ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Predictive Plant Care

Team No. 58

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1 Introduction

1.1 Problem

Having a plant in your house can be a great way to liven up the room. However, many plants require consistent, oftentimes everyday care, and forgetting to take care of a plant can be detrimental to the plant's health. Leaving a plant unattended for a long time (such as going on a vacation) can also result in the plant dying out unless it's a low-maintenance plant that can survive for that long.

1.2 Solution

In order to eliminate the dependence on human interaction, we will create a plant care system that will take care of the plant's various needs such as water, sunlight, soil pH and nutrients. Each of the respective resources will have a sensor that monitors how much of that resource the plant has (such as the moisture level of the soil, how much light the plant is receiving, and soil pH). The plant's needs will be taken care of automatically based on either time or sensor outputs. Light will be administered predictively using a PID controller.

Our overall goal is to keep a plant alive for a long period of time. Specifically, we will be testing using a sunflower and we want to keep it alive and thriving throughout our time in the class. This will involve taking care of it on our own until we get our system working, but once we do the system should be able to take care of the plant on its own completely unless someone wants to put in some sort of manual input.

1.3 Visual Aid

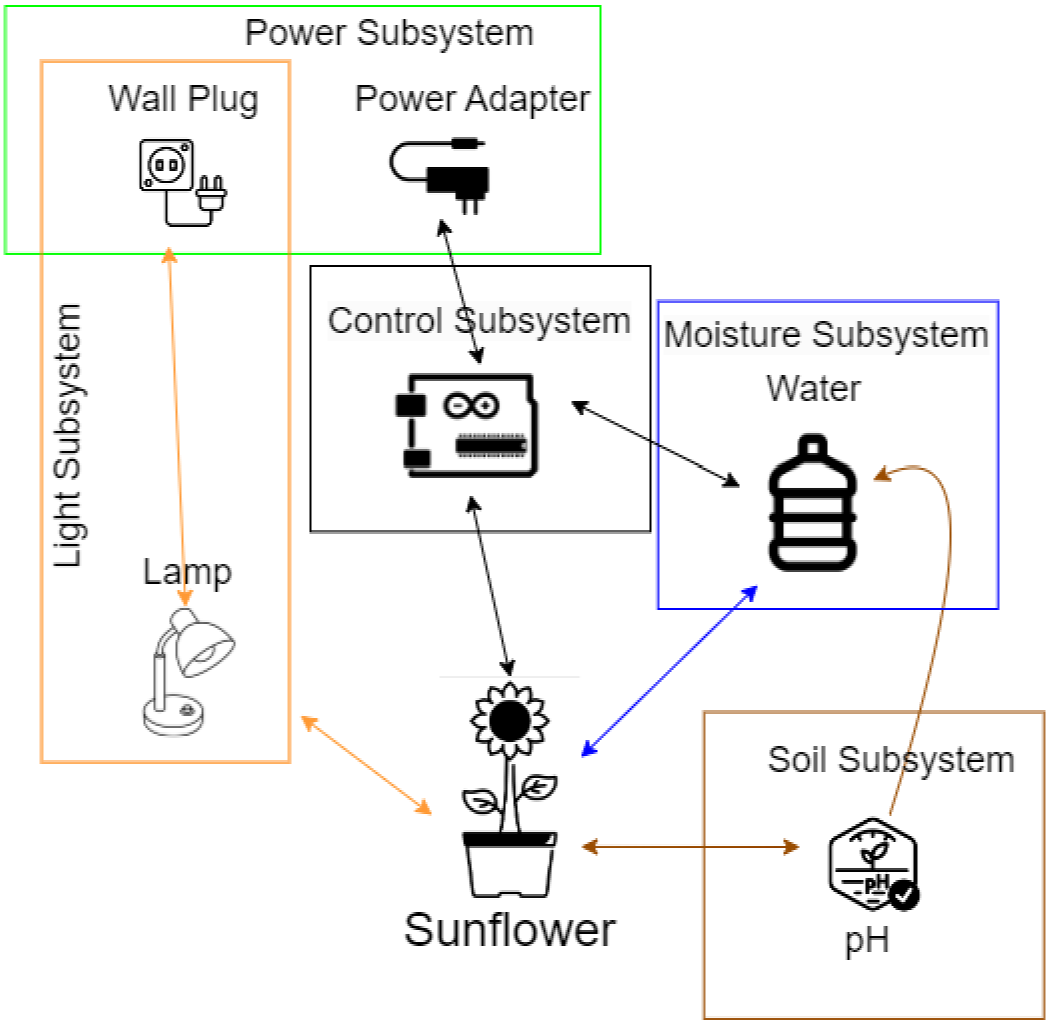

Figure 1: High level diagram of the Plant Care system

1.4 High-Level Requirements

1. The plant (sunflower) is able to grow at least 6 inches and produce one flower.
2. Light levels are able to be maintained between 12 and 20 DLI for a sunflower.
3. Moisture levels of the soil are able to be maintained between 12.1%-13.1% during flowering stages and 10.5%-11.5% during other times for a sunflower.
4. The device is able to receive and provide care for different plant requirements.

2 Design

2.1 Block Diagram

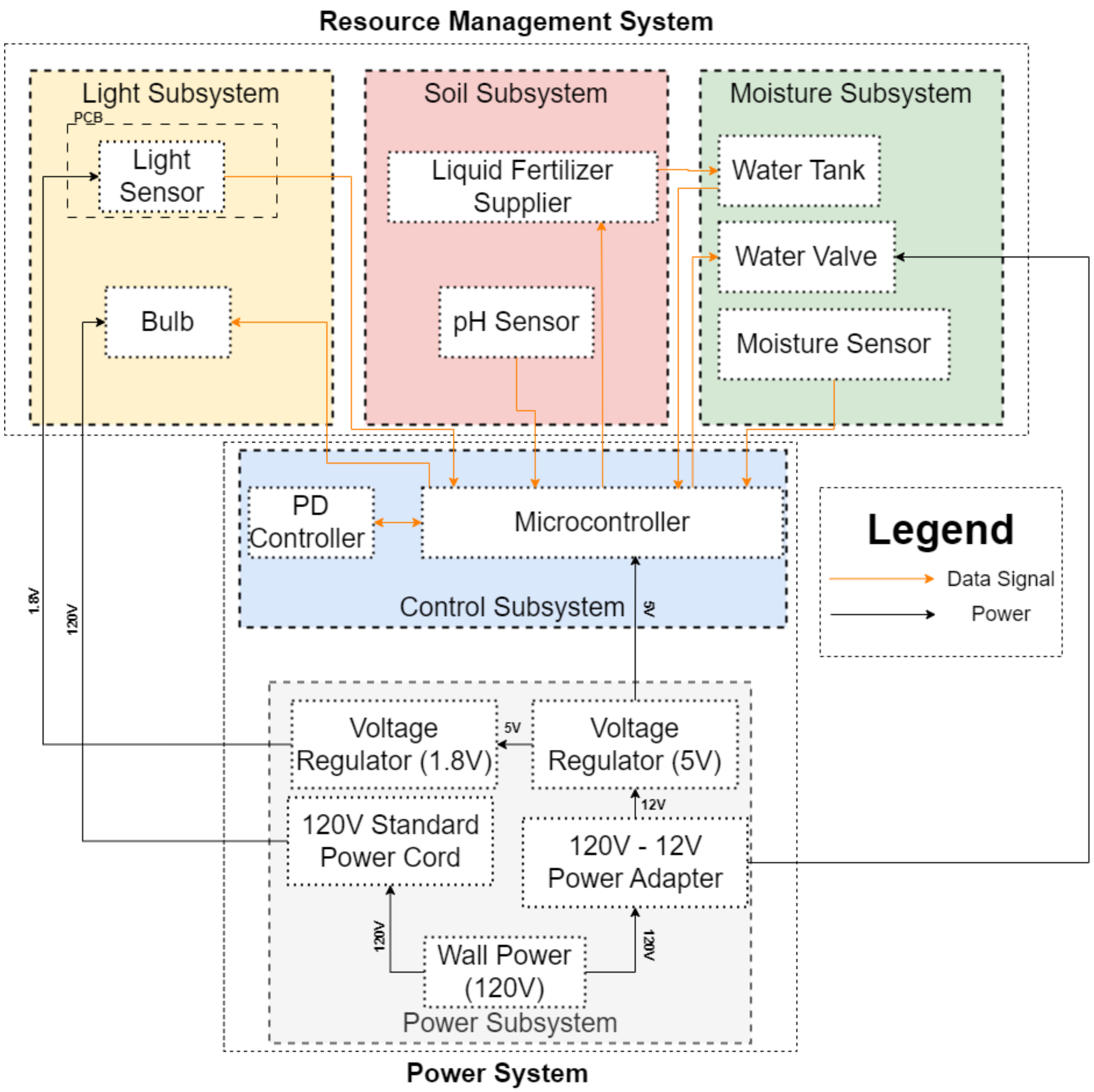

Figure 2: More detailed block diagram of the system

2.2 Physical Design

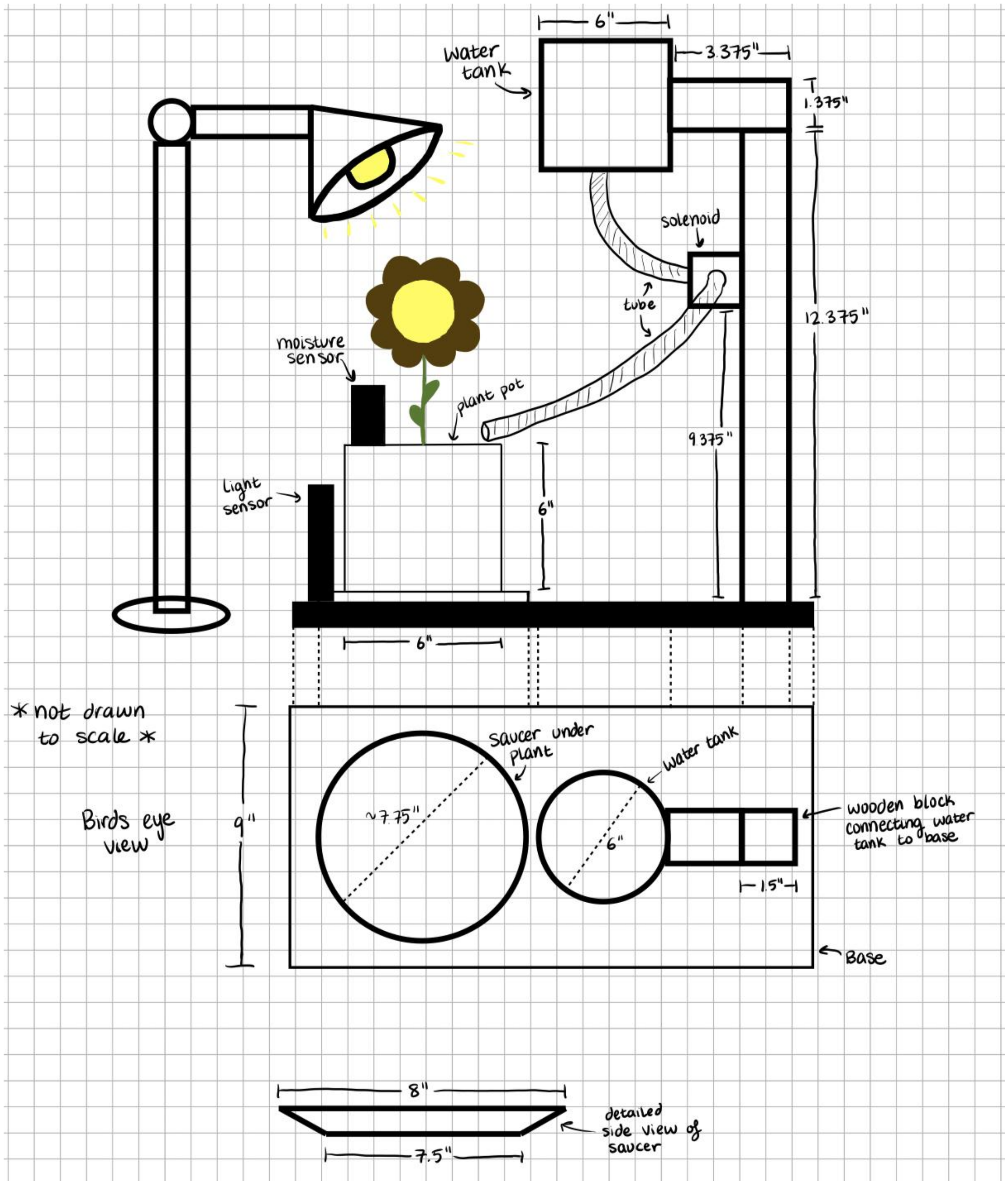

Figure 3: A physical depiction of the Predictive Plant Care system

The physical design is the result of modifying a system from a previous project that suits our needs well. The bottom board needs to be replaced by a larger one such that a saucer can fit into a circular recess in the board. The other modification that needs to be made is replacing the tubes so that they are clean and making one long enough to reach the center of the pot. The water tank is to the side of the pot because the plant should be able to reach a height taller than the water tank. As for the lamp, it has been placed off to the side so that the sunflower won't grow into it. The moisture sensor will sit in the pot and the light sensor will sit just outside the pot on the opposite side of the tube. Electronics will be placed in a box somewhere on the board.

2.3 Moisture Subsystem

2.3.1 Overview

The moisture subsystem contains the water tank, water valve, and moisture sensor. This subsystem is one of the most important subsystems of the device. We will be using the FC-28 soil moisture sensor. This sensor works by measuring the resistance between its two probes. The higher the resistance, the lower the water content of the soil. The output value ranges between 0-70050, 0 being 0% water content and 70050 being 100% water content.

The soil moisture sensor will send a signal to the microcontroller, providing updates on the level of moisture in the soil. When the moisture level gets too low, the microcontroller will send out a timed signal to the solenoid, releasing water to the sunflower for a set period of time.

We can calculate the amount of water needed using the field capacity and wilting point of the soil used. Field capacity is the limit of water held in the soil without draining. Wilting point is the minimum amount of water in the soil that a plant can extract. Sunflowers thrive best in sandy loam soil. Sandy loam soil has a field capacity of 0.23 inches of water per inch of soil depth and a wilting point of 0.10 inches of water per inch of soil depth. This means that the available water capacity is 0.13 inches of water per inch of soil depth. Sunflowers grow best in moisture levels of 80% of field capacity during flowering periods and 70% at other times. This means that the optimal moisture levels using sandy loam soil for a sunflower would be 12.6% during flowering stages and 11% at other times (for calculations see tolerance analysis).

2.3.2 Interfaces

- Controller Subsystem
    - The subsystem sends a signal to the microcontroller based on the moisture level.
    - A solenoid will open after receiving a signal from the microcontroller, releasing water.
- Power Subsystem

- The solenoid will receive 12 Volts from the power subsystem after receiving a signal from the microcontroller.

2.3.3 Requirements

The water subsystem needs to be able to do the following:

1. The moisture content of the soil must be consistently monitored (once every 5 seconds).
2. Water must be dispensed with a timed release when the moisture content is low.

Requirements	Verification
The moisture content of the soil must be consistently monitored (once every 5 seconds).	• Fill 2 cups with soil and water one of them. • Connect the FC-28 sensor to the PCB appropriately. • Monitor the voltage that the sensor outputs to the microcontroller. • Place the sensor in the cup with dry soil at the marked depth and measure the voltage. • Place the sensor in the cup with wet soil at the marked depth and measure the voltage. • Check that the moisture content of the two cups are significantly different.
Water must be dispensed with a timed release when the moisture content is low.	• Fill 2 cups with soil and water one of them sufficiently. • Place the sensor at an appropriate depth in the cup with dry soil. • Connect the solenoid and the sensor to the PCB appropriately. • Turn on the device and make sure the solenoid opens. • Turn off the device and place the

	sensor in the wet cup. ● Turn on the device and make sure the solenoid does not open.

2.3.4 Design Decisions

We will be using part of a previous semester project's water distributing system. It contains a water tank, tubes to and from a solenoid, a weight sensor, and wooden plants connecting everything. We will remove the weight sensor and replace the base and tubes. The weight sensor is unnecessary, the current base is too small, and the tubes could possibly be moldy. The solenoid also needs a 12 Volt input to work. This led us to make the power subsystem use a 100-240V AC to 12V DC power adapter to accommodate for the solenoid. When we replace the tube going from the solenoid to the plant, we will make it longer than it is currently. It is currently set up assuming the plant would be placed directly under the water tank. However, the sunflower would grow taller than the bottom of the water tank and needs more direct sunlight, so we will use a longer tube and offset the water subsystem to be directly next to the plant (see figure 1).

2.4 Light Subsystem

2.4.1 Overview

The light subsystem contains the light sensor and the lightbulb. This subsystem is also one of the most important subsystems of the device. While the sunflower is still growing (pre-flowering), it is recommended to have a Daily Light Integral (DLI) of 12-16 mol·m-2·d-1. Once the sunflower bud emerges, it is recommended to have a Daily Light Integral of up to 20 mol·m-2·d-1. The DLI is the amount of Photosynthetic Active Radiation (PAR) per 24 hours. PAR is the type of light required for photosynthesis to occur. To encourage flowering, it is recommended to have a photoperiod of more than 12 hours but less than 20 hours a day. The photoperiod is the amount of time a plant receives light within 24 hours. With the PAR38 GE Grow Light for Plants, it supplies 50 micromoles per second of PPF. This means that to supply a minimum of 12 mol·m-2·d-1 of DLI, excluding natural light, this light would need to be on for a minimum of 14.5 hours a day. To supply a maximum of 20 mol·m-2·d-1 of DLI, excluding natural light, this light would need to be on for a maximum of 24 hours a day.

We will be designing our own PCB that will contain the light sensor system. We will be using the AS7341 – 11-Channel Spectral Color Sensor to measure and calculate the photosynthetic photon flux density (PPFD) for our system. We can then use the PPFD to calculate the DLI. The PPFD is the amount of PAR that reaches the plant.

We will also be creating a PID controller to control the duration of time that the light is on. The light sensor will be an input into the controller, which will take into account the natural light as well as the light from the light bulb. The PID controller will aim to achieve 14 mol·m-2·d-1 of DLI each day during the growing phase, and 18 mol·m-2·d-1 of DLI each day during the flowering phase.

2.4.2 Interfaces

- Controller Subsystem
  - The subsystem sends a signal to the microcontroller based on the light levels.
- Power Subsystem
  - The light sensor will receive 1.8 Volts from the power subsystem.

2.4.3 Requirements

The light subsystem needs to be able to do the following:

1. The light sensor must be able to measure the PPFD for the system.
2. The PID controller must be able to monitor and control the light duration between 12 and 20 mol·m-2·d-1 of DLI.

Requirements	Verification
The light sensor must be able to measure the PPFD for our system.	• Place the light sensor under the lamp • Place a phone under the lamp (with the PPFD-measuring app on) • Turn on the lamp • Check the values between the phone and the light sensor and make sure they are the same within ~14 micromoles/square meters/second of PPFD
The PID controller must be able to monitor and control the light duration between 12 and 20 mol·m-2·d-1 of DLI (aim for 12 for this verification)	• Place the light sensor under the lamp • Turn on the lamp • Check that the PID turns the light off between 14 and 14.5 hours later.

2.4.4 Design Decisions

Due to our limited budget, we were very limited on which light sensors we could use. All of the cheap light sensors that we've found simply detects light and does not measure the amount of light. Low quality light sensors that measure the amount of light present are $80+, which we simply cannot afford given our budget constraints. We then started looking through academic papers that have created their own light sensors that measure light amounts such as PPFD and/or DLI. We found a recent study (Low-Cost Light Sensors for Indoor Agriculture, Kurasaki, Byrd, 2023) that used the AS7341 sensor to measure PPFD. This study found that, compared to a $270 quantum light meter, this sensor (assembled cost of $51) was able to measure PPFD within 7 micromoles/square meters/second error of the quantum meter. We were able to obtain this light sensor for no cost from the manufacturer. With the AS7341 sensor, we will also need a diffuser in the form of a clear acrylic sheet to make sure that each channel in the sensor receives the same amount of light. We will also need to make sure that the sensor receives 1.8 Volts of power consistently.

Due to the lack of consistent sunshine and freezing temperatures currently outside, we decided to replace the sun with a grow light. We decided to go with the GE PAR38 grow light. This light produces 50 micromoles/second of PPF, which will allow the plant to get sufficient photosynthetic light (see light system overview for calculations). It's a bit on the expensive side ($40), but it was the cheapest bulb that could produce sufficient light.

2.5 Soil Subsystem

2.5.1 Overview

The soil system will be in charge of determining the state of the soil over time through monitoring different qualities of the soil. Specifically, the most important quality that we want to measure is the pH of the soil. We want to use our microcontroller and build a sensor utilizing its aspects in order to detect the value of pH. Typically, pH of soil wants to stay between 6.5-7.5, so that is our target range. If the pH is too low or too high, the plant's caretaker will be notified by a visual on the system that will let them know to add certain materials to bring the soil level back within range. If possible, our soil subsystem will also monitor the nitrogen levels in the soil and resupply nitrogen should it get too low.

2.5.2 Interfaces

- Control Subsystem
  - The subsystem sends a signal to the microcontroller based on the pH levels.
  - The control subsystem sends a signal to add fertilizer and/or pH solution to the water tank.
- Power subsystem
  - Gains 5V for use for the soil subsystem from the microcontroller.

2.5.3 Requirements

The soil subsystem needs to be able to do the following:

1. The pH and content of the soil must be monitored moderately often (at least once a minute, ideally constant).
2. Users must be notified of the need to fertilize the soil in some way once pH or levels are outside the specified range.
3. System must be able to resupply a small amount of fertilizer to restore nutrients or pH solution to lower pH.

Requirements	Verification
The pH and content of the soil must be monitored moderately often (at least once a minute, ideally constant).	• Set up the pH sensor and connect it to the display and microcontroller. • Monitor the voltage that the microcontroller picks up from the sensor. • Place the sensor in the pot with the plant about 2/3 of the way into the soil. • pH should be able to be shown in real time on the display.
Users must be notified of the need to fertilize the soil in some way once pH or levels are outside the specified range.	• To test if it can detect changes in real time, can use fertilizer that raises or lowers the pH of the soil. • Check by adding a small amount of fertilizer (<10g) and checking if the pH will change. • If the pH goes beyond the desired range (6.5-7.5), a small alarm will emit from the LLC speaker connected to the microcontroller.

2.5.4 Design Decisions

We found that, although we had hoped to look at nutrients such as nitrogen, phosphorus, and potassium, it ended up being a little too impractical and expensive to measure these quantities outright. However, we will still be using fertilizer that is rich in these nutrients, so it should still be okay.

In addition, it would be quite difficult to create a mechanism that would be able to supply fertilizer or another source of nutrients on its own, and this would mostly be mechanical anyways, which is not the focus of this course. Therefore, we have decided that this subsystem will merely alert when the contents of the soil need to be altered in some way, instead of fixing the soil automatically, and will therefore require manual input from the user to fix the system based on the alert that they receive.

2.6 Control Subsystem

2.6.1 Overview

The control system will connect the sensing system and power through to the microcontroller to allow every component to work together. It will be directly connected to the sensing systems so that if any of these systems have an overabundance or lack of resources, the microcontroller can send commands to give less or more resources respectively. The microcontroller used for this project will be the ATMega328P-AU.

2.6.2 Interfaces

- Moisture Subsystem
  - A voltage signal ranging from 0-5 Volts will be sent to the ATMega chip periodically, indicating soil moisture.
  - The microcontroller will send a signal for a set period of time to turn on a MOSFET, allowing 12 V to turn a solenoid on causing water to flow
- Light Subsystem
  - A voltage signal of 1.8 Voltz will be sent to the AS7341 sensor.
  - An I2C signal will be sent to the ATMega chip, indicating light levels.
- pH Subsystem
  - The pH sensor will send a signal ranging from 0-5 Volts to the ATMega chip, indicating the pH of the soil.
- Power Subsystem
  - The microcontroller will receive power at 5 Volts from the power subsystem.

2.6.3 Requirements

Requirements	Verification
The control system must be able to utilize the capabilities of the microcontroller to send out and read in	• Must be able to connect to the moisture subsystem and read in the signal from the moisture sensor. If the moisture gets too low, it must be able to output a

signals that will affect the automation of the entire plant care system.	signal opening the solenoid and allowing moisture through. • Must be able to connect to the light subsystem, reading the signal from the light sensor and adjusting the light's on/off cycle. • Must be able to connect to the soil subsystem and read signals from the pH sensor, and output a signal adding fertilizer if it gets too low.
The microcontroller must be able to send voltages out to multiple different devices that are connected to it.	• The microcontroller in the control system must take an input voltage from the power system. • The microcontroller will then output the signal to the various subsystems.

2.6.4 Design Decisions

As our project involves a large amount of measuring signals and sending out signals in response to those, we needed a chip that was capable of having multiple input and output signals. The ATMega328 has a large number of GPIO pins which should suit the needs of the project quite well. The soil moisture sensor and module was built to interact with Arduino, sending a signal ranging from 0 to 5 Volts. Using a chip that is on an Arduino (the Uno) will allow for easier use.

2.7 Power Subsystem

2.7.1 Overview

The power subsystem is what will provide power to the rest of the subsystems. This will be done through a 100-240V AC to 12V DC power adapter that will take power from the wall and send it to a DC-DC converter, converting that down to 5 Volts. 12 Volts is also used to power the solenoid in the moisture subsystem. The 5 Volts will then be used to power the microcontroller. The microcontroller will then power most of the other sensors through several 5V pins. The lightbulb will be powered by a separate wall plug.

2.7.2 Interfaces

- Moisture Subsystem
  - 12 Volts from the power subsystem will be used to turn the solenoid on and off.
- Controller Subsystem
  - 5 Volts from the power subsystem is used to provide power to the microcontroller.
- Light Subsystem
  - The lightbulb will be receiving power from the power subsystem (through a wall plug).

2.7.3 Requirements

Requirements	Verification
Power system must be able to provide the requisite amount of voltage to each subsystem that requires it.	• 12 volts to the moisture subsystem, through a power converter. • 5 volts to the control subsystem, through a power converter (this voltage will then be used between the moisture, light, and soil subsystems). • 120 volts to the lightbulb, directly from a wall plug.

	• These voltages will be tested via a multimeter to verify they are the correct amounts.
Power system must be able to provide power to multiple devices without overloading.	• To accomplish this, we not only have separate power supplies, but we are also splitting some power via power converters. • The voltages down each path of the converters will also be tested to verify the correct amount of voltage is passing through.

2.7.4 Design Decisions

In using the parts of a previous project, we need to be able to provide 12 Volts to the solenoid while also needing 5 Volts for the microcontroller. This means that there needs to be a power converter on the board to obtain both of these voltage levels. The lightbulb requires a significantly higher voltage than the other components, so we decided on plugging it in separately and using a MOSFET to control the light instead.

2.8 Tolerance Analysis

In order to accurately create a model for the moisture level of the plant, we have to have some way for the system to calculate the water moisture range that would be suitable for the plant. This is a little risky since it involves calculations as it goes along and finding out a good value based upon the data in a certain amount of time. We don't want our moisture level to be too high or too low, so the system needs to find a good balance. However, we can compare our plant and the area of the soil that our plant is in to other similar cases in order to provide a rough estimate for how much moisture our plant may need each day. From there, it should only need to make rough changes in order to find a good, consistent moisture addition.

The optimal moisture content of the soil depends on which soil is used. We will use sandy loam soil. We can find the optimal moisture of the soil based on the soil's available water capacity and the sunflower's optimal water depletion. Available water capacity is the field capacity subtracted by the wilting point. The field capacity is the maximum water held in the soil without draining due to gravity and the wilting point is the minimum amount of water in the soil in which a plant could still extract water. Sandy loam soil has a field capacity of 0.23 inches of water per inch of soil depth and a wilting point of 0.10 inches of water per inch of soil depth, which means that sandy loam's available water capacity is 0.13 inches of water per inch of soil depth.

Sunflowers grow best in moisture levels of 80% of field capacity at flowering stages and 70% of field capacity at all other times. For a moisture level of 80% of field capacity, this means the optimal water content within sandy loam soil would be 0.184 inches of water per inch of soil depth, which would be 5.2 cubic inches of water per inch of soil depth. Assuming we use a 6" diameter pot with a 5" depth, this would amount to 25.99 cubic inches of water total in the pot, which is 425.9761 grams of water. The density of sandy loam soil is 1460 kg per cubic meter, which means the optimal moisture level for a flowering sunflower would be 12.6%.

For a moisture level of 70% of field capacity, this means the optimal water content within sandy loam soil would be 0.161 inches of water per inch of soil depth, which would be 4.55 cubic inches of water per inch of soil depth. Assuming the same pot size as before, this would amount to 22.75 cubic inches of water total in the pot, which is 372.8725 grams of water. Assuming the same density of sandy loam soil as previously, the optimal moisture level for a growing non-flowering sunflower would be 11%.

3 Cost and Schedule

3.1 Cost Analysis

Description	Manufacturer	Part #	Quantity	Cost
Big Smile Sunflower Seeds	Johnny's Selected Seeds	1312.51	50 seeds (1 packet)	$5.20 + shipping and tax
GE Grow Light for Plants PAR38 + lamp	General Electric	39111800	1 lightbulb	$43.97 + shipping and tax
AS7341 11-Channel Spectral Color Sensor	AMS	AS7341	1	$0 (free sample)
8 inch Plastic Plant Saucer	Vigoro	VS8VG	1	$0.98 + tax (free shipping with pick up)
Trade 1 Ga. Black Thermoformed Nursery Pot	Trade	TFR001G0G18	1	$1.48 + tax (free shipping with pick up
Soil Moisture Sensor and Module for Arduino	ARCELI	YL-69 & HC-38	1	$5.99
Microcontroller	Microchip Technology	ATMEGA328P-AU	1	$2.86
1 uF Capacitor	Samsung Electro-Mechanics	CL05A105MQ5NNNC	1	$0.10
22 pF Capacitor	TDK Corporation	C1608NP01H220J080AA	2	$0.34

10 uF Capacitor	Holy Stone	C0805B106K025T	4	$0.29
100 uF Capacitor	Samsung	CL21A107MQYNNWE	1	$0.87
Shottky Rectifier Diode	Yangzhou Yangjie Electronic Technology Co.,Ltd	MBR0520	1	$0.38
10 kΩ Resistor	YAGEO	RC2512JK-0710KL	1	$0.31
120V AC - 12V DC Converter	Facmogu		1	$10.79
16 MHz clock	Raltron Electronics	AS-16.000-20-EXT	1	$0.18
Low Power MAX485 Transceiver Module	Maxim Integrated	MAX485	1	$0.31
pH Sensor	Sonkir	MS02	1	$9.99 + tax and shipping
Display Module	Solomon Systech	SSD1315	1	$2.24
Small Speaker	Soberton Inc.	SP-2306-1	1	$2.23
Liquid Fertilizer	Sensi Cal Mag Xtra		1 (250 mL)	$11.35 + tax and shipping
Barrel Power Jack	Wurth Elektronik	694106402002	1	$1.22

Total Cost	$90.36 + some tax and shipping (estimate about $100 total)

Machine shop: After our conversation with the machine shop, we are using a previous project's water delivery system, which will require a small amount of modification, most of which we can do on our own. Otherwise, we do not plan on using the machine shop for other parts, so the estimated Machine Shop time is 3 hours.

Labor Hours	Average Starting Salary for major (according to Payscale)	Hourly rate based on yearly rate	Estimated total number of hours on project	Total Labor Cost
Charlotte	$75,097	$36.10	150	$5415
Thomas	$80,765	$38.83	150	$5825
Tom	$80,765	$38.83	150	$5825
Total Labor Cost				$17065

Total cost = $17065 + $100 = $17165

3.2 Schedule

Week	All	Charlotte	Tom	Thomas
2/27-3/3	Design review, Order parts, Safety Training	Design light system	Design PCB	Design PCB
3/6-3/10	First Round PCB orders, Teamwork Evaluation 1	Design PID controller	Design base	Make modifications to moisture system
3/13-3/17	Spring break			
3/20-3/24	Plant sunflower, Revisions to PCB design, Assemble power system	Create PID controller	Validate moisture system	Modify lamp
3/27-3/31	Second round PCB orders, Individual Progress Reports, Assemble control system	Debug PID controller	Assemble light system	Revisions to PCB design
4/3-4/7		Validate light system	Validate light system	Integration tests
4/10-4/14	Team Contract Fulfillment	Finalize Assembly	Integration Tests	Integration Tests
4/17-4/21	Mock demos, Fix minor bugs			

4/24-4/28	Final demos			
5/1-5/5	Final Presentation, Final Papers, Lab Notebook			

4 Ethics and Safety

One of the single biggest safety concerns in using our project is the lightbulb breaking and cutting the user. Also, the use of a 120V plug introduces the risk of a severe electric shock. Since both of these risks are present in our project, they pose a safety concern to any user and are of concern in regard to IEEE Code of Ethics Section I.1[1]. To minimize the risk of shock, we can put a warning for a shock risk on the wall plug and pack the lightbulb separately with a warning of fragility and the risk of sharp glass.

The biggest way to misuse this product would be to grow illegal plants with this device. This would include mostly any plant that could be produced into illegal drugs such as opioid plants or marijuana, depending on the location. While there is not much that we can do on our end to prevent this, we can very clearly discourage the misuse of our product.

Since we will be utilizing high voltages for our lightbulb and other devices, our entire group will be taking an additional safety training as a requirement for this course. In addition, since we will be working with many electronic devices around water as well, we will try to keep our subsystems separate as long as possible, and make absolutely sure that our solenoid for our moisture system fits on well so we don’t leak any water.

5 Citations

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