32 will be used to track the amount of time since the last water change.

To perform a water change, the previous temperature condition will be checked. Then, a sump pump (4547) will be used to direct water from the main water reservoir into the waste reservoir. Once this is done, a sump pump will direct water from the extra reservoir to the main reservoir. A motor driven spray bottle head will then spray nutrients in the main reservoir, abiding by the quantities listed previously.

The water and nutrient subsystem will be directly connected to the power subsystem and control/UI subsystem. Exact descriptions of these interactions are detailed in the power subsystem and control/UI subsystem documentation.

A final note for this subsystem regards its hardware layout. As seen in Figures 15 and 16, a switch is used to actuate the two sump pumps and sprayer. Design documentation, simulations and specifications for this subsystem can be found in the Special Note: The 5V/12V Switch section. This section is further into the report.

Requirements	**Verifications**
The amount of nutrients added using the sprayer during the fully automated water change will follow these proportions: - 10ml +/- 5ml of Floragrow per gallon - 7.5ml +/- 2.5ml of Floramicro per gallon	Sprayer will be tested with different STM32 timings into a graduated cylinder to test the amount of nutrients being sprayed out. Hooked up the whole system, the water change cycle will be manually ran to demonstrate drain - fill - spray
During a water change, the sump pump should drain water out of the pot to less than 10% of the normal volume. Water from the reserve reservoir should then be filled back to the normal volume using another sump pump	The sump pump can be audibly heard while running. We can manually run the refill cycle to hear the different actuators running in order. We can also manually manipulate our temperature probes to read higher than expected temperatures to check if the reservoirs will fill or not. Finally we can do a wet run where we will observe whether the

if the reservoir temperature is within 63-77 degrees.	sump pump stops on float switch contact.
Sump Pumps and Sprayer will run when a high signal is sent from GPIO	We can create a program that can test each GPIO pin to run the power mosfet switch that these components will be attached to. We can either hook these devices directly in to listen for actuation. Or we can use an oscilloscope to test when the MOSFET switch closes or opens

Lights

The grow lights subsystem plays multiple roles in plant care. Not only do grow lights help expose the plant to necessary light to promote photosynthesis, but they also produce heat (which is good for many plants). This subsystem is straightforward in that our device will use pre-made grow lights. In the circuit schematic (Figure 18), this is represented by the LED array. Note that this is connected to an n-type MOSFET, which functions as a switch to turn it on/off based on the STM32's digital output signal labeled and connected to the subsystem as LIGHTGPIO (refer to Figure 13 to see associated connection on STM32). For more information about how the MOSFET switch operates, refer to the Special Note: 5V/12V Switch section.

The type of plant being grown will determine how much light is necessary. A light sensor (LTR-329) will be used to track the amount of light the plant has received in a 24 hour period, and this will be stored in the STM32's flash memory. The sensor data will be communicated using I2C protocol. The appropriate connection labels can be seen in Figure 13 and Figure 18. The SCL pin is an I2C serial clock input and the SDA is an I2C serial data input/output pin. According to the datasheet, there's a read bit that has to be set in order to access the data. Once the data has been read, the status bit is set to 0 to prevent a repeated read of the same data [25]. Let's take a look at an example: spinach requires 12 hours of light per day along with a temperature of 60-70 degrees Fahrenheit [5]. Maintaining a moderate temperature within the Smart Pot while shining grow lights can be a difficult optimum to reach because they produce heat. This is where the shade and on/off switch for the LEDs come into the picture. Based on sensor output, the STM32 will provide a signal (STEPGPIOs) to the stepper motor driver ULN2003 to drive the 5V stepper motor (1286-1219-ND), which will in turn operate the shades that provide coverage for the plants as shown in Figure 19. This is done if the Smart Pot is ever too hot, but it has not reached the maximum limit. However, if the plant has received its maximum limit (i.e., if it reaches 12 hours of light in the case of Spinach) during the current 24 hour period, the lights will be turned off. Similarly, if too little light (< 12 hours) has been received, the lights will be turned on. Do note that if the temperature is too high (above 70 degrees F), the device may not turn the lights off if the desired amount of light exposure is not reached (< 12 hours). When this is the case, fans will be actuated for air circulation and the shade will be deployed to help maintain a cooler environment. The shade is a component exclusive to the grow lights subsystem, but because all of the stated environment factors go hand-in-hand, the other subsystems will work together to attain the necessary balance.

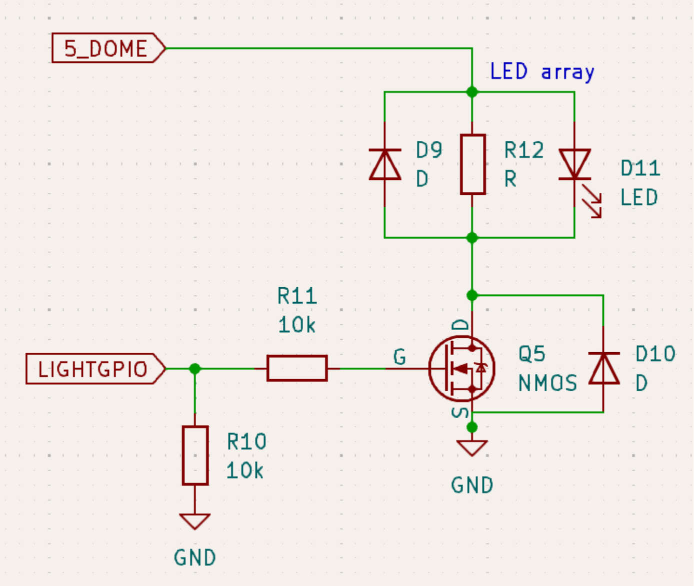


Figure 17: LED with on/off switch

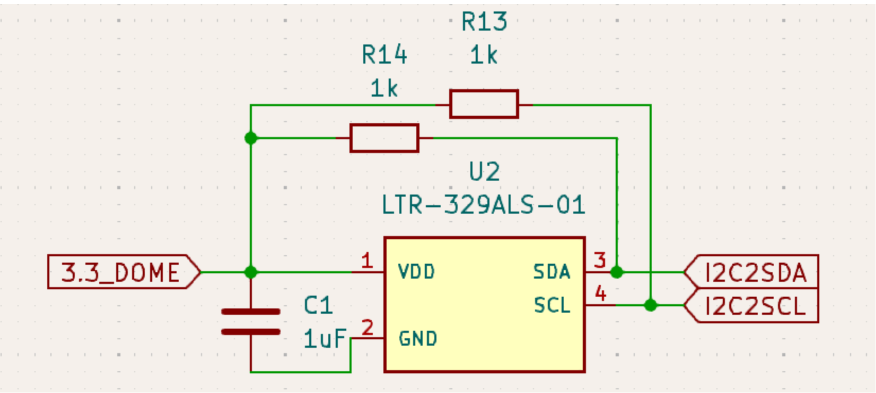


Figure 18: Light sensor in the grow lights subsystem circuit schematic

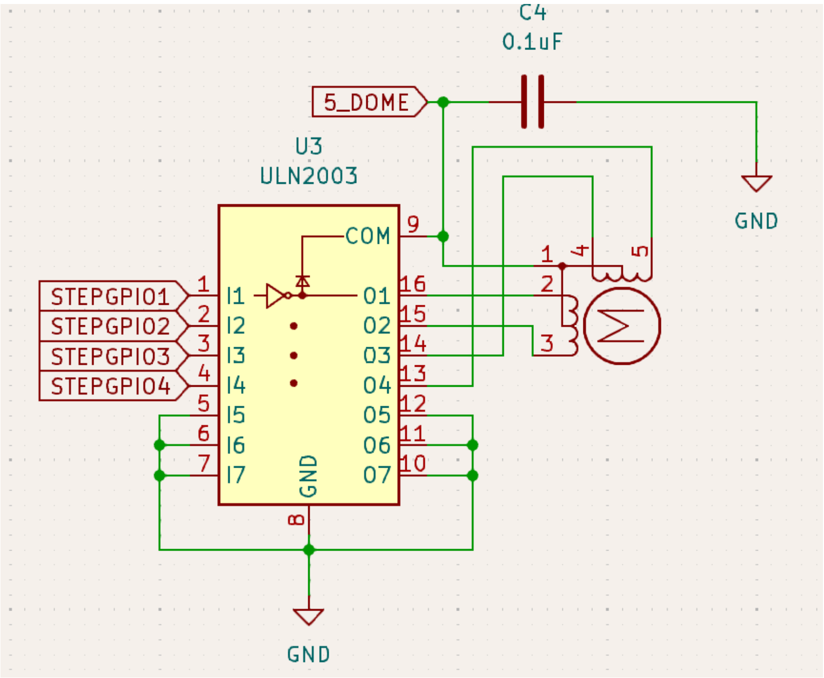


Figure 19 : Stepper motor driver powering the 5V stepper motor

To verify that the grow lights subsystem is functioning at the highest standard, a requirements and verification table is given below.

Requirements	**Verifications**
The amount of light received by a plant type should not exceed 16 hours. Ideally, it should be approximately 12 hours. The absolute minimum required per day is 6 hours of light exposure. The bounds are defined as follows: ● Maximum upper limit: 16 hours ● Ideal: 12 hours ● Lower bound: 6 hours Range of operation for actuation response: 6-16 hours; amount of light received will be measured for the entire 24 hour period.	If an absolute maximum of 16 hours is reached, the lights will be turned off and the shades/fans will be turned on. If an ideal of 12 hours is reached, decisions will be made according to the temperature readings, that is, if it exceeds ~70 degrees +/- 5 degrees F., the fan/shades will be operated and the lights will remain on. If it's below 6 hours (absolute minimum), the lights will be turned on. This will be tested based on actuation response.
Light data is output on the TFT LCD and is updated every minute.	This can be seen on the TFT LCD under the plant stats option. It should increment with every minute that passes (hour and minute will be displayed as it reads the data).
Stepper motor driver allows for operation of the stepper motor to move the shades	Similar to the nutrients/water subsystem, we can create a program that can test each

through the digital HIGH output signal from the STM32 GPIO. Similarly, the grow lights are turned on and off with the n-type MOSFET and the STM32's signal.	GPIO pin to run the power mosfet switch that these components will be attached to. We can either hook these devices directly to listen for actuation (movement of stepper motor operating the shades) or we can use an oscilloscope to test when the MOSFET switch closes or opens.

Humidity

The humidity subsystem tracks the humidity levels of the plant's environment/enclosure, thereby controlling the associated device settings to allow for better air circulation to either increase or decrease the humidity. Different plant types at different stages of their growth require certain levels of humidity. For instance, if the chosen hydroponic plant type was Spinach, it would require 40 to 70 percent humidity levels [6]. Maintaining the numbers between this range is important for the healthy growth of Spinach. This will be attained by tracking real-time data of the humidity levels with a humidity and temperature sensor (SHT35-DIS-F) as shown in Figure 22. If the levels are too high, our device will adjust the vents using the servo motor (HS-311) powered with 5V and signaled by the HUMIDITYGPIO on the STM32 (Figure 20 and Figure 13). Once the ideal humidity level is reached, the vents will maintain this level by closing. The fan from the oxygenation system will also assist in maintaining these levels. It will circulate the air out of the enclosure, getting rid of some of the moist air. Once a measurement within the range necessary for the specific hydroponic plant type is achieved, the fan will be turned off and the vents will be closed. In terms of its behavior and interaction with other subsystems, the humidity sensor will communicate with the STM32 by sending and receiving relevant humidity. This will be done using I2C.

As shown in Figure 21, the SHT35-DIS-F humidity sensor is powered with 3.3V and has a similar pin configuration to the light sensor with the serial data input/output and serial clock input/output. According to the datasheet of the humidity sensor, the I2C communication requires a clock pulse to be generated as a START condition along with the master requesting a read [26]. The SHT35-DIS-F (used for humidity and air/environment temperature sensing) will then acknowledge this and send data in the format of 2 bytes of temperature data, number of bits sent, 2 bytes of humidity data, number of bits sent. The STM32 will then have to acknowledge the bytes of data sent for the sensor to continually measure and send data. If a value within the ideal range is detected (40 to 70 percent relative humidity with a tolerance of +/- 5% and an enclosure environment/air temperature reading within 60-70 degrees F +/- 5 degrees F), everything will remain as is [10]. If this is not the case and the value is higher than the given range, the servo for the enclosure vent will be powered and the STM32 will send a signal to open the vents and fan out the air. If the value is lower than the range, it will close up any open vents and turn the fans off. The fans will use the MOSFET switches to turn on/off (Figure 22). This is identical to the n-type 5V/12V switch in the other subsystems [detailed in a later section – *Special Note: the 5V/12V Switch/Switch Operation*]

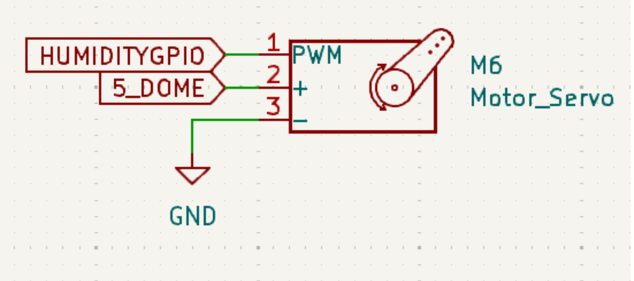


Figure 20: Servo motor for humidity subsystem

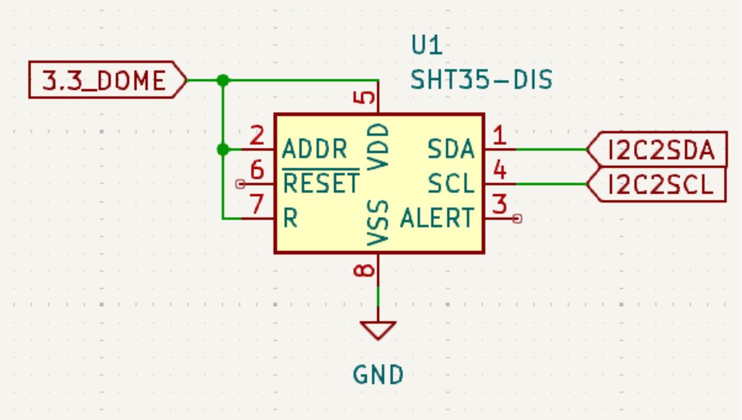


Figure 21: Humidity sensor snapshot from circuit schematic

Requirements	**Verifications**
Maintain humidity levels of 40 to 70 percent with a tolerance of +/- 5%	The listed sensor (SHT35-DIS-F) tolerance level on the datasheet for relative humidity is +/- 1.5% so expecting a measured value within the specified range and a +/-5% tolerance is reasonable. This will be measured by reading in the bytes for humidity data. We can test this by tracking the displayed output for humidity levels on the TFT LCD.
Maintain enclosure environment/air temperature levels between 60 to 70 degrees F with a tolerance of +/- 5 degrees F	The listed sensor (SHT35-DIS-F) tolerance level on the datasheet for temperature is +/- 0.18 degrees F, so expecting a measured value within the specified range and a +/-5 degrees F tolerance is reasonable. This will be measured by reading in the bytes for temperature data. We can test this by tracking the displayed output for humidity levels on the TFT LCD.
Measure and update humidity and temperature data every minute	This can be seen on the TFT LCD under the plant stats option. An acknowledge will be sent to continually read and receive data. It should display changes within every minute if applicable. This will

	be tested by manually altering humidity levels (ex: by using a mister/humidifier).
Fan turns on/off using MOSFET switch and servo motor allows the enclosure vents to move through the digital HIGH output signal from the STM32 GPIO.	Similar to the nutrients/water and light subsystem, we can create a program that can test each GPIO pin to listen for a digital HIGH signal or we can hook these devices directly to listen for actuation, in this case, the movement of the servo motor operating the enclosure vents. Similarly, for the fan, we can listen for a digital HIGH signal from the STM32 and a resulting actuation response of the fan turning on/off. We can also use an oscilloscope to test when the MOSFET switch closes or opens.

Oxygenation

The oxygenation subsystem oxygenates and agitates the hydroponic water to facilitate plant growth and impede algae and bacteria. It also ensures constant air flow within the Smart Pot enclosure, protecting the plant from rot and mold. To perform these operations, an air stone attached to an air pump will be inserted into the Smart Pot main reservoir. A fan will be incorporated onto the side of the Smart Pot enclosure (clear top of the Smart Pot), and air vents controlled via a motor will be located at the top (of the enclosure). The air stone will continuously run (powered with 5V), while the fan and air vent will be turned on/off and opened/closed on a timed basis and/or if the humidity/temperature levels fall below/above the range respectively. The control unit (STM32) will send a signal to the fan (FANGPIO) and air vent servo motor when the air in the enclosure should be refreshed. This will turn the fan on and open the enclosure vents for some time, followed by them shutting off/closing again [refer to the humidity subsystem for details on fan and enclosure vent operation]. Note that the fan and air vent are also considered a part of the humidity subsystem, and aid in lowering enclosure humidity if it ever is too high. Overall, the oxygenation subsystem is closely tied with the humidity subsystem, and is actuated on by the control subsystem.

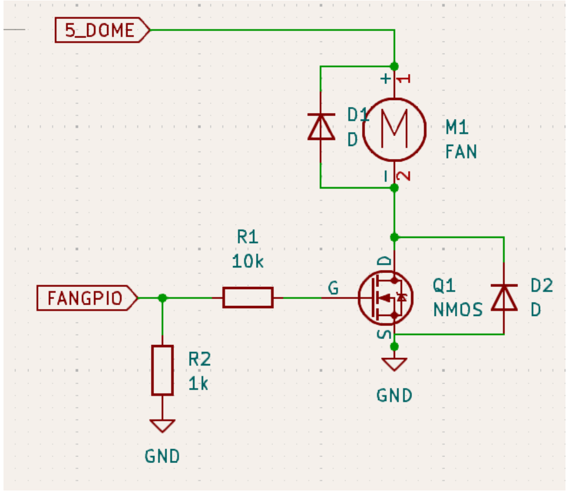


Figure 22: Schematic/wiring of the fan from oxygenation subsystem

Requirements	Verifications
Air pump controlling the air stone should continuously run while the system is powered on.	Always powered with 5V. Air pump and airstone is visibly agitating the water.
The fan should be actuated when the STM32 directs it to do so using the MOSFET on/off switch.	For the fan, we can listen for a digital HIGH signal from the STM32 and a resulting actuation response of the fan turning on/off. We can also use an oscilloscope to test when the MOSFET switch closes or opens.
The motor to control the vent position should be able to both open and close the vent in accordance to humidity conditions.	Similar to the other subsystems, we can create a program that can test each GPIO pin to listen for a digital HIGH signal or we can hook these devices directly to listen for actuation, in this case, the movement of the servo motor operating the enclosure vents.

Special Note: The 5V/12V Switch

The output pins of the STM32 are voltage controlled, and digital outputs can range from 0V to 3.3V. The STM32 GPIO pins produce a miniscule amount of current (8mA per pin), but they are tasked with enabling all actuators. A majority of the actuators in this system (sump pumps, servo motor, etc) require 5V to 12V power supplies, and the STM32 cannot provide this. As such, creating a voltage controlled switch that can be toggled by the STM32 is the best course of action. This switch will allow any actuator to be supplied 5V or 12V with sufficient current when the STM32 sends the “on” signal.

Due to the fact that this switch is used in nearly every subsystem, a full description of this switch is given here. This includes circuit schematics, simulations, and component specifications/selections.

Switch Operation

Below is a diagram of the switch which supplies 12V. Note that the 5V and 12V switches are the same (except that one supplies 12V while the other supplies 5V), and every component within the switch circuit is rated up to 12V.

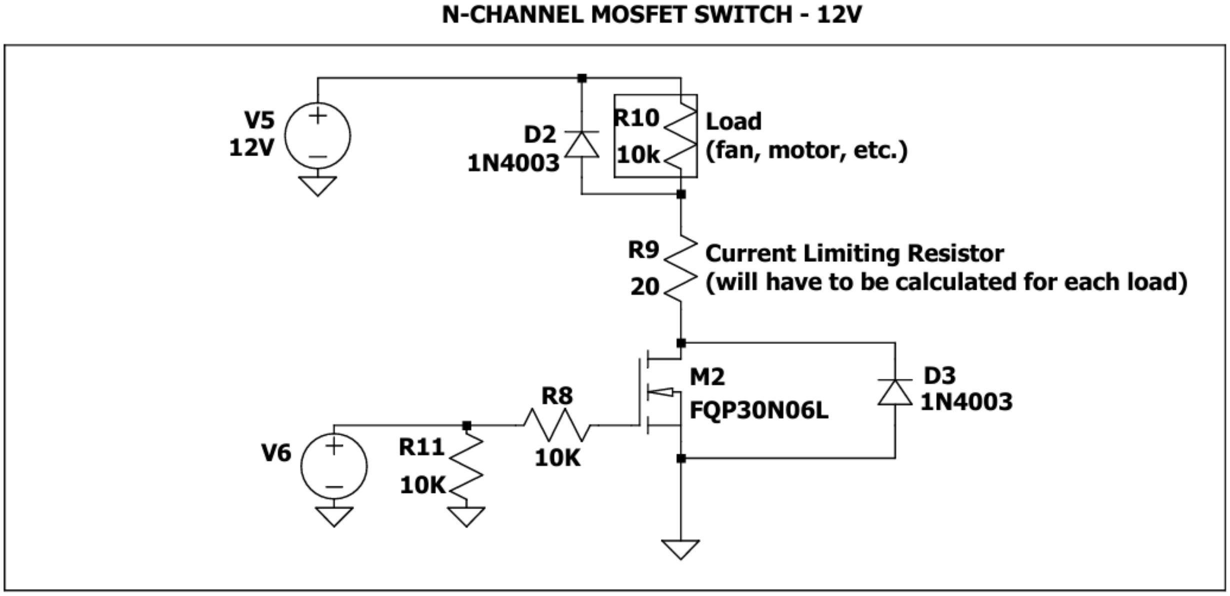


Figure 23: Schematic/wiring 12V MOSFET Switch

Voltage V6 represents a signal coming from a GPIO pin on the STM32, and V5 represents either the 12V or 5V rail. In the schematic above, it represents the 12V rail. The STM32 signal is connected to resistors R11 and R8. R11 is a pull down resistor, while R8 is current limiting to protect the gate of the n-channel MOSFET. Resistor R10 represents the load that will be supplied power (can be a fan, servo motor, sump pump, etc.), while resistor R9 is also current limiting. Note that R9 is optional and is only needed if the load (R10) has low internal resistance and its maximum supply current is at risk of being reached. Lastly, diodes D2 and D3 provide reverse voltage and surge protection.

When the STM32 wants to turn on the load, it will send a high 3.3V signal to the n-channel MOSFET. This signal will remain high for as long as the actuator is desired to be on for. So, while a low signal from the STM32 indicates an “off” actuator, a high signal indicates an “on.” This “on” will “close” the transistor, thereby connecting one end of the load to power, while the other is connected to ground (assuming the current limiting resistor R9 is not there). This properly biases the load, allowing it to turn on. When the STM32 sends a low signal, this “opens” the transistor, forcing both ends of the load (actuator) to be at 5V or 12V. The voltage across this actuator is 0V, so it will be “off.”

Component Selection for Switch

There are three components in this switch where their electrical characteristics truly matter. These are the n-channel MOSFET, the protection diodes, and the 10K ohm resistors. These components must be able to survive any voltages/currents that this system may subject them to.

Specifications for N-channel MOSFET	N-channel MOSFET Chosen
● Must be able to handle Vds=12V. ● The maximum Id must be able to handle current coming from the 5V or 12V source. ● Vgs must be able to handle 12V. ● Vth must be low enough for the STM32 to be able to “close” the transistor.	● FQP30N06L ● Vds max = 60V ● Vth=2.5V ● Id max = 32A ● Vgs max = +/-20V

Specifications for Diode	Diode Chosen
● Can survive current as high as 0.5A consistently (This is about 10% of the total current supplied to the system - it is not expected that a component being protected by this diode experiences this high of a current). ● Can survive a reverse voltage of 20V (this diode will be hooked up to a source of max 12V). ● Only allows current in one direction.	● 1N4003 ● Max forward current DC = 1A ● Reverse voltage max = 200V ● Rectifier diode

Specifications for 10K Ohm Resistors	Resistor Chosen
● Can handle 1.089mW (3.3V across, 10K ohm resistor, P=V^2/R)	● CF14JT10K0 ● Pmax = 0.25W

Simulation of Switch - 12V

This switch was simulated in LTspice to verify its functionality for both 5V and 12V sources. Below is a diagram of the locations where the voltage was simulated, as well as the simulation for the 12V switch.

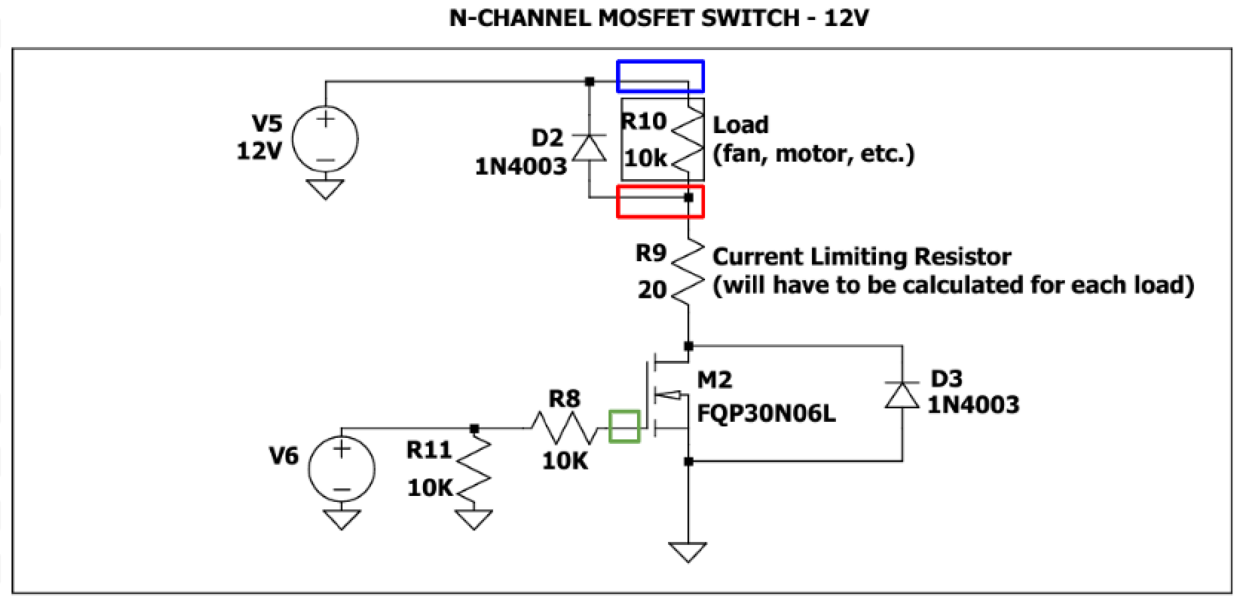


Figure 24: Diagram of Voltages Documented for 12V Switch during Simulation

The green waveform below represents the voltage at the gate of the n-channel MOSFET. This signal would come from one of the STM32 GPIO pins. In the simulation, this signal starts at 0V, is then held high at 3.3V for about 2 seconds, and then falls back low indefinitely. This simulates the SMT32 turning on an actuator for 2 seconds.

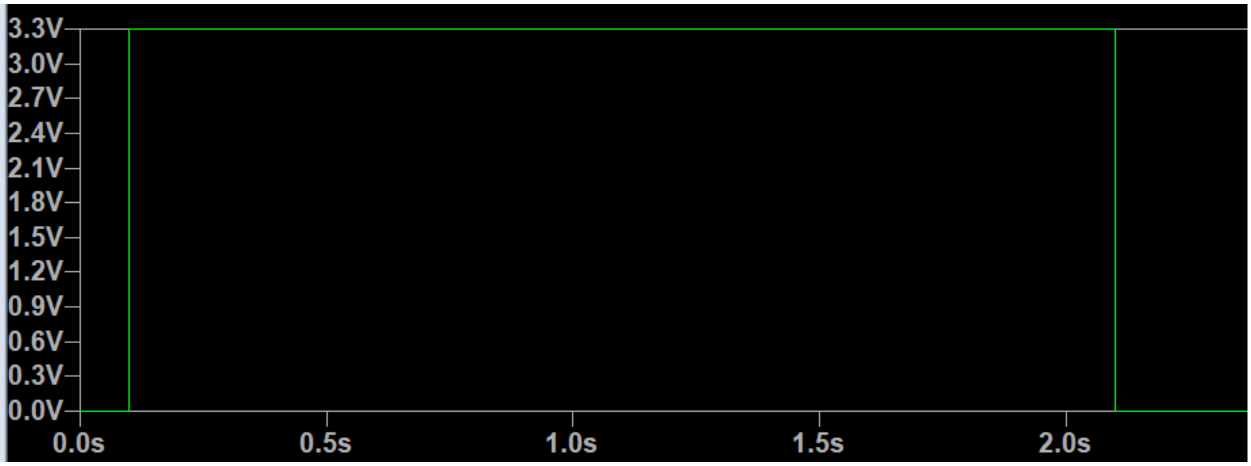


Figure 25: Simulation Waveform of STM32 Digital Output

In response to the STM32 signal, the voltage across the load (actuator) is given. The blue line represents the voltage of the side of the load connected to the 12V source, while the red line represents the side of the load which is connected to the drain of the n-channel MOSFET.

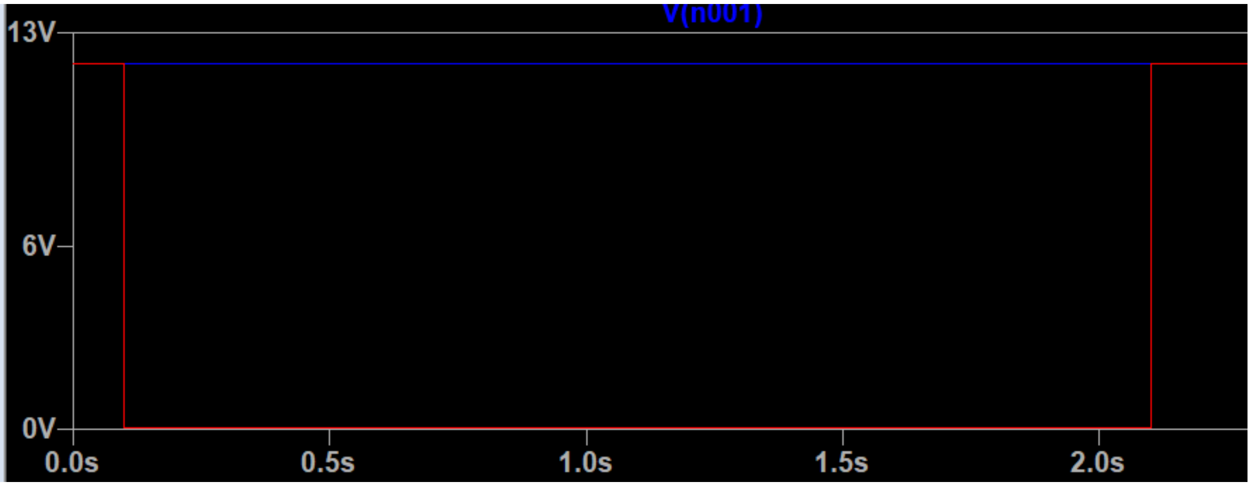


Figure 26: Simulation Waveform of Voltage Difference Across Load

As one can see, when the signal from the STM32 is low, the potential difference between the two sides of the load is 0V. This means that the load (which is the actuator) will be off. When a high signal comes from the STM32, the potential difference becomes 12V, allowing the actuator to turn on.

Simulation of Switch - 5V

The 5V switch is simulated below. Note the diagram which depicts the voltage readings which are included in the simulation.

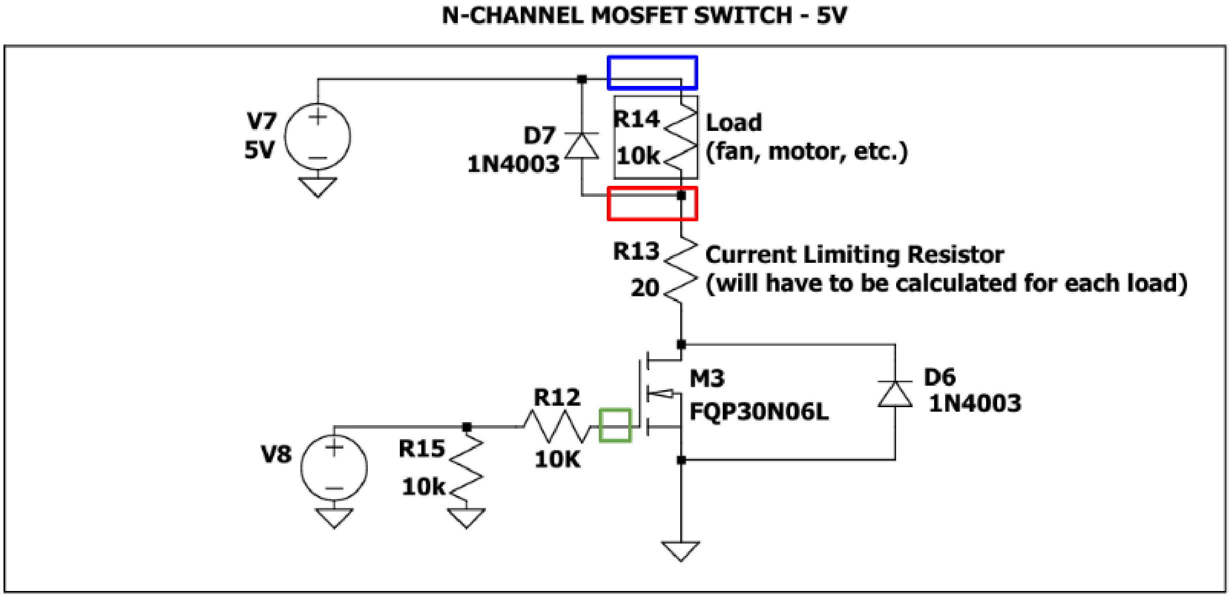


Figure 27: Diagram of Voltages Documented for 12V Switch during Simulation

In the simulation, the signal from the STM32 GPIO pin (green waveform) starts at 0V, is then held high at 3.3V for about 2 seconds, and then falls back low. This simulates the SMT32 turning on an actuator for 2 seconds.

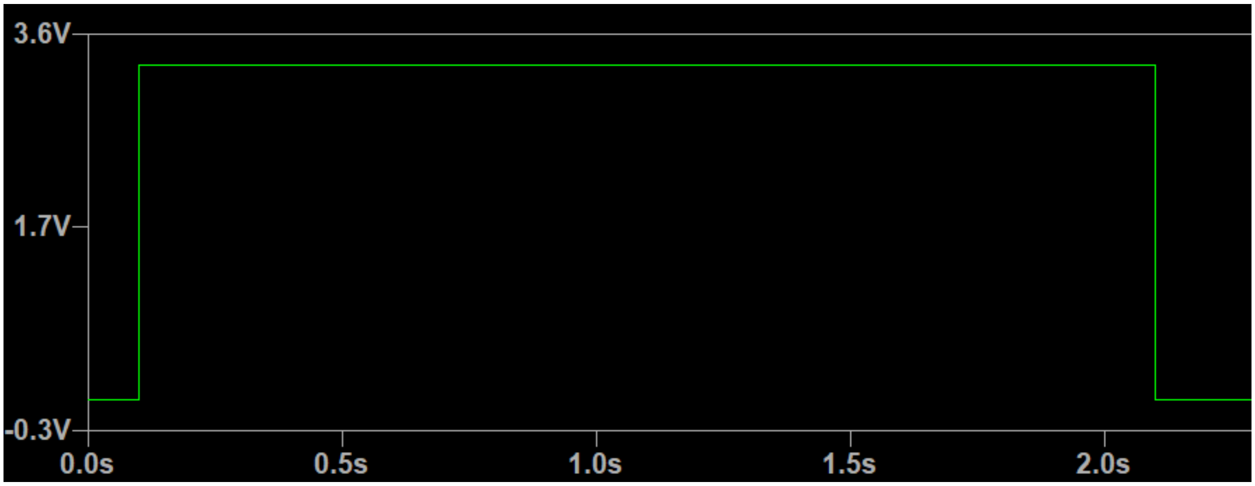


Figure 28: Simulation Waveform of STM32 Digital Output

In response to the STM32 signal, the voltage across the load (actuator) is given. The blue line represents the voltage of the side of the load connected to the 5V source, while the red line represents the side of the load which is connected to the drain of the n-channel MOSFET.

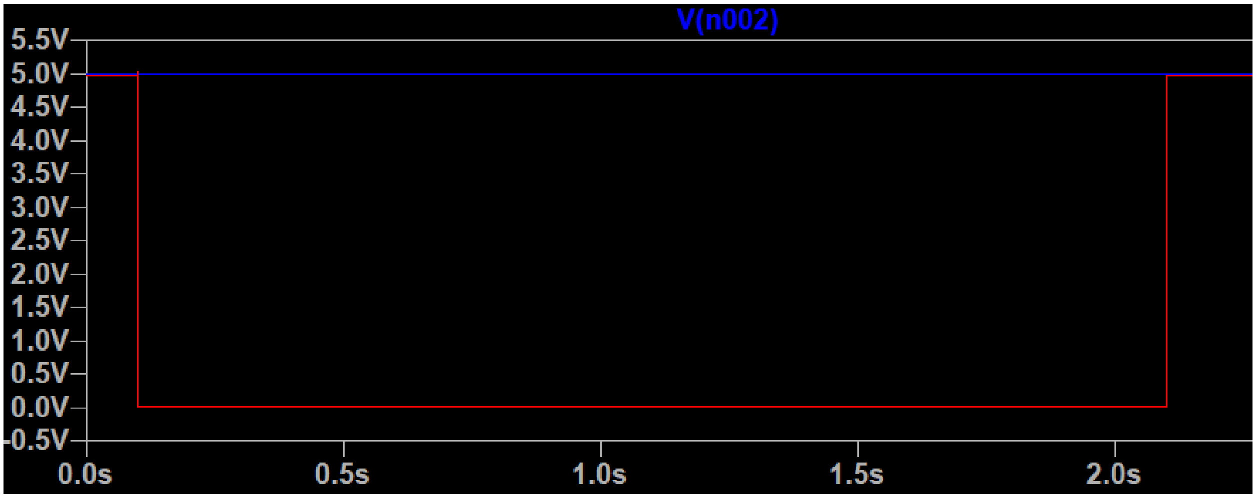


Figure 29: Simulation Waveform of Voltage Difference Across Load

Just as with the 12V switch, a low signal (0V) from the STM32 translates to a potential difference across the load (actuator) of 0V, effectively turning it off. On the other hand, a high signal forces a potential difference of 5V (turning the actuator on).

Electronic Design / PCB Layout

While each subsystem is meant to delineate the functions of our project and the devices that can support those functions, using the configuration in the subsystems block diagram verbatim is not particularly practical for the PCB layout. Within a subsystem there can be multiple devices that are positionally distinct from each other. Thus we developed a block diagram that reflects the number of circuit boards required for the design and specifies which devices will be on which board. This general PCB layout was used for calculating current consumption and assigning appropriate power regulation to each board.This block diagram is displayed below, followed by the KiCad circuit schematic.

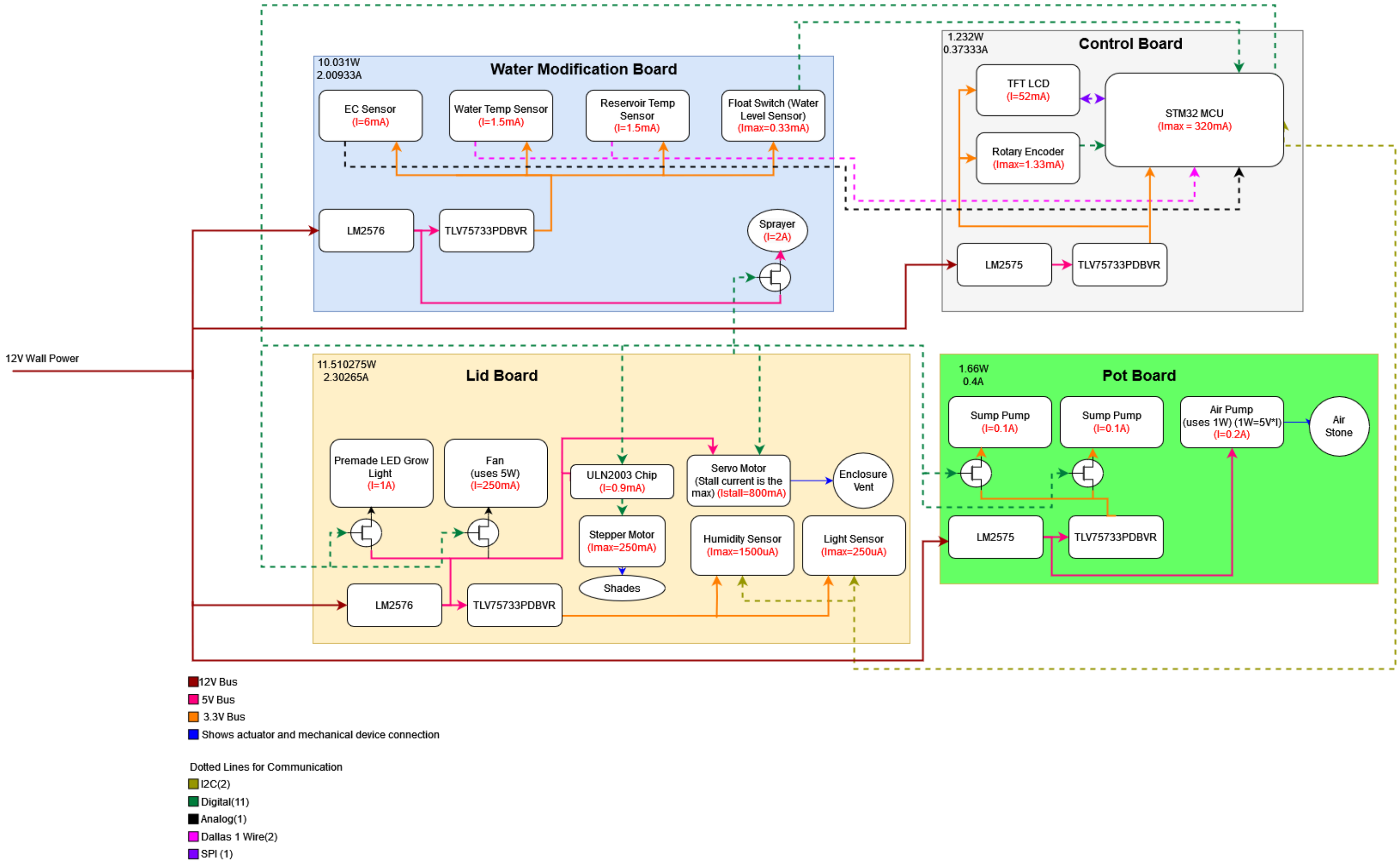


Figure 30: Block diagram of the PCBs and their devices - subsystems divided

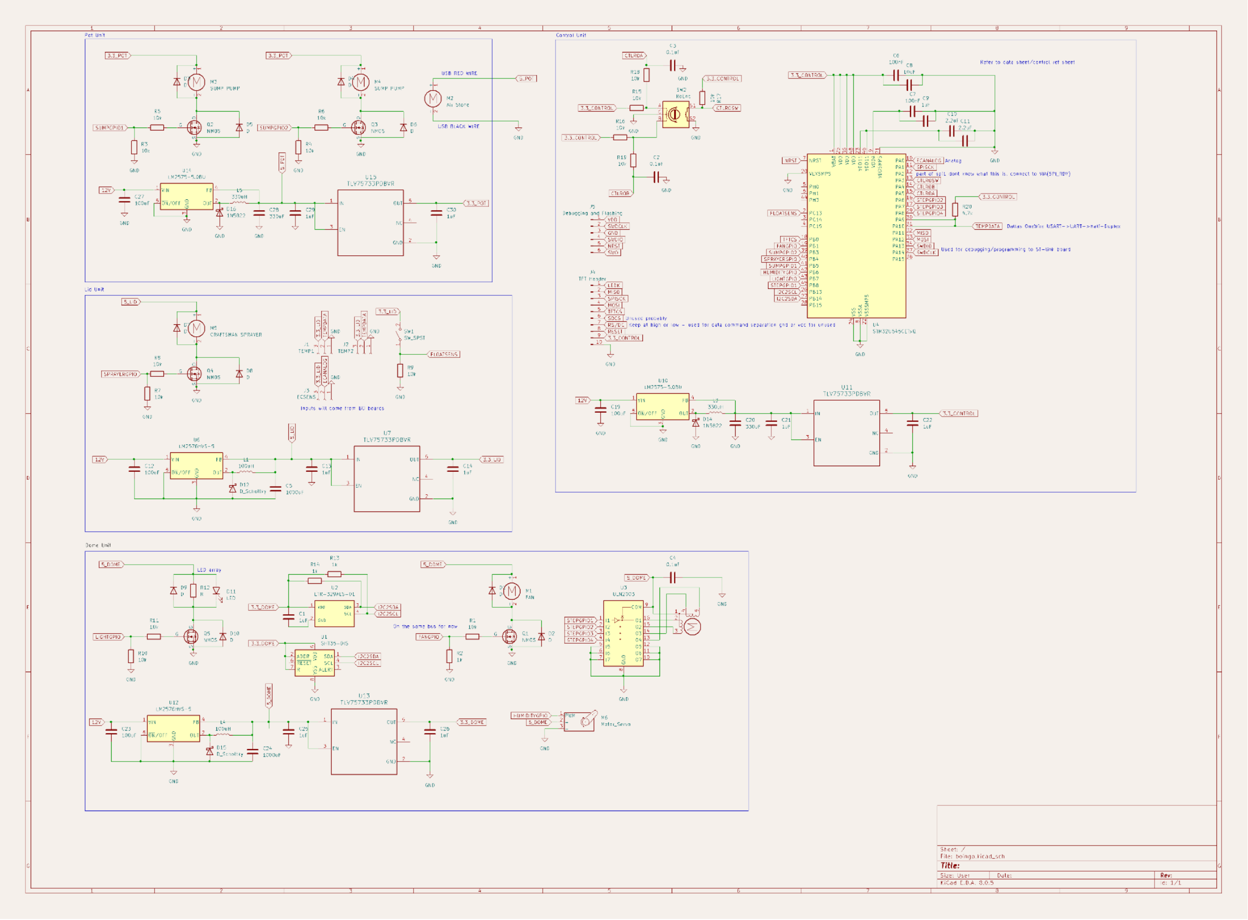


Figure 31: Circuit diagram of PCBs in above figure individual device schematics in their respective subsystem

In addition to the PCB division, headers are added for sensors and programming. Most of the sensors to be bought are already attached to breakout boards with their own headers ready to be plugged in. Thus the pinouts for those headers are reflected in our circuit schematic.

Complete explanations of the design choices that contributed to this design are denoted in all subsystem descriptions (located earlier in this report).

Tolerance Analysis

Power Regulation

To figure out the amount of power our PCB needs, we need to total up the amount of current each device in our circuit needs. This is done by referencing datasheets, amazon links, or doing online research for each device. For the STM32, the datasheet (pg 130) gives its current consumption. This is denoted below.

For the power subsystems, our initial idea is to use three different ICs in different configurations. These are listed below, as well as descriptions of what they do.

1) **TLV75733PDBVR**: IC REG LINEAR 5.5V to 3.3V 1A, SOT23-5
2) **LM2575-5.0WU-TR**: IC REG BUCK 12V to 5V 1A, TO263-5
3) **LM2576HVS-5.0**: IC REG BUCK 12V to 5V 3A, TO263-5L

The wiring of these chips will be discussed first. Below is the wiring diagram for the LM2575. This wiring and the components chosen were recommended by the manufacturer. An explanation of why these choices were made is given below.

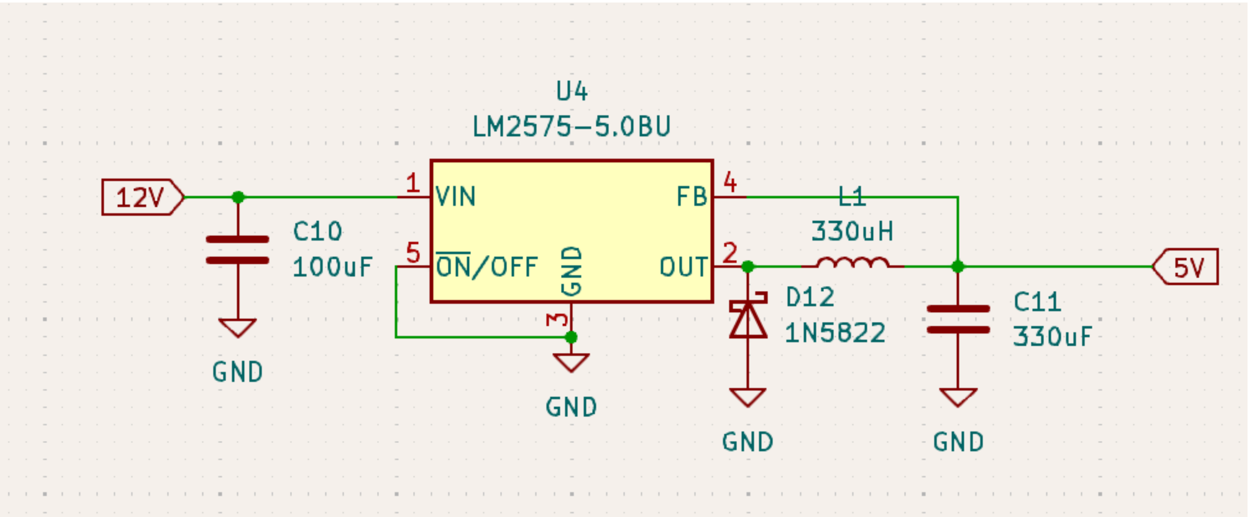


Figure 32: Simulation Waveform of Voltage Difference Across Load

This chip converts 12V to 5V with the capability of outputting 1A. In order to do so, the chip is enabled via its active low ON/OFF pin. Both this pin and the GND pin are grounded. The 12V rail is connected to the Vin pin. C10 (100uF) serves as a debounce capacitor, filtering out any noise from the 12V. The chip then converts this 12V to 5V, and the 5V is output at the OUT pin.[28]

An LC circuit is connected in series with the OUT pin. LC circuits are filters that only allow frequencies near their resonant frequency to pass through. The resonant frequency is defined as follows:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{330e-6 \times 330e-6}} = 1,461,477.898\ Hz$$

Any frequency that is not near this frequency will be attenuated. Refer to the image below, which gives a depiction of what frequencies will be filtered. In this image, the resonant frequency is 5032Hz. In our case, it is 1,461,477.898Hz.

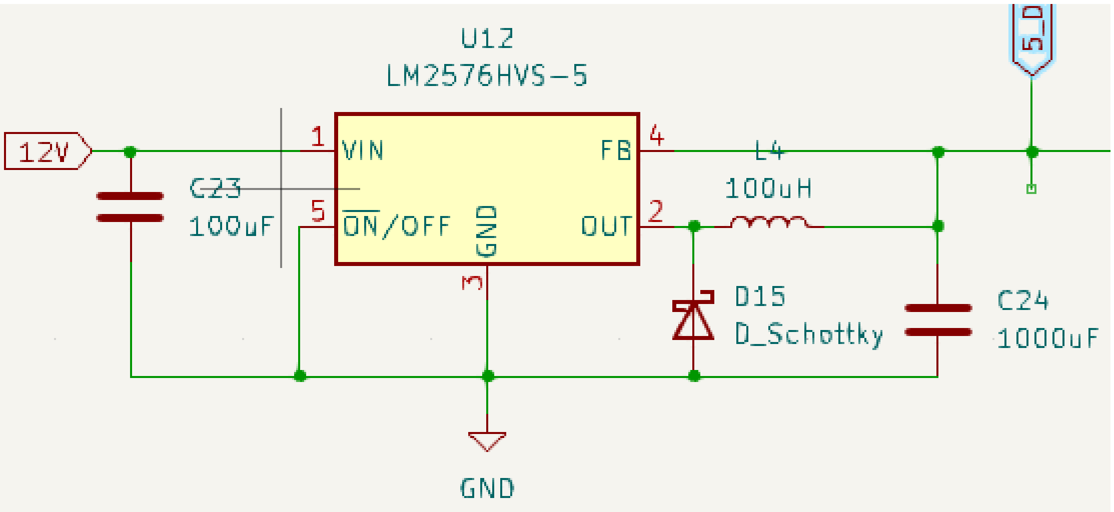


Figure 33: Diagram of the alternate power distribution boards based on the TSP564208DDCT

Similarly, the LM2576 provides similar capabilities as the LM2575. The key difference is the amount of available current that can be drawn. 3A of current can be supplied from the LM2576, making it beneficial for motor applications.[16] In the circuit drawn below, the circuit also uses a LC network similar to the LM2575. These values come from the datasheet, these provide a band pass filter for a comparatively low frequency.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{100e-6 \times 1000e-6}} = 503\ Hz$$

Attenuating all noise except for a small grouping of very high frequencies is beneficial in general as it reduces the amount of variance in the voltage supply which can both damage and affect the functioning of precision electronics.

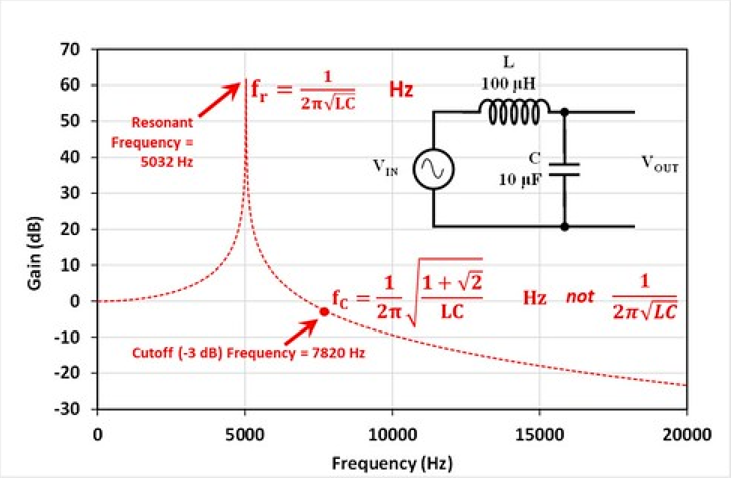


Figure 34: Diagram of LC filtering

Experiencing noise at a frequency of 1,461,477.898Hz is unlikely because most EM noise exists within the KHz range. So, this LC circuit essentially filters out all noise (both low and high) that is most likely to be a part of the 5V output. This allows the output voltage across the capacitor to be steadily DC.

The Schottky diode serves as a flyback diode. In the event that the output from the OUT pin falls low, the flyback diode will protect the rest of the circuit from getting fried from the sudden spike in voltage the inductor will experience.

The final step down for both buck converters is the TLV75733, which will convert a 5V to 3.3V. It uses two decoupling capacitors to further filter out voltage variances resulting in a clean 3.3V output. Its voltage out variance is within +-3%, which is within acceptable range for both sensors and the STM32.[17] Our design therefore enables a 3.3V line on each board to draw 1A max and the 5V line to either draw the remaining 1A or 3A of available amperage.

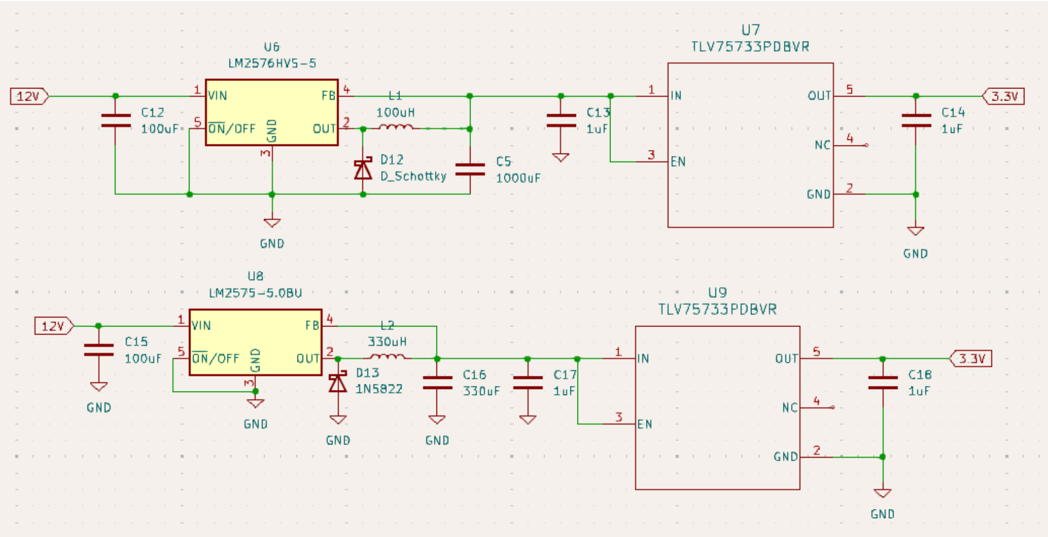


Figure 35: CIrcuit diagram of both power distribution boards

These two circuits will be referenced in our current calculations and will be assigned to each board according to the needs of each board.

Alternate Solutions

While the LM2575/76 solution for voltage conversion is simple and tested. Another viable solution using newer hardware would be to use TI's TPS564208, which is a single chip variable step down regulator that can output up to 4A.[15] This would reduce the number of IC's needed for power regulation. However, the construction is harder due to the number of onboard capacitors and transistors needed. In addition, the implementation for our purposes isn't as clear as the implementation for the LM2575/LM2576 chips. These will be a secondary option to optimize cost and board size if needed.

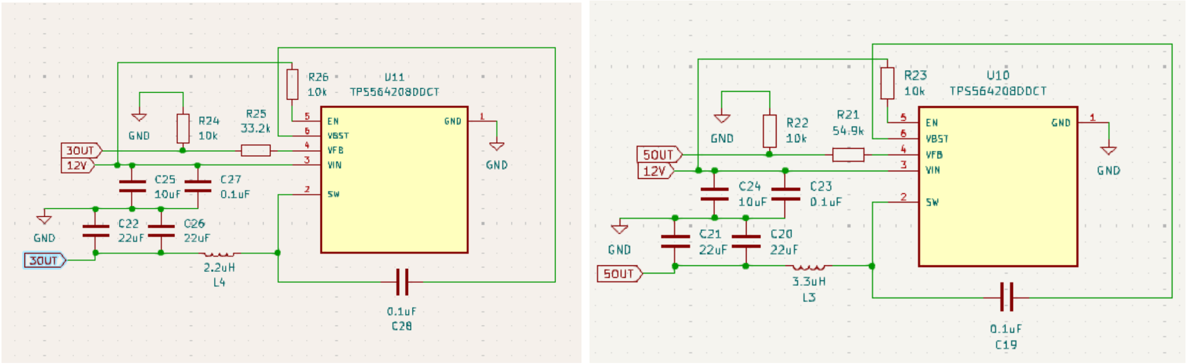


Figure 36: Diagram of the alternate power distribution boards based on the TSP564208DDCT

Current Analysis

In this section, we will be looking at current consumption of each board and matching them to an appropriate power supply circuit. Currents are either derived from the data sheets in the citations or the product link in the BOM.

Control Board

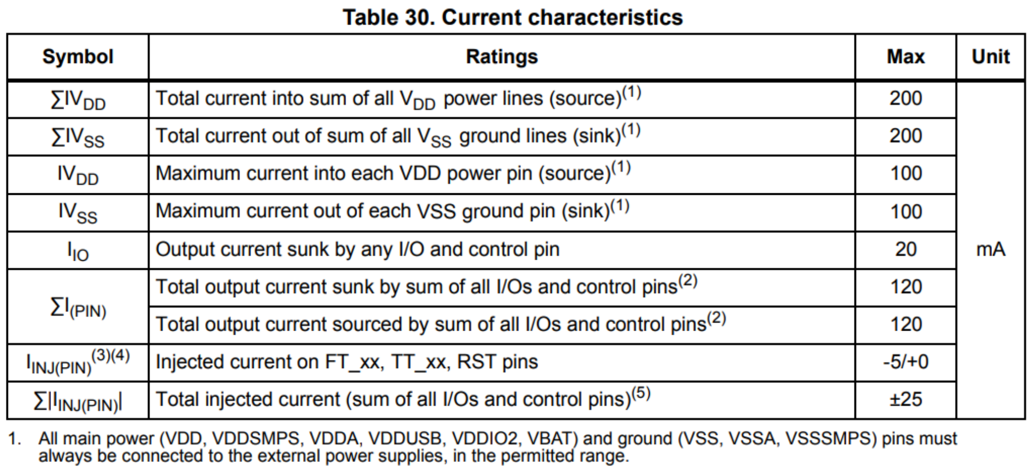


Table 30. Current characteristics

Symbol	Ratings	Max	Unit
ΣIV_{DD}	Total current into sum of all V_{DD} power lines (source)(1)	200	mA
ΣIV_{SS}	Total current out of sum of all V_{SS} ground lines (sink)(1)	200	
IV_{DD}	Maximum current into each VDD power pin (source)(1)	100	
IV_{SS}	Maximum current out of each VSS ground pin (sink)(1)	100	
I_{IO}	Output current sunk by any I/O and control pin	20	
$\Sigma I_{(PIN)}$	Total output current sunk by sum of all I/Os and control pins(2)	120	
	Total output current sourced by sum of all I/Os and control pins(2)	120	
$I_{INJ(PIN)}$(3)(4)	Injected current on FT_xx, TT_xx, RST pins	-5/+0	
$\Sigma\|I_{INJ(PIN)}\|$	Total injected current (sum of all I/Os and control pins)(5)	±25	

1. All main power (VDD, VDDSMPS, VDDA, VDDUSB, VDDIO2, VBAT) and ground (VSS, VSSA, VSSSMPS) pins must always be connected to the external power supplies, in the permitted range.

Figure 26: Diagram of the alternate power distribution boards based on the TSP564208DDCT

The control board consists of a TFT LCD, Rotary Encoder, and a STM32 U545 microcontroller. The max current for the TFT LCD and Rotary Encoder are relatively straightforward to calculate. On the Adafruit website where the LCD is sold, the driver circuit and LCD both use 1mA each. Backlighting the LCD in the worst case scenario is 50mA resulting in a total current draw of 52mA on the 3.3V line. [13]

1mA(LCD)+1mA(ST7735S)+50mA(Backlighting) = 52mA

The rotary encoder max current can only be derived from the pull down resistors. Since we use 10k resistors for 3 different switches, our calculation would be:[18]

$$3*(3.3\text{V}/10000\text{ Ohms}) = 0.99\text{mA} \text{ -> } (1\text{mA rounded})$$

For the STM32, two maximum current values can be derived from the datasheet. In section 5.2 we can find that the absolute maximum current that can supply the STM32 is 200mA and the total max output current sourced from the STM32 is 120mA. This results in a 320mA figure. A more accurate figure can be found in section 5.3.6 where the max current consumption of the CPU in run mode at the worst conditions would be 33mA. Using the absolute maximum I/O source current we come to a figure of 153mA.[19]

$$320\text{mA} + 0.99\text{mA} + 52\text{mA} = 373\text{mA - Absolute}$$
$$153\text{mA} + 52\text{mA} + 1\text{mA} = 206\text{mA - Typical}$$

In total we find that the total amperage draw for the control board would be less than 373mA at absolute worst conditions. We opt to use a combo of LM2575 buck converter and TLV75733PDBVR LDO regulator to provide 3.3V 1A power. This amperage draw is well below the max value for the power circuits

Lid Board

The lid board consists of an off the shelf battery operated sprayer that will be converted to operate on a continuous DC supply. In addition it will host water temperature sensors, an electric conductivity sensor, and a float switch. The sensors all have a rating from their datasheets. Both temperature sensors are a waterproof packaging of a common DS18B20 temperature sensor, which has a max current of 1.5mA.[23] Running both will take up 3mA. As for the EC sensor, the website indicates the max operating current as 6mA. Finally the float switch current is dependent on the pulldown resistor despite the 1A max rating.[22] We use a 10k resistor and the current can be calculated with Ohms Law as:

$$3.3\text{V}/10000 = 0.33\text{mA}.$$

Since these components reside on the 3.3V line we can then calculate the total current as:

$$3\text{mA}+6\text{mA}+0.33\text{mA} = 9.33\text{mA}$$

This is within the range of our 1A 3.3V source from the TLV7533PDBVR.

For the craftsman sprayer, it is powered by 4 AA batteries and has a stated operating voltage of 4.5V. We can infer that the batteries are wired in series to accomplish this supply current. Each AA is 2000mAh. The sprayer can stay on consistently for 60 minutes.

$$2000\text{mAh}/60\text{ mins} = 2\text{A supplied}$$

$$2A+0.00933A < 3A$$

From the expression above, we see that our total current draw is less than 3A. This meets the requirement for our LM2576 step down circuit chain. Therefore we will use a combination of LM2576 and TLV75733PDBVR to power this board.

Dome Board

The dome board consists of both a stepper and servo motor, 2 I2C based sensors, a fan, LED array. The devices that utilize the 3.3V rail are the light sensor and humidity sensor. Both values are derived from their datasheets and have a current of 250uA and 1500uA respectively. [25][26]

$$0.250mA + 1.5mA = 1.75mA$$

The devices that reside on the 5V rail are the stepper motor and driver chip, servo motor, LED array, and fan. All of these have ratings directly from their sources of purchase.

$$1A(LEDs) + 0.2509(stepper\ and\ driver) + 0.25(fan) + 0.8(servo) = 2.309A$$

On the 5V line we have a total of 2.209A of current draw. This along with the sensor chips show us that the total current draw is less than 3A. Because of this we will use a combination of LM2576 and TLV75733PDVR. This will provide a max of 3A on the 5V line and 1A from the 3.3V line.

Pot Board

This board holds the sump pumps and the air pump. All of these components are motors with a fixed current draw and the sump pumps are rated to run a 3.3V 100mA. The air pump current draw can be inferred through its rated wattage of 1W and intended USB power.

$$5V * I = 1$$
$$I = 0.2A$$

The total current draw can be calculated as follows:

$$0.2A + 0.1A + 0.1A = 0.4A.$$

Since our total draw is lower than 1A, we can use the LM2575 and TLV75733PDBVR to get a 1A 5V line and 1A 3V line that draws from the 5V.

Power Supply

In total our current draw from these 4 boards is:

$$0.4 + 2.309 + 2.009 + 0.373 = 5.08A$$

We choose to use a 12V 6A power supply. This is more than enough to cover any internal resistances and operating currents of our power regulation chips as they are all in the mA range. Our initial power supply will be a generic one intended for laptops.

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Cost and Schedule

Cost Analysis

Labor

Upon graduation, the average cost of what a University of Illinois Electrical and Computer Engineering graduate makes is $88,321/year for Electrical Engineering [20] and $118,752/year for Computer Engineering [8]. In a year, there are 52 weeks/weekends, amounting to 52*2 = 104 non-business days. This results in 365-104 = 261 working days in a year. $88,321/261 days = $338.39/day for EE and $118,752/261 days = $455/day. An average working day is 8 hours/day. For EE, this amounts to $42.30/hour (338.39/8). For CE, this amounts to 455/8 = $56.88/hour. We estimate this project will take, on average, 10 hours/week for 7 weeks (starting the week of Oct 7th and ending the week of Nov 18th). A reasonable salary/labor costs for each team member would be about $42.30/hour * 2.5 * 70 hours or $56.88/hour * 2.5 * 70 hours, amounting in a total of $7402.50 for EE or $9954 for CE per team member. To provide an average cost, let's say the labor costs per team member is the average of the CE and EE costs, i.e., ($7402.50+$9954)/2 = $8678.25. For 3 team members, this is $8678.25*3 = $26,034.75 in labor costs.

Parts

Note: Some of the parts listed have been provided for coursework taken prior to this class or have been part of group members' personal projects. Parts such as these are listed as personal inventory. The price is still listed for these parts to provide an accurate estimate for how much the Smart Plant Pot costs to make.

Name	Description	Manufacturer	Manufacturer Part Number	Cost [$]	Quantity	Link
Air Stone & Air Pump	Aquarium Air Pump Mini USB Fish Tank Oxygen Air Pump Portable Ultra Silent Air Aerator Pump Energy Saving Oxygen Bubbler with Air Stone and Single Outlet Silicone Tube 1W	Amazon	B093GR8HRQ	8.99	1	Link
Fan	2PCS, 1 pin 8025 Fan 80x80x25mm DC 5V Fan, USB	Amazon	N/A	7.99	1	Link
Rectifier Diode (Protection)	200VOLT 1AMP RECTIFIER DIODE 1N4003, through-hole	Diotec Semiconductor	1N4003	0.17 [E-shop]	10	Link
12V, 3A Wall Adapter	12V 6A power adapter with barrel connector	Parts Express	120-079	17.98	1	Link
5.5V-3.3V Stepdown Linear	IC REG LINEAR 3.3V 1A SOT23-5	TI	TLV75733PDBVR	0.33	4	Link

Regulator						
12V-5V Stepdown Buck Switching Regulator	IC REG BUCK 5V 1A TO263-5	Microchip Technology	LM2575-5.0WU-TR	1.75	2	Link
12V-5V Stepdown Buck Switching Regulator	IC REG BUCK 3A TO263-5L	UMW	LM2576HVS-5.0	6.86	2	Link
N-MOSFET, 2.5V turn on, can handle Vds=12V	N-MOSFET, Through hole, Vds max: 60V, Vth=2.5V, Id max=32A	Fairchild	FQP30N06L	0.80 [Personal Inventory]	5	Link
LCD screen	128x160 TFT LCD SPI ST7735R DRIVER	Adafruit	358	19.95	1	Link
Rotary Encoder	Rotary Encoder with Middle Switch	Bourns Inc	PEC11R-4115F-S0018	1.5	1	Link
STM32 Microcontroller	Low power version with more clocks and more IOs some models are free	ST	STM32U545CET6Q, pkg: LQFP48	6.47 [Sample]	1	Link
Sump Pump	3V 100mA works like a DC motor, 1 meter distance	Adafruit	4547	4.45	2	Link
Tubing for Sump Pump	Tubing for Submersible Pumps - PVC 6mm ID - 1 Meter Long	Adafruit	4545	1.5	2	Link
Temperature Sensor	Serial Communication 3-5.5V	DFRobot	DFR0198	6.9	2	Link
EC/TDS Sensor	Analog 3.3V	DFRobot	SEN0244	11.8	1	Link
Float Switch	Float Switch sensor 1A 200V max	PIC GmbH	PLS-041A-3PAI	4.82	1	Link
Sprayer	Battery Op sprayer 4.5V(probably 5v tolerant)	Craftsman	CMXCAFG190640	8.98	2	Link
Pre-made grow lights	Plant Grow Light,yadoker LED Growing Light Full Spectrum for Indoor Plants,Height Adjustable, Automatic Timer, 3.75"L x 3.75"W x 24"H 5VDC USB	Zhiya	Vineen	8.49	1	Link
Stepper driver	1.5amp max single 800ma multi	Toshiba	ULN2003APG	0.56 [Personal Inventory]	1	Link
Stepper motor	5V Stepper Motor	Diligent, Inc.	290-028	4.95 [Personal Inventory]	1	Link
Light sensor	Adafruit LTR-329 Light Sensor - STEMMA QT/Qwiic	Adafruit	LTR-329	4.5	1	Link
Servo motor	Servo Motor	HiTec	HS-311	15.99 [Personal Inventory]	2	Link
Humidity sensor	SENSOR HUMI/TEMP 5V I2C 1.5% SMD	Digikey (Sensirion AG)	SHT35-DIS-B10KS	7.33	1	Link
Pot	Blue cylinder pot, 8" diameter at top, 4.5" at bottom, 7" depth	Home Depot [Personal Inventory]	10000-03920 [Personal Inventory]	3.97 [Personal Inventory]	1	Link
Pot Clear Enclosure	FixtureDisplays® 6PK,Tall Medium ReusablePlastic Mini Greenhouse/Dome,10.25"L x 10.25"W x 8.25"H,Clear,1.3lbs, Vent @ top of dome,	FixtureDisplays	15186-6PK-NF	8.02	1	Link
Water Canister (Menards Bucket)	Prime high density polyethylene (HDPE), Bucket 3.5 Gallon	Menards	20-3105-P1	3.19	2	Link.

Water Canister Lid (Menards Bucket Lid)	Lid for 3.5 Gal Bucket	Menards	1130903	2.48	2	Link
Total				228.54		

Grand total of labor costs for all 3 team members and all components for the Smart Plant Pot is approximately $228.54 + $26,034.75 = $26,263.29

Schedule

Week	Task	Member
October 7th - October 14th	Design review [Oct 8th], modify design document according to feedback	Morgan, Gavin, Trisha
	Purchase first round of parts	Morgan, Gavin, Trisha
	Finalize PCB design for review [finalize schematic changes on KiCad]	Morgan, Gavin, Trisha
	3D print pot lid and enclosures	Gavin
October 14th - October 21st	First round PCBWay orders [make this deadline]	Morgan, Gavin, Trisha
	Begin soldering components	Morgan, Gavin, Trisha
	Begin oxygenation and humidity subsystem on dev board [Goal: step-down wired with MOSFET switch done with basic communication to turn fans/motors on and off based on sensor data]	Physical Design: Gavin Firmware: Trisha Testing: Morgan
October 21st - October 28th	Complete oxygenation and humidity subsystems and begin first round of testing [Goal: servo works with enclosure vent; air pump, stone, and fan appropriately react to the signal from STM32]	Morgan, Gavin, Trisha

	Begin nutrient/water and grow light subsystem [Goal: Figure out specifics of I2C communication for light sensor and temperature sensor]	Morgan, Gavin, Trisha
	Second/final round of parts and 3D printing based on test fit	3D printing: Gavin Parts and testing: Morgan, Gavin, Trisha
October 28th - November 4th	Complete nutrient/water and grow light subsystem and begin second second round of testing [Goal: sprayer and sump pumps respond to signals from STM32 based on the data from TDS sensor and float switch respectively; stepper motor drives the shades and grow lights are adjusted according to data from temperature sensor]	Physical Design: Gavin Firmware: Trisha Testing: Morgan
	Integrate oxygenation, humidity, nutrient/water, and grow light subsystem [includes power/control system and any communication/wiring between subsystems]	Physical Design: Gavin Firmware: Trisha Testing: Morgan
November 4th - November 11th	Finish up soldering and test individual subsystems	Morgan, Gavin, Trisha
	Continue integration, modify any subsystems/ communication between subsystems	Morgan, Gavin, Trisha
November 11th - November 18th	Prepare for mock demo	Morgan, Gavin, Trisha
	Ensure design passes all individual subsystem functionality/unit tests	Morgan, Gavin, Trisha
	Start final paper/presentation	Morgan, Gavin, Trisha
November 18th - November	Complete mock demo	Morgan, Gavin, Trisha

25th		
	Continue testing and recording data for final paper and presentation	Morgan, Gavin, Trisha
November 25th - December 2nd	Fall break [continue working on final paper/presentation]	Morgan, Gavin, Trisha
December 2nd - December 9th	Final Demo	Morgan, Gavin, Trisha
	Mock presentation	Morgan, Gavin, Trisha
December 9th - December 16th	Final presentation	Morgan, Gavin, Trisha
	Final paper	Morgan, Gavin, Trisha

Ethics and Safety

Safety

Safety for this project mainly revolves around the usage of high voltage AC power sources. For the Smart Pot, the power subsystem will be directly connected to an outlet. This being said, it is imperative that proper precautions are taken when interacting with this source. According to UIUC Electrical Safety policy, it is important to disconnect any power sources before providing maintenance to a system [3]. In the case of the Smart Pot, this means unplugging the power subsystem from the wall every time PCB manipulation is required. Doing so eliminates the possibility of a person coming in direct contact with the outlet power supply. This recommendation is also repeated by OSHA, while adding that properly insulated tools should also be used when working with these sources.

Working with high voltage power sources poses an increased risk when doing so around water, which is the case for the Smart Pot. This being said, it is important to ensure that all water canisters/containers are properly maintained and sealed such that the possibility of leaks is minimized. This is an industry standard, as seen through most laboratories being a “No Food, Not Drinks Allowed” space (emphasis on the “No Drinks”) [3]. This is especially echoed here at UIUC, especially in the ECE 385, ECE 391 and ECE 486 laboratories. Note that in these labs, water bottles (which are sometimes permitted) are required to have a sealed top to protect any power sources from coming in contact with their contents. As one can see, water and power do not (and should not) mix, which means precautions will have to be taken when working on the Smart Pot system. Systemwide leakage surveys should be conducted prior to powering on the Smart Pot to eliminate the risk of water damage and electric shock. If water leakage is spotted, the Smart Pot should immediately be disconnected from power, and the area thoroughly cleaned.

The last area of concern revolves around the mishandling of liquid nutrients. Though they are used by millions of people every day, it is important to remember that they are chemicals and should be handled with care. Most liquid plant fertilizers contain nitrogen. While good for facilitating plant growth, exposure to large amounts can cause skin redness and irritation. In addition, ingestion of these chemicals is highly toxic and can lead to hospitalization. This being said, following Federal chemical handling guidelines would be a great way to keep anyone who needs to handle liquid nutrients safe. According to OSHA, proper PPE must be worn when working with chemicals. This includes gloves, safety goggles, etc. This rule is seconded by UIUC, where the use of fume hoods are also recommended. Chemicals should also be stored in non-food containers to prevent accidental ingestion or exposure. With this being said, our group will need to hold each other accountable for ensuring proper PPE use when handling liquid nutrients.

Ethics

This project sets the stage for automated farming in the future, and with it brings ethical dilemmas. First and foremost, there is the concern that devices like the Smart Pot can be used to grow plants to create illicit substances. Plants such as cannabis, coca, and opium poppy can be used to create abusable drugs like cocaine and opioids. With the current design of the Smart Pot, there is no way to inhibit a user from growing these plants with one of our devices. By making plants easier to grow, the Smart Pot could possibly increase drug production and support a criminal trade. The IEEE Code of Ethics states that the safety, health and welfare of the public is paramount and that unlawful conduct should be avoided. This however begs the question: how can we protect against the misuse of the Smart Pot? Well, if the Smart Pot were to ever become commercial, background checks could be conducted on consumers interested in purchasing it. Not only this, but in future versions computer vision can be implemented to recognise the type of plant being grown in the Smart Pot, and if this plant falls under a restricted category, the Smart Pot will cease growing the plant. Protecting the consumer is of the utmost importance, and ensuring that this technology is not used for wrong is imperative.

The last ethical issue of the Smart Pot is the impact it could have on working class families. To elaborate further, if all farming becomes autonomous in the future, then many individuals who work on farms as laborers could possibly lose their jobs. The IEEE Code of Ethics emphasizes avoiding conflicts of interests when it comes to new technologies, and this situation is clearly a conflict of interest with respect to this demographic of workers. If the Smart Pot were to ever make it to market and be largely commercialized, free classes could be offered to teach these laborers a new skill set - maintaining this new technology. While farming technology evolves, the jobs associated with it will evolve too.

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