March 30, 2017
Dr. Andrew Rawicz
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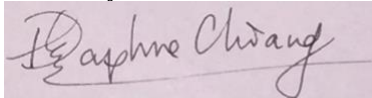
Re: ENSC 405W/440 Design Specification for Gaia

Dear Dr. Rawicz,

The enclosed document, Design Specification for Gaia, describes the details of how our project for ENSC 405W/440 will be designed. We anticipate a product that removes the difficulty of growing plants inside a house. Whether it is an exotic orchid or a plant that yields fresh produce, Gaia provides the necessary care and environment for all types of plants to thrive with minimal human dependency.

This document is meant to illustrate the hardware and software designs of our system and how it will be constructed. It provides the information and relevant figures and tables of what components will be used and how. This will follow the system's requirements as described in the requirements specification document. Any changes in design since the proposal will be explained and the reasoning behind decisions in the types of components or way of implementation will be given. This document will be referred to when building the proof-of-concept, prototype, and final product versions of Gaia.

Applied Agricultural Innovations is an up and coming company composed of five engineering students: Daphne Chiang, Sunny Sun, Jenny Cheung, Philip Tang, and Jerry Hung.
Please feel free to contact us for any questions or concerns. We will be pleased to address any of your inquiries by email at mca123@sfu.ca or phone us at 778-875-668.

Sincerely,

Daphne Chiang
CEO
Applied Agricultural Innovations
Attachment: Design Specification for Gaia

Design Specification
Applied Agricultural Innovations

Product - Gaia

March 30, 2017

Team Members:

Daphne Chiang

Philip Tang

Sunny Sun

Jerry Hung

Jenny Cheung

Abstract

Gaia is capable of housing one plant and takes care of a plant's needs including watering, light, temperature, and humidity. This document is the design specification of Gaia made by Applied Agricultural Innovations. It outlines design specifications for the overall system, individual systems, and user interface. For the overall system, it includes physical and electrical designs. Individual systems are separated by features: watering, lighting, humidity, and temperature control systems. Each system, including user interface, contains mechanical, hardware, and software specs. All the design specifications are described with Solidworks model, dimensions, and some descriptions to back up the engineering decisions. Specifications are also distinguished between different stages of the project (proof-of-concept, prototype, and production versions) and matched up with the requirement specifications. The safety design, test plans, and User Interface Appendix are also included.

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Glossary

Fluorescent	The emission of electromagnetic radiation, especially of visible light, simulated in a substance by the absorption of incident radiation and persisting only as long as the simulating radiation is continued
Grommet	An eyelet placed in a hole in a sheet or panel to protect or insulate a rope or cable passed through it or to prevent the sheet or panel from being torn
Incandescent	Electric light with a wire filament heated to such a high temperature that it glows with visible light
LED	Light-emitting diode, a semiconductor diode that emits light when a voltage is applied
Lux	The SI unit of illuminance, equal to one lumen per square meter
Microcontroller	A computer present in a single integrated circuit, which is dedicated to perform one, task and execute one specific application. It contains memory, programmable input/output peripherals as well a processor
Thermoelectric	Producing electricity by a difference of temperatures
Photosynthesis	The process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water
UI	Short for user interface
UV	Short for ultraviolet, an electromagnetic radiation with a wavelength from 10 nm (30 PHz) to 400 nm (750 THz)

1. Introduction

Gaia is the name of the ancient Greek goddess of the Earth and it is also known as "the hypothesis that the living and nonliving components of earth function as a single system in such a way that the living component regulates and maintains conditions so as to be suitable for life" according to the Merriam-Webster [1]. Parallel to its mythical derivation, we aim to build Gaia to become a system that invigorates the plants it contains through regulation and maintenance of its living environment. Conveniently, its purpose supports those who lack the time, resources, skills, and/or freedom to tend to their cherished flora. This new link in the chain allows for the perfect symbiosis between the plants that bring life to a home, and the users who can comfortably relax and enjoy it all.

Being a self-sufficient system in plant care, automation is supported with temperature (heat/cool), lighting (visible), and watering. Working in tandem, these critical features replicate the optimal living environments for their selected flower or crop species. With a tower-like design which enables uninterrupted viewing of the hosted plant, the system encases the living article through a rectangular prism of clear plastic material. Through this setup, efficient temperature regulation for the plant is possible from its thermoelectric heater/cooler mechanism. Pumping water from its reservoir in the base of the tower, Gaia can maintain suitable soil moisture levels for a long period of time. Were the background lighting insufficient to the plant, additional LED lights activate and provides an ample supply of energy to support photosynthesis. To the users, affectively using Gaia is but the three simple steps "place, plug, and pick"—place a plant inside, plug in the sensor to the soil, and pick a species through the LED display.

1.2. Intended Audience

The design specification is intended for all staff of Applied Agricultural Innovations. These specs are the standards and descriptions for engineers to design Gaia. This document will be referred to during design, implementation, and testing phases. The project manager shall refer to the design specifications throughout the progress of the development phase. Engineers shall refer to the specifications as they implement the product. Test engineers shall refer to the test plans from this document to test if the functionalities meet the expected results.

2. System Specification

Gaia is an autonomous luxury growth chamber. It controls the humidity, temperature, lighting, and watering conditions according to the species of plant it is taking care of. The device has a humidity sensor and can increase the humidity of the environment if it is too low. Gaia will have a temperature control system that will lower or increase the temperature inside the device if necessary. If the lighting outside of the device is not enough for the plant, Gaia will turn on or increase light with LEDs. Gaia will also automatically water the plant if the soil moisture level falls to the watering threshold of that plant. Gaia will also have a LCD screen on the device and

a phone app. The screen displays the current plant species inside Gaia and the temperature and humidity inside of the device. The app is where the user selects the type of plant species and has a manual mode. With the manual mode, the user can turn on blue or red LED lights and water their plant whenever they choose by pressing a button. The app will display a warning if the water level in the watering tank is low and will display information on the current conditions inside of Gaia.

3. Overall System Design and Justifications

The design of Gaia has changed from its original design in the project proposal. In addition to the watering, lighting, and temperature systems a humidity control system has been added. This is because while air humidity is not the most important contributor to a plant's health, for some plant species having a high air humidity will be beneficial to their growth and is a feature Gaia will support. During a meeting with Sherryl Bisgrove [2], an associate professor in plant cell & developmental biology at SFU, she discussed the importance of watering a plant properly over the rest of the features and emphasized the importance of nutrients in soil.

There are two main ways fertilizer is administered to potted plants: solid and liquid fertilizer [3]. Instead of a customized system to administer fertilizer, Gaia will make use of the commercial products available. Liquid fertilizer can be poured into the watering tank which will ensure that the plant can receive a suitable amount of fertilizer while it is being watered. The other option is to use solid fertilizer as instructed. The solid fertilizer can be inserted directly into the soil and distributes fertilizer for a long period of time.

Another change from our initial proposal is to add a phone app to Gaia. An app will make the initial setup and plant species selection process easier than using a LCD monitor and control buttons as was expected in requirements [4] [R95] and [R97]. It also removes the need for [R94], a time of day selection, as Gaia can simply get the information from the phone app. The app can display more data about the plant's environment and introduces an automatic and manual control mode to Gaia.

The automatic control mode will be completely hands free. The device will control the systems and administer changes to the plant's environment according to the requirements of the species. The manual mode is directed towards enthusiasts and researchers. While the humidity, temperature, and lighting systems are still controlled by Gaia, the watering will be controlled by the user. Also, the manual mode has red and blue light available for the user to control as they like. Increasing the plant's exposure to red or blue light will encourage it to flower or grow respectively [5]. Originally the device also included UV lights as a part of the lighting system. However, after some discussion with Professor Bisgrove, it was decided to remove the lights due to the unproven effects of UV light on plants and the potential harm to users from exposure to UV light. These changes were made with the intention to make Gaia more appealing to its target market and expanding its features.

4. High Level Control System Design

4.1. Processing Unit Selection

The processing unit selection takes into account several functional requirements [R98-R102] that must be upheld, along with additional features that better suit the goals of designing and building Gaia. Picking the optimal microcontroller for the job boiled down to the selection between the Arduino Mega and Arduino Uno. It should be noted that both meet the requirements specified in [R98-R102]. Below in Table 1 is a breakdown of features and specifications afforded by both controllers:

Table 1: Comparison between Arduino Mega and UNO

Microcontroller	Mega	UNO
Price	$45+	$25+
Input voltage	7-12 V	7-12 V
Digital I/O Pins	54	14
Analog Inputs	16	6
Flash Memory	256 KB	32 KB
Clock Speed	16 MHz	16 MHz
SRAM	8 KB	2 KB
Dimensions (LxW)	101.52 x 53.3 (mm)	68.6 x 53.4 (mm)
Wi-Fi compatible	Yes - with attachment	Yes - with attachment
LCD display compatible	Yes - with attachment	Yes - with attachment

A visual comparison of the two devices are shown below in Figure 1.
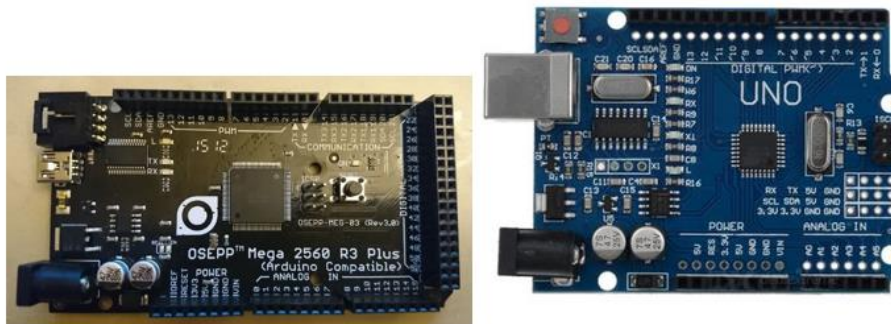
Figure 1: Arduino Mega (left) and Arduino UNO (right)

Ultimately, the decision to use the Arduino Mega was chosen. Functionally, the Mega offered more expanded hardware capabilities at the expense of a larger cost. Evidently, the most important parameters considered for this choice belonged to the increased non-volatile memory and the pin count for peripherals.

Greater Pin Count

The extra I/O pins on the Mega are absolutely critical to its reliability and ease of manufacturing. With the project requiring various pins for soil, water, temperature, light, display, and redundancy, there is little room to spare even for the Mega. Though it is possible to use the UNO to meet the same requirements, this would be inefficient due to need for additional circuitry, time, and complexity.

Expanded Memory

The main benefit of supporting 256 KB of flash memory as opposed to the lower 32 KB offered by the Uno is in affording the option to further expand the project. Every plant species Gaia can support requires some storage and with 8x more, this feature grants Gaia far greater flexibility without the need for external storage options.

4.2. System Design

This section is a high-level description of the entire system as well as its internal relations among each subsystem. Figure 2 is a block diagram that describes the system that will be Gaia.
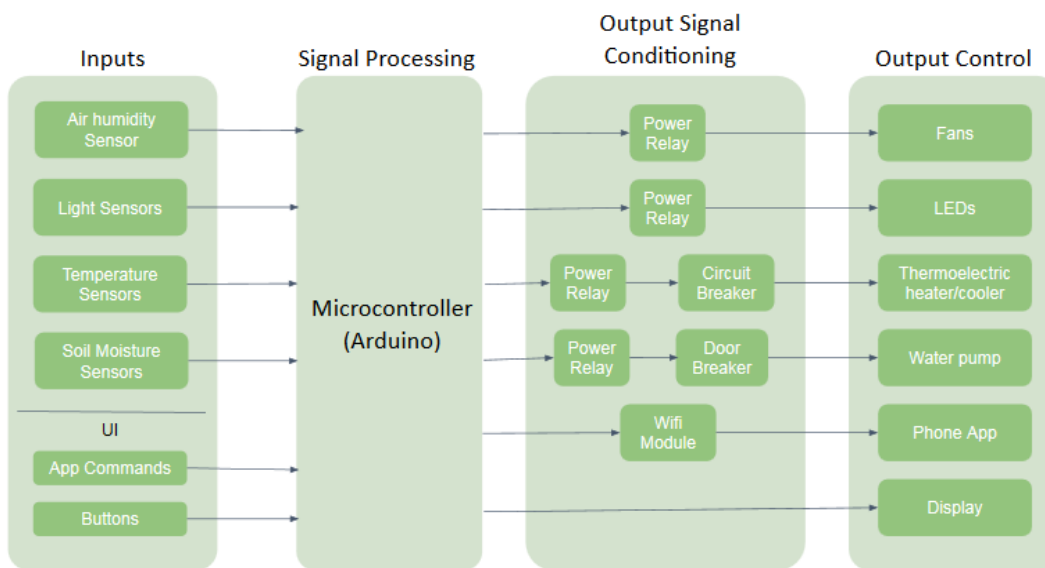
Figure 2: High-level System Block Diagram

Inputs to the system consist of environmental measurements such as temperature, humidity, soil moisture, and brightness, as well as button presses and application commands. All of the inputs are received through the I/O pins save for the app commands which will be checked through Wi-Fi.

The processing of the input signals will be entirely dealt with by the microcontroller (Arduino Mega) and will be processed according to the software developed by AAI. The goal of the software will be to synchronize input processing and to facilitate actuation of all the components within the requirements [R46-R48].

On the other end of the system diagram, the outputs will be conditioned for proper current and voltage levels for each actuator. Mainly the power relay will provide proper current switching

to power the devices other than the display or app data. Together, the system will act to produce the most suitable environment for the plant species while sending data to the user.

4.3. Main System Process

The main system process oversees the general operation and processing of all the information received by the controller. It is run upon start up and will loop continuously through the main loop. The flowchart of its operations is shown below in Figure 3.
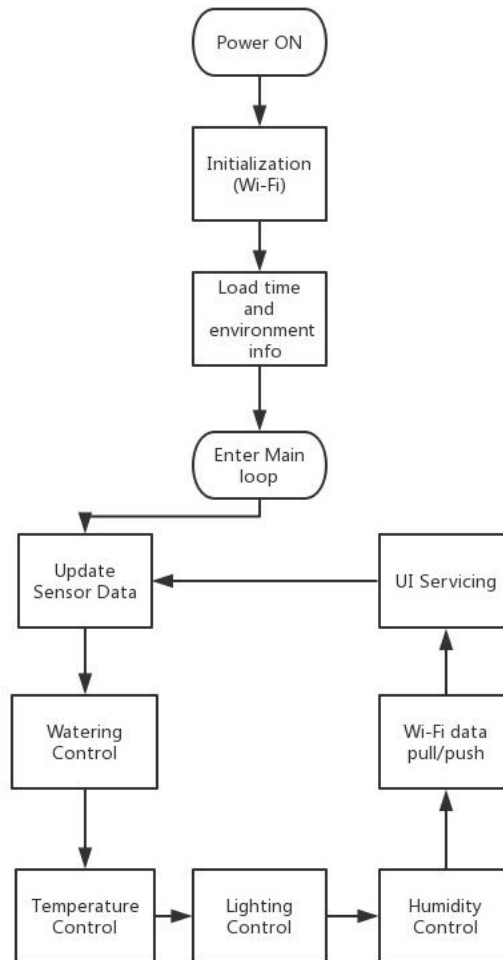
Figure 3: Flowchart of Gaia's main system process

For a reference to the representation of each flowchart shape, check Appendix A: Basic Flow Shapes Diagram.

From start up, each process undergoes its own routine that accomplishes a specific task. At the main loop, each environmental control process gets equal service and none of the processes are capable of hanging and stalling the system. Start up will occur the moment power is switched on and the system flow will only stop if power is disconnected. The flow will provide complete automation of the plant care and account for user instructions when given.

5. Physical Design

5.1. Overall Appearance

From start up, each process undergoes its own routine that accomplishes a specific task. At the main loop, each environmental control process gets equal service and none of the processes are capable of hanging and stalling the system.

Startup will occur the moment power is switched on and the system flow will only stop if power is disconnected. The flow will provide complete automation of the plant care and account for user instructions when given.
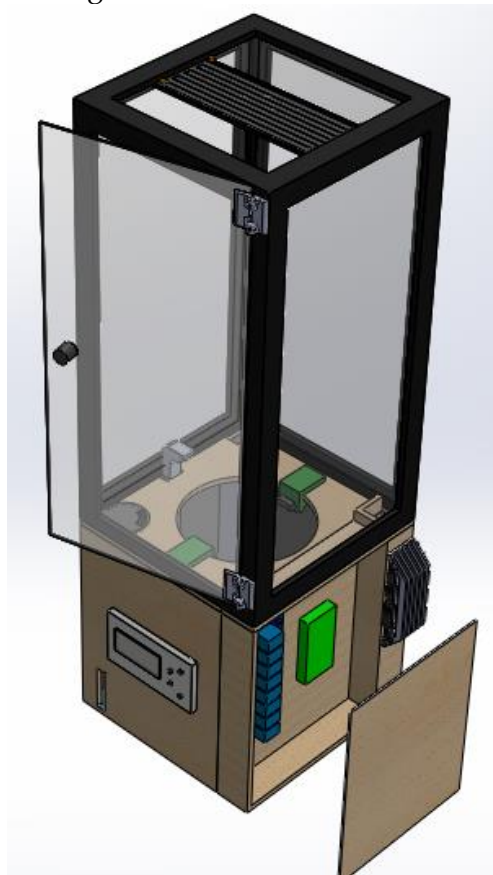
Figure 4: Solidworks model of Gaia with access panel removed

The rectangular tower shape satisfies [R5] and provides a roomy structure for plant growth.

5.2. Dimensioning

To account for the dimensioning of the construction, Figure 5 below details the main dimensions of Gaia in its prototype and production models.
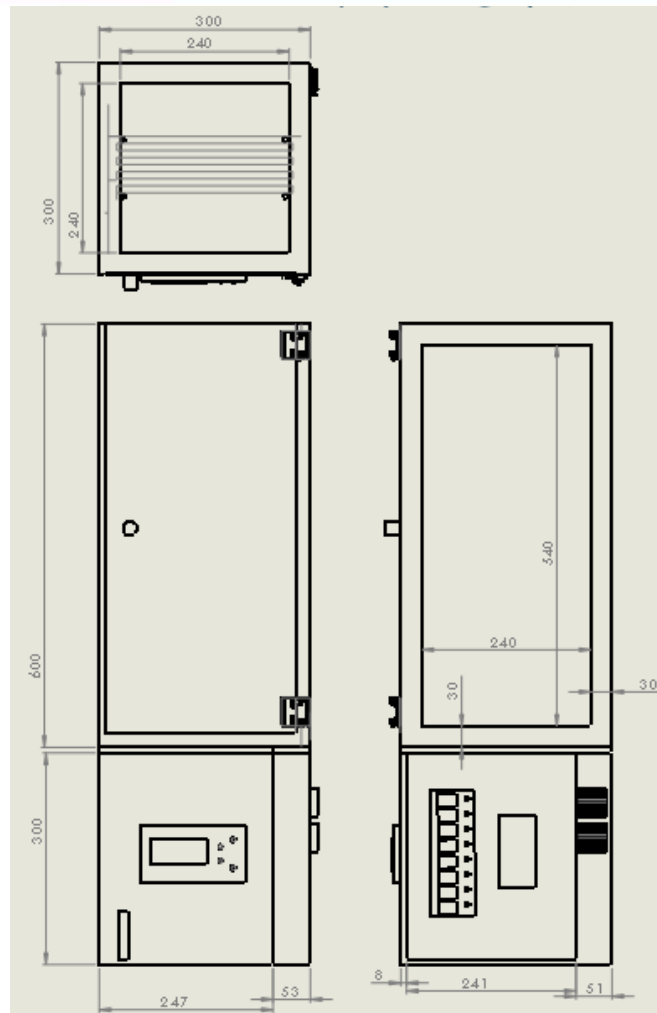
Figure 5: Top, front, and side view with main dimensions of Gaia (all units in millimetres)

During the proof of concept stage, the dimensions will be more flexible to allow for a simpler and quicker build at the cost of a loss in aesthetics though this is of no concern. The above dimensions also comfortably fit into the sizing requirements held by [R6, R7].

5.3. Enclosure

The upper section of Gaia consists of five transparent sections that allow light in, but traps air. It holds the lighting system and its frame will work to conceal most of the wiring. Additionally, a swinging door is positioned at the front. At its prototype and production stage it's completed likeness will appear as Figure 6 below.
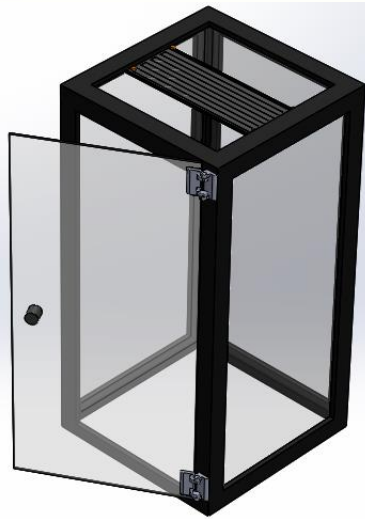
Figure 6: Solidworks model of the enclosure section of Gaia

Prior to the final design, several design decisions were weighed. The first design decision was in the construction of the frame. Design options were:

1. Entirely transparent enclosure
2. Transparent enclosure with opaque frame
3. Transparent front with remaining sections opaque

The weighing of these choices resulted in the following Table 2 of pros and cons of the design options:

Table 2: Comparison among valued characteristics of each enclosure design

Characteristic	Option 1	Option 2 (Chosen)	Option 3
Cost	High	Mid	Low
Difficulty	High	Mid	Easiest
Visual appearance	Sleek	Decent	Simple
Light ingress	High	Moderate	Low
Heat Loss	High	Less High	Low
Durability	Fragile	Strong	Most durable

The decision for option 2 with the frame and transparent windows is owed to our decision to equally value ease of construction, and functional outcomes of the design. Its visual appearance would have been mostly subjective, and it was at a minimum loss for durability compared to option 3.

Another design decision was in the choice of transparent material used in the enclosure. The goal of using transparent material was for the users to enjoy their plant unobscured while letting in sunlight or home lighting for plant growth.

Our options for the material were:
1. Clear acrylic
2. Glass
3. Plastic sheets

The weighing of these choices resulted in the following Table 3 of pros and cons of the design options:

Table 3: Comparison of different materials

Characteristic	Acrylic (Chosen)	Glass	Plastic sheets
Cost	High	Mid	Low
Difficulty	Mid	High	Easiest
Visual appearance	Good	Most luxurious	Poor
Fog Resistance	Mid	Low	Mid
Heat Loss	Low	Mid	High
Durability	Most Resilient	Low	Expendable

The final decision for selecting acrylic owed to its satisfaction for [R9, R33] in being durable and shatter resistant yet clear. Its installation and processing was deemed acceptable given its added benefit of being a better insulator. Overall its higher unit cost was of minimal concern granted this project is meant as a high-end product. The plastic sheet option however is also not rejected as it is an excellent option for the proof-of-concept model of Gaia.

The front door of the enclosure will swing out to the right since the average user will likely be right handed. Its material will consist of the same clear acrylic as the windows and will be held by a pair of simple hinges. The user will have a simple knob bonded to the door as means of opening and closing the door.

5.4. Base

The base of the Gaia design contains many of the sensors and watering components as well as the main housing for the pot of the plant. It holds the water and carries the user interface on the exterior. Figure 7 below is the base of Gaia that is separated from its other main components.
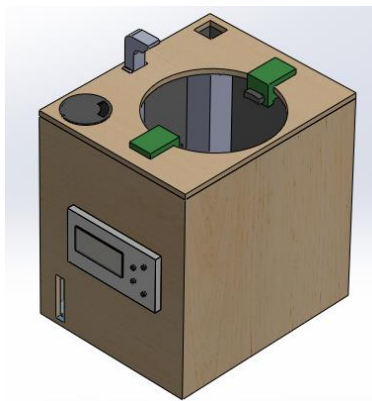
Figure 7: Solidworks Model of the base of Gaia

Note that the locations of each subsystem and their respective peripherals are described in their own specific section in this design spec. This design was opted over the original design from the proposal which did not have the hole in the center. At the cost of a higher difficulty in construction, the hole in which the pot resides in offered greater stability, safer watering methods [R41], and a sleeker look [R8].

The pot containment hole will be capable of holding pot sizes from 12 to 18 cm in diameter for the prototype. The hole has spring loaded arms that will push against the sides well enough for the lips of the pot to rest on the top of the grippers. The symmetric placement and constant pressure will serve well to maintain a stable pot placement. The arms will look like Figure 8. They are attached to the pot containment hole with clips on the edge of the hole.
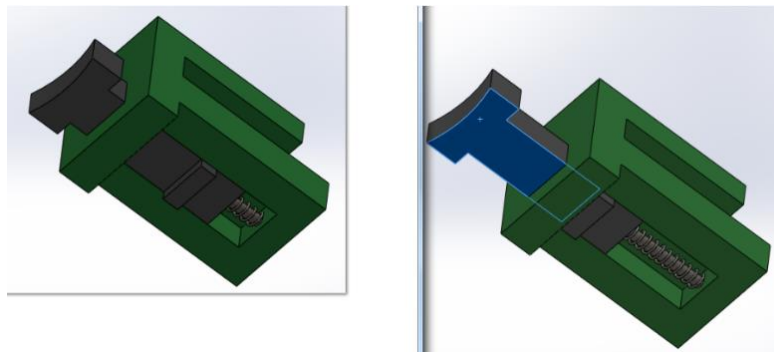
Figure 8: Pot Containment Arms

The main construction material for the exterior of the base will be from wood rather than metal or plastics. This design option was chosen for the following purposes:
      1. Wood is relatively light and will work to satisfy [R49]
      2. Strength is well within the operational range of carrying a potted plant [R32]
      3. It is easy recyclable, reusable, and renewable [R53].
      4. Price per volume is the lowest of the three

As for the interior, the walls will be waterproofed with a thin layer of plastic sheeting and silicone with additional waterproofing for leads from electrical components.

For the prototype and proof of concept design, reclaimed wood will be sufficient to construct Gaia. During production, wood will be purchased from reclaimed wood suppliers in bulk.

5.5. Control Module

The control module of Gaia contains the bulk of the core electronic components including the Arduino, switching elements, wiring nodes, and heating/cooling system. Below is Figure 9, an image of the isolated control module with the access panel removed.
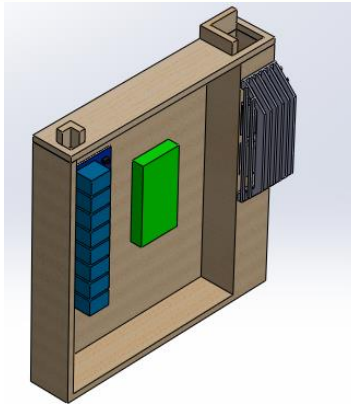
Figure 9: Solidworks model of the control module

The control module was designed to be well protected from the water from the base and enclosure. The core electronics will be mounted as depicted from the previous figure and is protected by two layers of walling (base wall + control module wall).

From this section, wiring will be snaked through the top walled-hole and into the enclosure to power electronics above.

Power to components in the base will be met by sending wiring through small holes well above water level on the upper level of the control module. Additionally, the small holes will be sealed off with silicone for greater water proofing.

The separate module for the main electronics components was selected for the following
1. Excellent protection from water damage
2. Modularity allows for easy debugging and maintenance
3. Ease of construction
4. Localized electronics save on wiring costs

6. Electrical Design

Gaia has one single power source using standard wall outlets which are 120V AC 60Hz. An AC adapter is used to convert the voltage to 12V DC for powering the internal components. From summing the current requirements, the power supply must be capable of delivering 6.34A. For protection purposes, the circuit needs an 8A circuit-limited circuit breaker before distributing the current to each subsystem in the device.

As shown in Figure 10, to reduce the complexity and increase the safety of our design, a power relay to bridge between the devices and the power supply is used. Each device connects to one power relay, and a microcontroller controls power relay. Considering the number of devices available, nine power relays are needed. By wiring the devices in parallel, the individual subsystem components will have minimal interaction with each other. Most of the devices operate on 12V DC, but the fans need 3V. Voltage dividers between the power relay and the fans to convert from 12V to 3V DC are necessary.
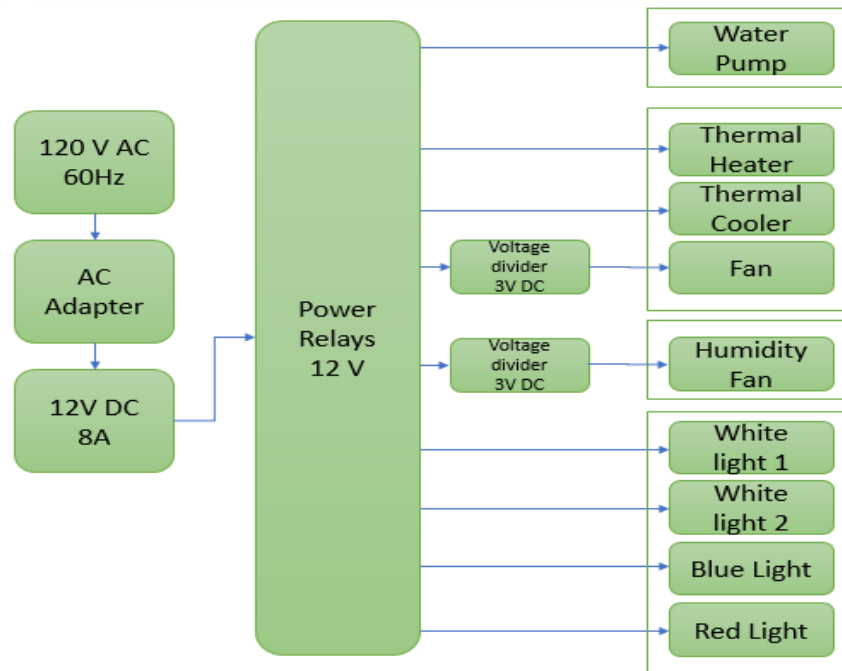
Figure 10: Subsystem power branch

Our choices in internal devices resulted in the following Table 4 for the power consumption of the internal components.

Table 4: Internal components power consumption table

Device	Voltage	Current	Power
Water pump	12 V	400 mA	4.8 W
Fan -- humidity	3 V	300 mA	0.9 W
Fan -- temperature	3 V	300 mA	0.9 W
Thermal heater	12 V	5 A	60 W
Thermal cooler	12 V	5 A	60 W
Light white 1	12 V	90 mA	1.1 W
Light white 2	12 V	90 mA	1.1 W
Light blue	12 V	70 mA	0.8 W
Light red	12 V	90 mA	1.1 W

When the system is fully operating, since the thermal heater and cooler can not be on at the same time, the maximum current it can take from the power source is 6.34A, and the power consumption is 60.7W [R16]. Therefore, a 12V 8A AC adapter is good enough for Gaia.

A 5V battery will be used to power the microcontroller for the proof-of-concept design because it is easier to control and debug the system. The final production version of Gaia uses 120V AC 60Hz standard wall outlets.

7. Lighting System

Figure 11 is the system diagram of lighting system.
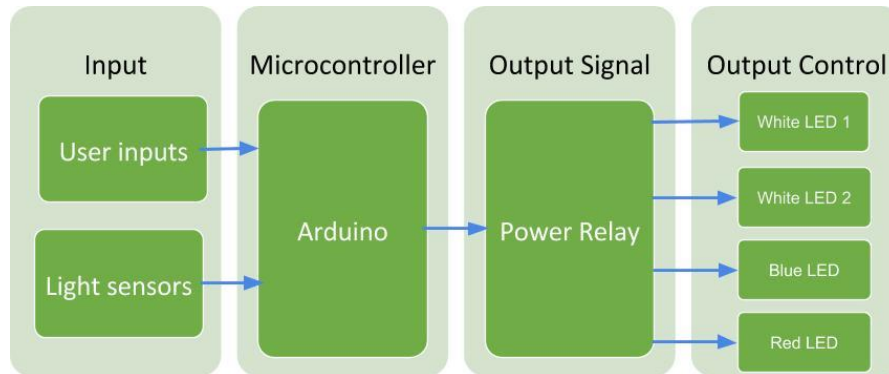
Figure 11: System Diagram of Lighting System

The input of the light system consists of user inputs and light sensors. The lighting system has four light sensors connected to the Arduino. They will measure the lux of the light outside of the device and the Arduino will take the average value of the four. User inputs are received from the app and transferred to the Arduino via Wi-Fi.

The Arduino processes the signals from the app and the light sensors according to the software developed by AAI. Connecting the LEDs to the Arduino is a power relay, one channel for each LED light strip, two white strips, one blue, and one red.

If the device is in manual mode the blue and red LED lights are controlled by user inputs, fulfilling the requirement [R71]. The white LED lights have two levels of intensity. The Arduino will turn on the white LED lights depending on the signals received from light sensors as mentioned in requirement [R72].

7.1. Physical/Mechanical Design

Figure 12 shows the placement of the LED light strips.
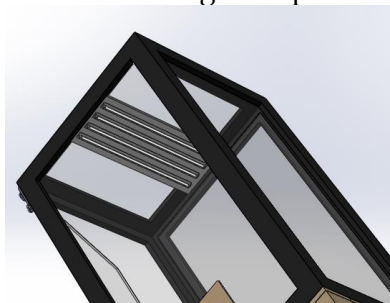
Figure 12: Location of LED light strips

Figure 13 shows the location of light sensors, which are the orange markings.
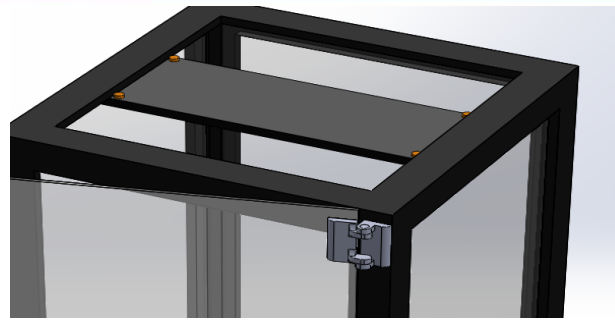
Figure 13: Location of light sensors

The dispersion of the light sensors makes it easier to wire because it is close to the LED light strips while providing an accurate lux measurement.

7.2. Hardware Design

When choosing the type of light, several functional requirements [R71-R77] were considered. The light source must be available in natural white light as well as blue and red light. The heat emitted by the light should also be negligible in order to reduce its impact on the temperature inside of the enclosure. There are three common types of light sources which are used for growing plants indoors. Table 5 compares the features of LED, fluorescent, and incandescent light bulbs [6].

*Table 5: Comparison of different types of light*

Characteristics	LED (Chosen)	Fluorescent	Incandescent
Percent of energy wasted as heat	9%	96%	98%
Life time	30,000 hours	10,000 hours.	1,200 hours
Cost per bulb	$9.95	$3.95	$1.25
Turns on instantly	yes	slight delay	yes
Durability	durable	fragile	fragile

Functionally, LED lights have the longest lifetime out of the three, which is 30,000 hours. 30,000 hours is equal to three and half years, which meets requirement [R35]. In order to reduce the effect of the light system on the temperature inside the device, a light source that emits as little heat as possible will be a better choice for Gaia [7]. According to table a, the heat emitted by the LED light is the lowest of the three. Although LED light is more expensive than the others, LED lights are the still best choice for Gaia with consideration of the percent of energy wasted as heat and life time.

Gaia uses photocells for the light sensors. This photocell is chosen because it is the most common type of light sensor used in Arduino projects. Also, the price of this photocell is very economical, which is less than a dollar.

Gaia offers three different colours of LED lights; blue, red, and white. The blue and red lights are supplementary and are meant for the manual mode of our device while the white light is critical for plant development and is controlled by the microprocessor at all times.

According to the meeting with Sherryl Bisgrove, Associate Professor of Plant Cell & Developmental Biology in SFU, white LED lights are the most important type for the plant. The full-spectrum white LED light will provide all of the wavelengths that plants need to photosynthesize, grow, and develop.

Although the white LED lights cover the full-spectrum, blue and red lights are needed for certain stages in the plant's development [8]. The blue LED lights are used in the vegetative stage. By using blue light, the plant will grow stronger stems and leaves. The red led lights are often used during the flowering stage to encourage plants to bloom and to help promote fruit development.

In order to handle two levels of light intensity, there are two white LED light strips in Gaia. One white LED strip will be turned on when the controller determines the ambient light intensity is low. Two white LED strips will be turned on when the light intensity level is considered dark.

7.3. Software Design

The lighting process is shown as a flowchart in Figure 14.
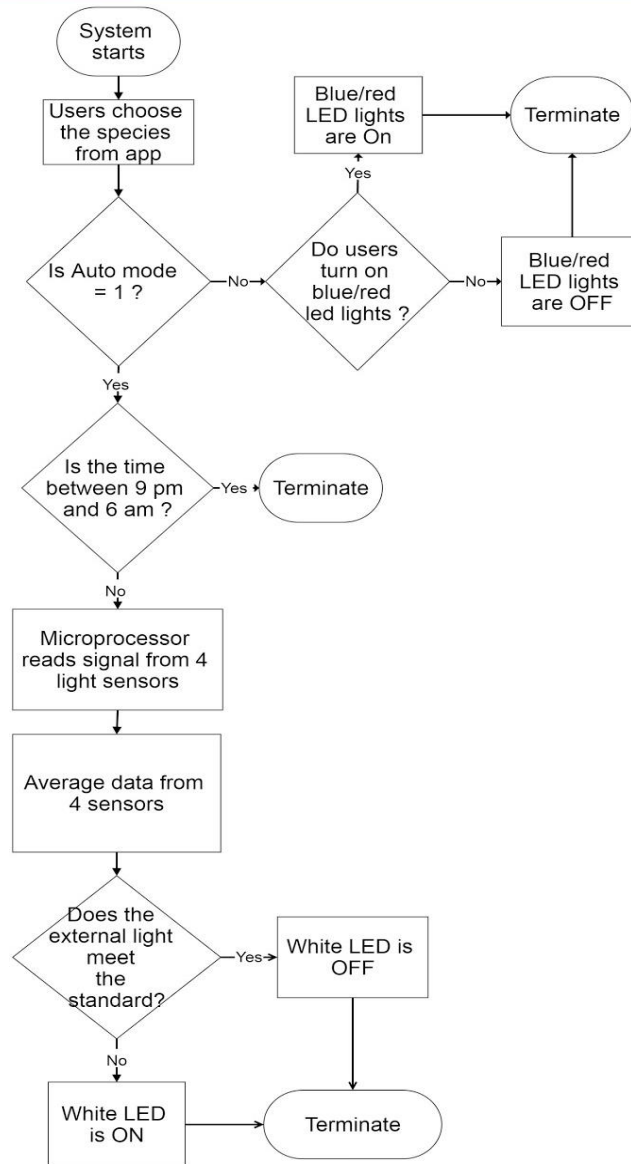
Figure 14: The flowchart of the lighting process

At the beginning of the process, the system will check the status of auto mode. If the auto mode is zero, the system will check the user's input for the blue/red LED lights. After finishing the process, the system will end and move on to the next process.

The system will check the time first if the auto mode is one. The white LED lights will not be turned on during the night. Gaia will turn on one or two LED light strips, depending on external light intensity, if the external light intensity does not meet the requirement during the daytime. This decision is made by comparing the amount of lux which the plant requires with the current external light the plant is exposed to. If the external light intensity is sufficient, Gaia will not turn on the white LED light and end the process.

8. Watering System

The watering system of Gaia controls an electric pump to maintain the soil moisture. When the system is operating in manual mode, the pump is controlled by users through a phone application. When the system is in auto mode, the pump is simply controlled by a microcontroller and triggered by two soil moisture sensors. If the soil is determined as dry, then the Arduino board will turn on the power relay to power the pump. However, due to safety concerns and [R45], whenever the door of the device is open, the pumping function will be suspended. Figure 15 shows the big picture of watering system.
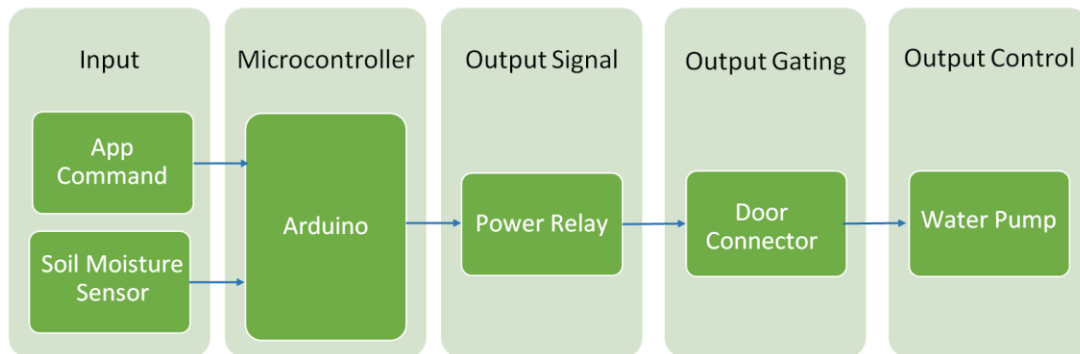
Figure 15: System Diagram of Watering System

8.1. Physical/Mechanical Design

Grommet
According to [R68] of the Requirement Specification, the water tank shall be refillable by users. The grommet, highlighted in blue and located on the top left corner of Figure 16, was designed for users to refill the water tank. Most of the time, the grommet will be closed to keep water from leaking. This is especially important in order to fulfill our safety requirement [R34]. However, when users want to refill the tank, they can simply open the grommet and pour water in.
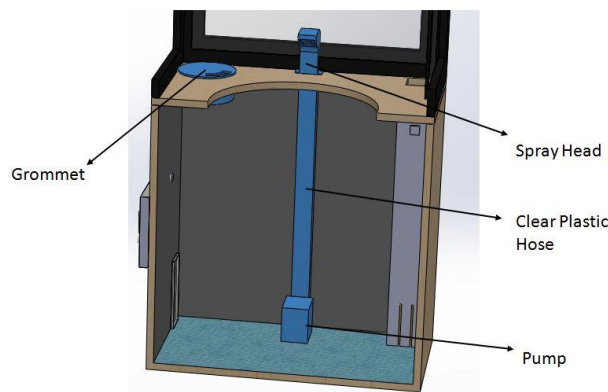
Figure 16: Solidworks model of the watering system

The water level indicator, shown in Figure 17, designed to let users see the water level. The indicator will have a scale to show the water level as a fraction. Table 6 shows the dimension of the grommet.
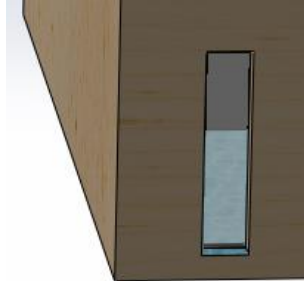
Figure 17: Solidworks model of the water level indicator

Table 6: The dimension the grommet

Name of Part	Hole Size	Overall Length
Diameter	20 mm	60 mm

Pump System

The spray head, next to the grommet in Figure 16, was designed to follow requirements [R59] and [R34]. The watering system would use an electric pump to bring water from the water tank to the soil through a plastic hose and a spray head. Table 7 shows dimensions of the pump system.

Table 7: Specifications of the pump system

Name	Electric Pump	Plastic Hose	Spray Head
Inside diameter	5.4 mm	9.5 mm	13.0 mm
Outside diameter	10.0 mm	12.7 mm	15.0 mm

8.2. Hardware Design

When considering how to implement the watering system, we had two main design options which were studied and evaluated. The first option was to power a pump which was submerged in the water tank to pump water up to the potted plant. The second option was to have the water tank situated above the soil level and power a valve to open and release water to the plant below, letting gravity push the water down. Table 8 below outlines the pros and cons of the two designs.

Table 8: Comparison between characteristics of electric pump and valve options

Characteristic	Electric Pump (Chosen)	Gravity and Electric Valve
Cost	~20	~15
Difficulty	Low	Mid
Water Reuse	Yes	No
Power Usage	Mid	Low
Precision	High	Low (flow rate affected by remaining H_2O)
Dangers?	Pump gets clogged	Valve stuck open

Ultimately the pump option worked best as it allowed for reuse of water, consistent output, and safer operation at the cost of a few dollars.

Figure 18 is the circuit for the watering system of Gaia. It includes an electric water pump, three water level indicators, two soil moisture sensors, a door breaker, a power relay, and an Arduino board.
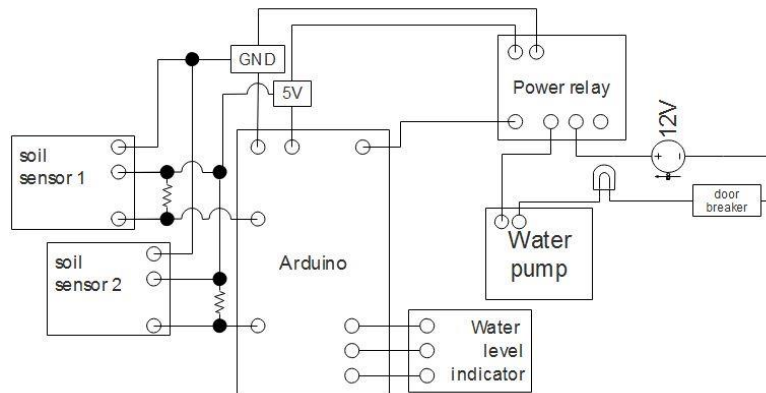
Figure 18: Watering System circuity

8.3. Software Design

The main process of watering system is shown in Figure 19.
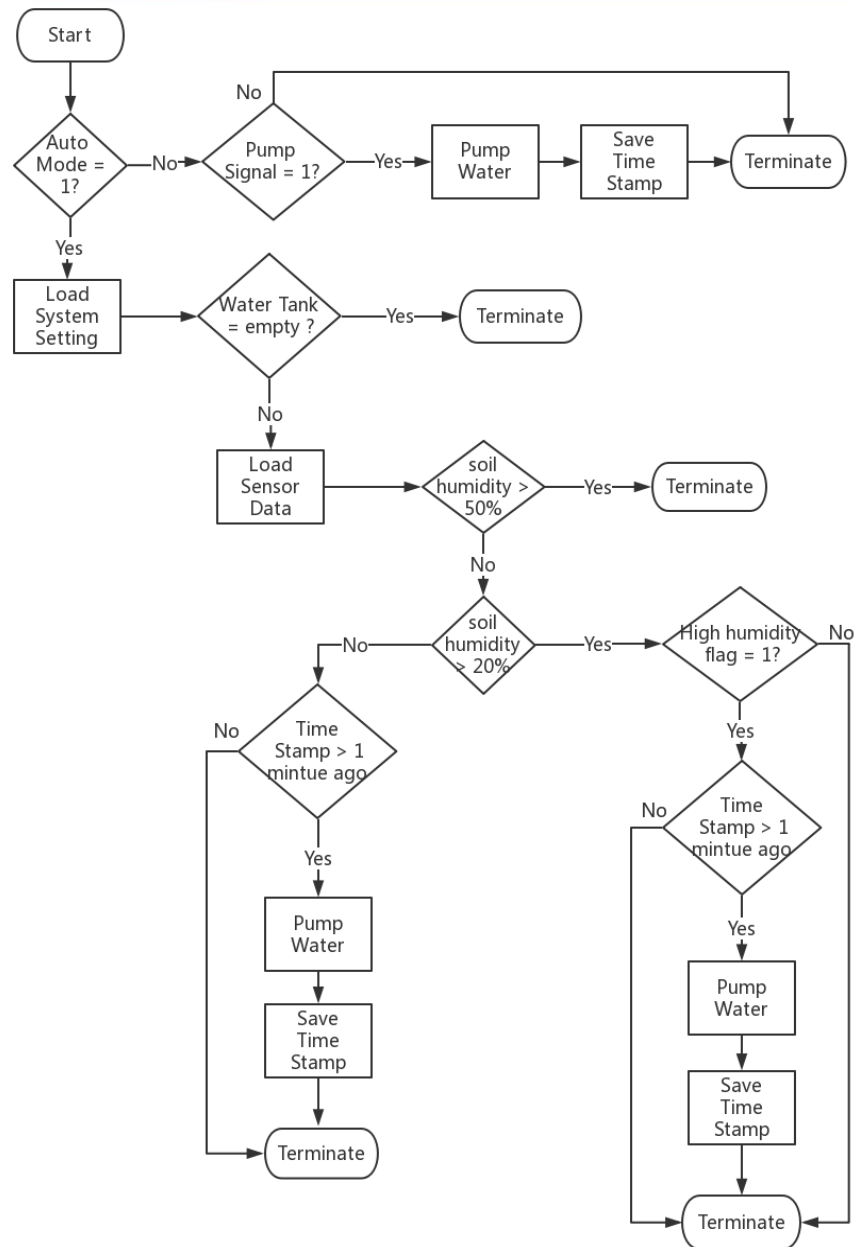
Figure 19: The flowchart of the watering system

When the main loop enters this process, the water system will first check which mode the system is operating in. If auto mode signal is zero, the system is in manual mode. As mentioned in the justification section, the system will authorize users to control the watering system. However, there is a one minute wait time for the water to disperse into the soil. Once a user waters the plant, he/she must wait for one minute before they can pump the water again. If the auto mode signal is one, the system is in auto mode, meaning that the system has full control of the watering system.

In manual mode, the system will check the pump signal. If pump signal is one, the system will trigger the electric pump to pump water and save the current timestamp. The system will use the timestamp to check if users waited long enough to pump again. If pump signal is zero, then the system should terminate this process.

In auto mode, the system will load the settings, such as plant species and watering condition parameters. Then, the system will check the water tank level. If the water tank is empty, then this process is terminated to prevent pumping air through the electric pump. If the water tank is not empty, the system will load data from the soil humidity sensors. The soil humidity sensors show how moist the soil is. If the soil humidity is greater than 50%, then terminate this process to avoid overwatering. If the soil humidity is in the range between 50% and 20%, the system will check whether this plant species needs a high humidity environment. If yes, the system will check the latest timestamp, pump water, save the new timestamp, and terminate. If the soil humidity is less than 20%, the system will do the same, check the latest timestamp, pump water, save the new timestamp, and terminate.

9. Humidity System

The humidity system of Gaia will increase the air humidity of the plant's environment if it is insufficient for the plant species. It has an air moisture sensor which sends data to the microcontroller. If the microcontroller sees that the atmosphere needs to have the air humidity increased it will activate the power relay that controls the evaporation fan. The fan increases the evaporation rate of the water in the tank and delivers it into the enclosure to the plant's environment. The humidity system is as shown in Figure 20.
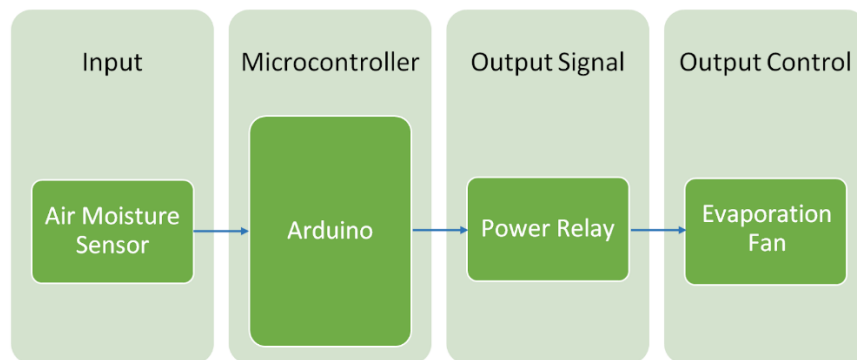
Figure 20: System Diagram of Humidity System

9.1. Physical/Mechanical Design

The humidity system has the same design for both prototype and production. As shown in the Figure 21, the square hole on the top is the mouth of a chute where the moist air enters the upper section. The bottom of the chute is connected to the water tank. The wall at the bottom has narrow slits to allow water to enter the chute. A fan is located inside the chute to increase the water's evaporation rate. The more water vapor generated means a higher air humidity. In order to increase the efficiency of evaporation, a sponge is placed at the bottom of the chute to

absorb water and increase the surface area of the water leading to a higher evaporation rate. There is a brace attached to the sponge to keep the sponge in place. Because the sponge absorbs the water in the chute, it prevents water from being spilled if the device were to be tipped over.

The humidity sensor will be placed inside of the plant enclosure near the bottom hinge of the door.
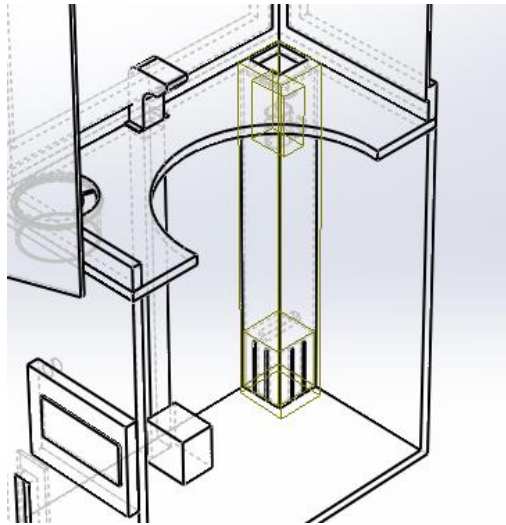
Figure 21: Solidworks model of the humidity system

9.2. Hardware Design

The air humidity system had two main design options which were studied and evaluated. The first option was to power a fan in order to increase the evaporation rate in the water tank, resulting in an increase in air humidity.

The alternative option was to purchase a separate humidity control device from a third-party vendor to handle the humidity control. Table 9 below outlines the pros and cons of the two designs.

Table 9: Comparison of two options of increasing air humidity

Characteristic	Fan (Chosen)	Humidifier
Cost	low	high
Difficulty	low	mid (need to hack it)
Power usage	low	high
Efficiency	mid	high
Flexibility	low	high (increase and decrease)
Dangers	mid (water may spread out if the device is tilted)	extra circuit, complex electric device with water may increase risk of error

Summarizing the value of each design, the fan-powered humidifier was deemed a better choice due to it having been proven to be effective in previous experiments, as well as being low in

cost, simplistic, and robust. Though at the cost of flexibility and efficiency, the priority of the humidity control was minimal and as such, did not warrant a premium to implement.

9.3. Software Design

The humidity process is shown as a flowchart in Figure 22.
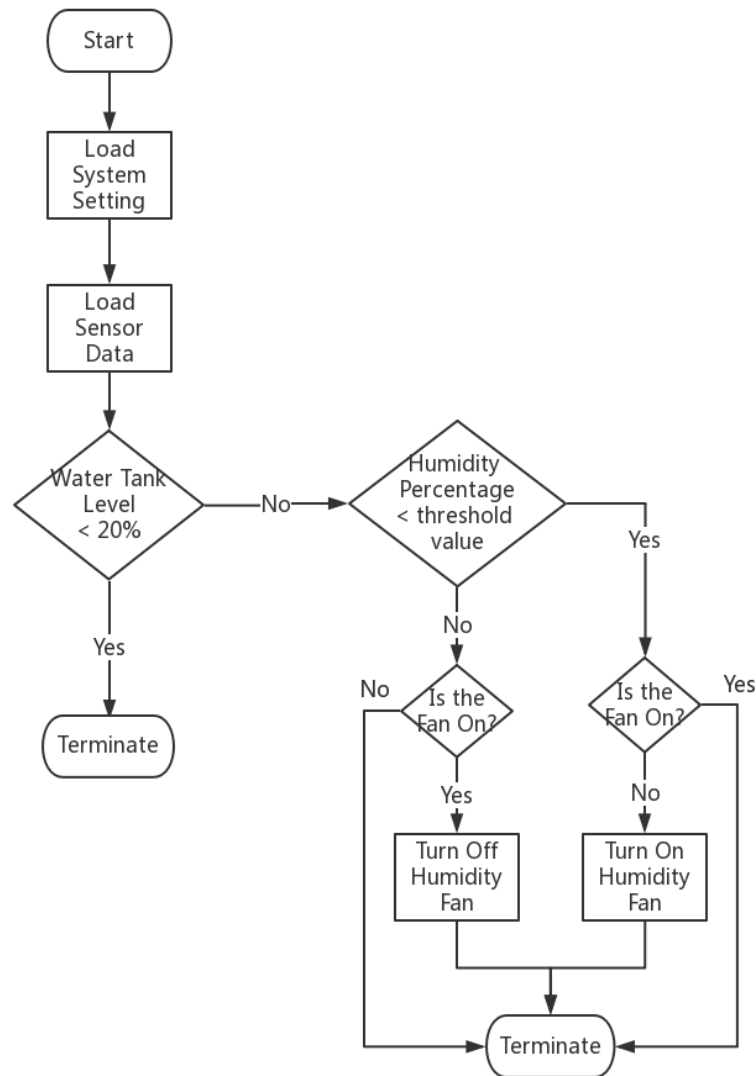
Figure 22: Flowchart of the Humidity System

When the main loop enters this process, the system will load the system settings and data from the air humidity sensor. Then, system will check whether the water tank contains enough water to support both the watering and humidity systems. Since maintaining a well watered plant is more important than an environment with high air humidity, the humidity system is less significant than the watering system. Therefore, the humidity system shall be terminated if the water tank level is less than 20% in order to preserve the water for the watering system.

On the other hand, if the water tank level is greater than 20%, the system will check if the current air humidity percentage is less than the threshold value. If it is not, the system will turn off the fan and terminate. If it is, the system will turn on the fan

10.   Temperature System

The temperature system of Gaia will be able to increase the ambient temperature inside of the enclosure by 10 °C and lower the ambient temperature by 5 °C according to [R85] and [R86]. The system uses two temperature sensors inside of the device and takes the average of the two values. If the average temperature is not within the ideal temperature for the plant species then the electrothermal device and fan will be turned on and adjust the temperature back within the threshold of the plant. Below is a system diagram of the temperature system.
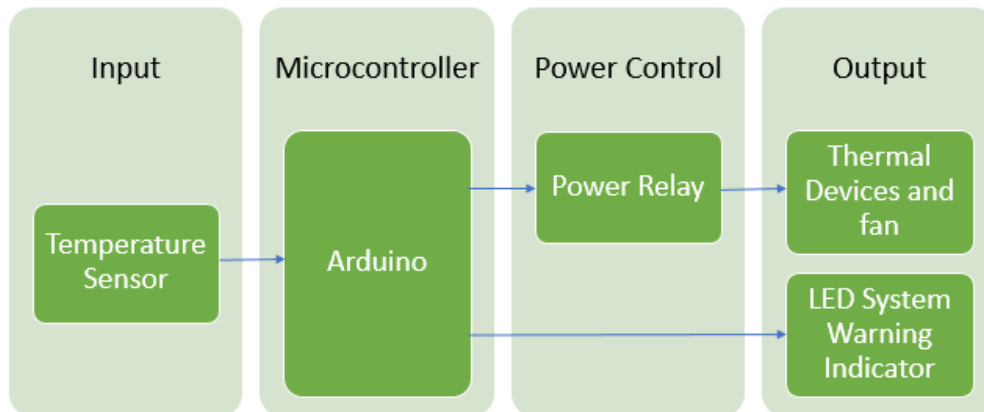
Figure 23: System Diagram of Temperature System

10.1.   Physical/Mechanical Design

As shown in Figure 24, there will be a tunnel along the corner of the device's base where a fan and two thermoelectric devices are. One thermoelectric device is for lowering the temperature and the other is for increasing the temperature. The fan will circulate the air up through the tunnel and into the chamber where plant is held. The thermoelectric devices will have heat sink fins on either side of it to help distribute the generated temperature change. The heat sink on other side of thermoelectric devices will keep exterior wall of device and the area around it from getting super heated or cooled.
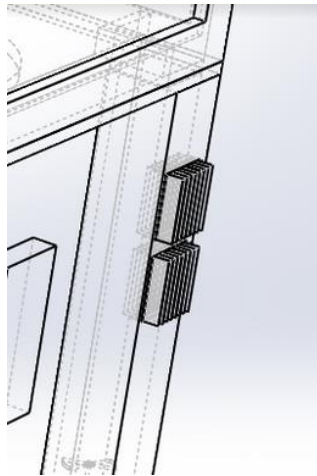
Figure 24: Solidworks model of the heat sink

The temperature sensors will be placed on the inside of the plant enclosure on opposite corners of the rectangle shown as red dots in Figure 25.
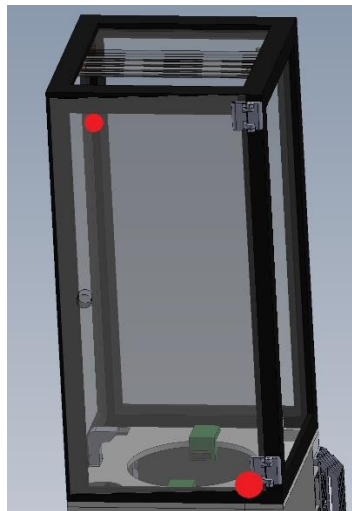
Figure 25: Temperature Sensor Location

10.2.   Hardware Design

Two thermoelectric devices were chosen to adjust the temperature of the plant's environment. By controlling which of the two thermoelectric devices are on, we can produce a cold or hot temperature. A motor controlled fan is positioned under the thermoelectric devices in order to help distribute air into device's plant chamber. An alternative to using thermoelectric devices was using a compressor based cooling system instead. Table 10 is a table comparing the pros and cons of using either method.

Table 10: Comparison of Thermoelectric Device and Compressor Based System

	Pros	**Cons**
Thermoelectric (Chosen)	- quiet - physically small - capable of heating and cooling	- localized cooling/heating - different efficiency of heating and cooling
Compressor Based Cooling System	- large area of effect even cooling	- has moving parts - noisy - cannot increase temperature

The thermoelectric device was chosen because it can increase and decrease temperatures and is also quiet and compact. This is especially important in order to fulfill our physical requirements and [R22]. Gaia operates indoors and should not be loud or bulky, something that a compressor based cooling cannot achieve.

Circuit

In the circuitry of the temperature system, the temperature sensors are connected to the Arduino board which is connected to the thermoelectric devices through a power relay. A motor with a fan attachment is wired to the power relay as well. Two thermoelectric devices were chosen so that one cools and the other heats. Two 6A current-limited circuit breakers are connected to protect the circuit and devices in both the prototype and production versions. The alternative was to use one thermoelectric device and control the current direction, and therefore heating and cooling, with an H-bridge. However due to the high current needed for the operation of a thermoelectric device, having one just for cooling and another just for heating was the preferred option. Investing in a high current H-bridge would be much bulkier and more expensive than having a simpler design with two thermoelectric devices. A high current H-bridge would require its own heat sink and more room would be needed to ensure that the generated heat is dispersed. Also, because one thermoelectric device can not change its temperature immediately when the direction of current is changed, using two devices will help reduce the wear on the devices.

Below, Figure 26, is the circuit for the temperature system of Gaia. The fan and the two thermoelectric devices are controlled by their own power relay channels.
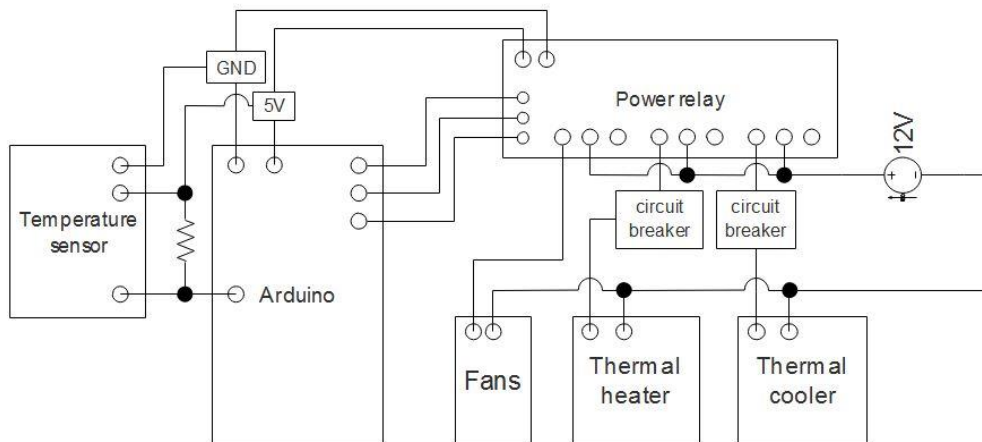
Figure 26: Temperature System circuitry

Table 11 is a compilation of the requirements of the devices in the temperature system of Gaia.

Table 11: Device requirements

Devices	Temperature Sensor	Thermal Device	Fan	Circuit Breaker	Power Relay
Quantity	2	2	1	2	3
Operating Voltage	5V	12V	3V	N/A	5V
Threshold Current	N/A	8.3 A	N/A	6A	N/A

Thermoelectric device

The thermoelectric device we are using, also called a solid state refrigerator, is built with n-type and p-type semiconductors. In order to meet the requirement that the power consumption of Gaia is no greater than 60 W [R92], the device is provided with 12V DC and 5A current. As shown in Figure 27, when the direction of the current switches, the surface of heating and cooling switches too.
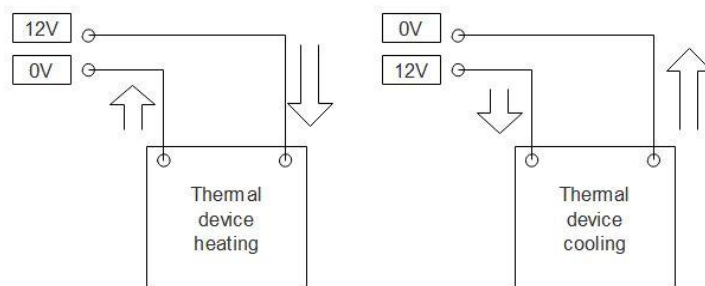
Figure 27: Thermoelectric Device

10.3.   Software Design

When the main loop enters this process, the temperature system compares the reading from the sensors with reference numbers. If the temperature of the device goes beyond the extreme threshold such as greater than 30 °C or below 10 °C, the system sends a warning and terminates the process. When the temperature is higher than 25 °C but not greater than 30 °C, the system needs to check whether the cooler is on or not and then decide to turn it on or leave it on.

When the temperature is within the desired range, the system checks and makes sure that no thermal devices are on at this period. Furthermore, when the temperature is below 15 °C but not lower than 10 °C, the system checks whether the heater is on or not and then decide to turn it on or leave it on. Figure 28 is a flowchart showing the process of the temperature system.

Figure 28: Flowchart for Temperature System

Noise considerations

Gaia's temperature system needs to distribute heated or cooled air into the plant chamber. When using a fan, using a good motor at a low voltage and higher amplitude will keep the noise level low. The thermoelectric device has no moving parts. Since only the ceramic insulation film is heated or cooled when changing the temperature of the environment there will only be noise coming from the motor, which will be minimized.

11.   User Interface

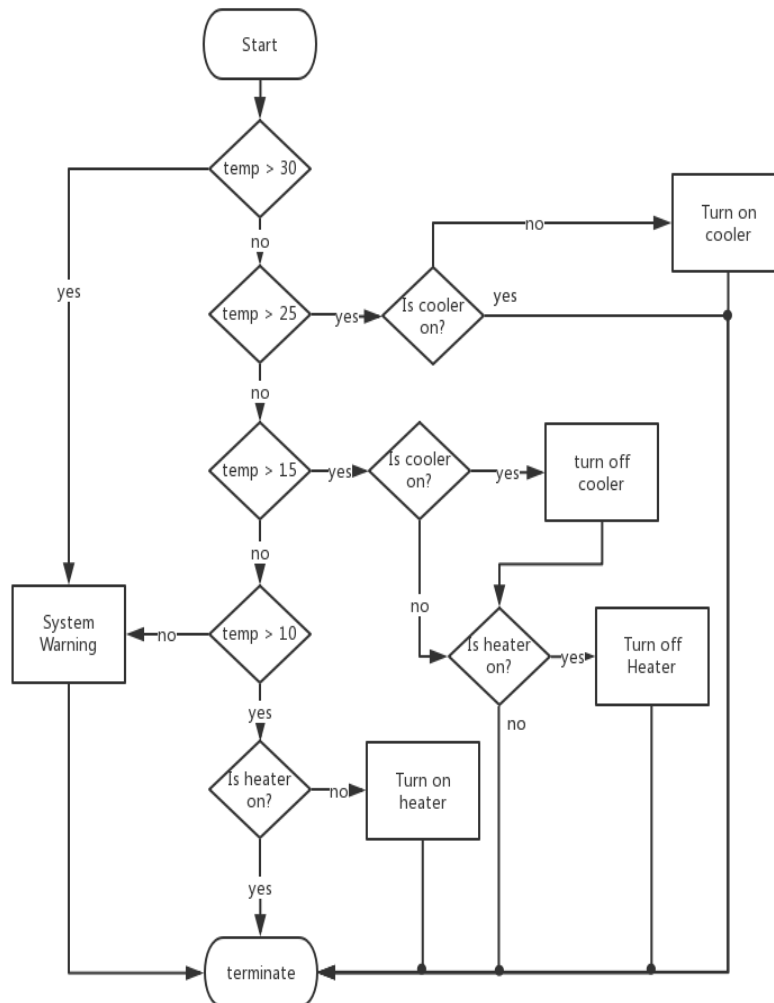As shown in the Figure 29, the UI of Gaia will have two parts. One is the LCD screen at the base of Gaia. It is where the user can select the Wi-Fi name and input the password to connect the device to the internet and after the setup process is complete, where the current species, temperature, and humidity in Gaia are displayed. The second part of Gaia's UI design is the phone app. The phone app will be where the user finishes the rest of the setup. It will allow the user to select the plant species and whether the device will be operating in manual or auto mode. The app will also display data from Gaia's sensors for the users.

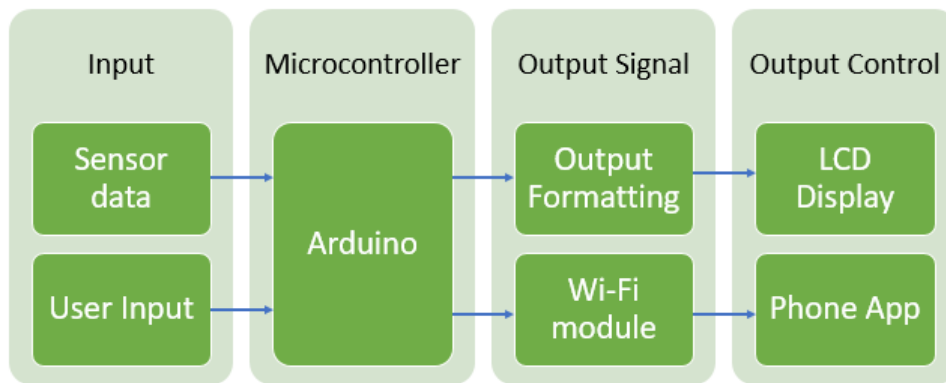*Figure 29: System Diagram of UI*

Table 12: Devices requirement for user interface

device	button	LCD 80 mm*36mm	Wi-Fi module
quantity	4	1	1
operating voltage	5V	5V	3.3V
data type	digital	digital	digital

11.1.   Phone App Design

When considering the platform for the development of the phone app it was between Android and iOS systems.

Table 13: Comparison of App Development between Android and iOS

Android (Chosen)	iOS
open source	requires license
more brands of phones and tablets	restricted to Apple products
can develop app on any computer	can only develop app on Apple computers
has back button in physical design	needs to implement back button into app

In the end, the platform chosen was Android. This is because the Android development software is more accessible and will be available for more devices. The lack of a product license is also a bonus.

The phone app will have several features. First is the selection of plant species. The app must have a list of Gaia's supported plant species where users can choose their plant. This selection will be sent to the Arduino board inside of Gaia and set the parameters for the temperature, lighting, humidity, and watering for the device.
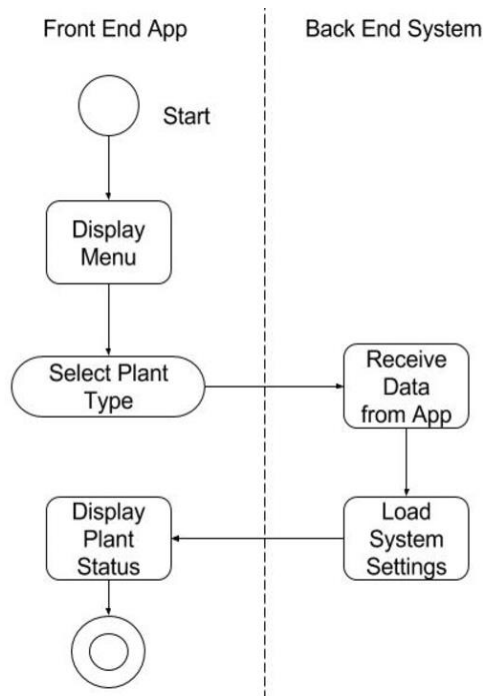
Figure 30: Plant Species Selection System

For a reference to the representation of each activity diagram shape, check Appendix B: UML Activity Diagram Shapes.

After that, the user must select whether they want the device to be in auto or manual mode. If the device is in auto mode, then all functions are controlled by the Arduino following set parameters. If the manual mode is selected then the user will have control over the watering system and the blue and red lights, all other functions are controlled by the Arduino.
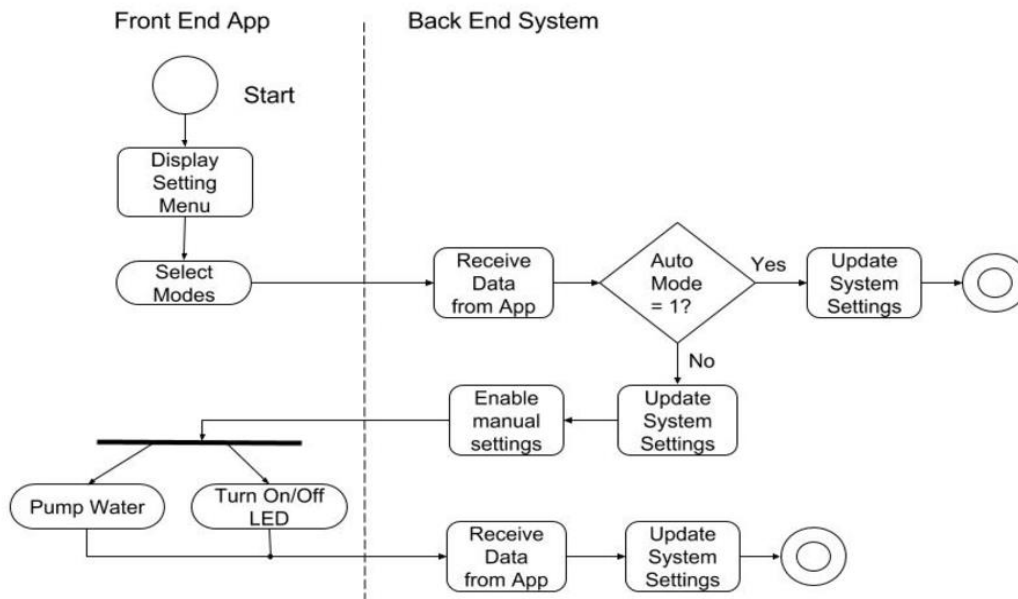
Figure 31: Device Mode Selection System

Once the mode has been determined and the device has been updated with the settings the phone app will be able to display the current status of the environment. This information should include the temperature and humidity inside of the enclosure, the current plant species selected and any other relevant data.

11.2.   LCD Display Design

The base of the device has an LCD screen mounted on its side. There are four buttons next to it for the up, down, select, and cancel functions as shown in Figure 32.

Figure 32: LCD and Buttons Layout

11.2.1. Hardware Design

The 2x16 LCD is chosen because there is not much information that needs to be displayed by the device since we are using the app as the primary source of information. Considering the price and complexity, 2x16 size is enough for Gaia's usage. Table 14 shows the pros and cons of different types of LCD screens.

Table 14: Comparison of different types of LCD

	Pros	Cons
LCD size of 2 lines x 16 characters (Chosen)	• small size • low cost • less I/O pins	• limits the information can be display • requires button
LCD size of 4 lines x 16 characters	• bigger size	• more costly • more I/O pins • requires button
LCD touch screen	• button free	• higher programing difficulty • more costly

11.2.2. Software Design
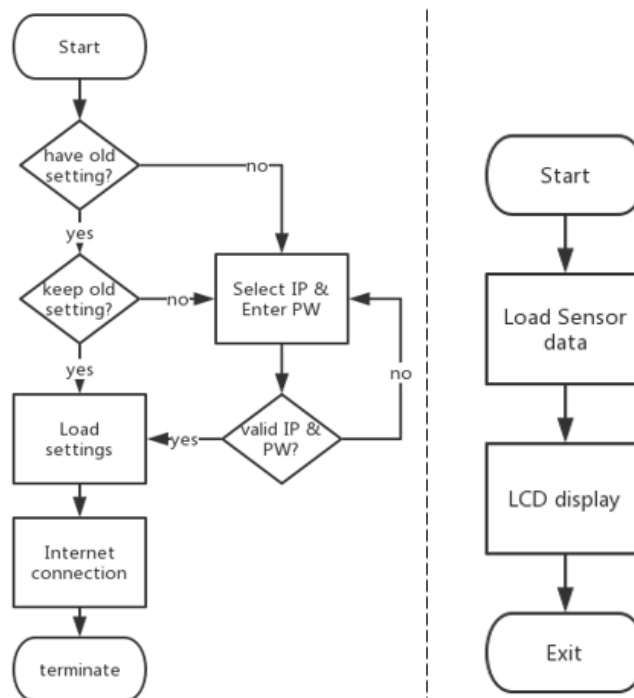
Figure 33: Flowchart of the setup process (left) and normal operation process (right)

After Gaia is turned on the LCD screen should provide a list of Wi-Fi networks for the user to select from. The password (if applicable) is then entered into the Arduino to connect to the internet. With a successful connection, the LCD will prompt the user to complete the system setup on the phone app. Once the rest of the setup is completed on the phone app, the screen will display to the user the current plant species, humidity, and temperature inside of the device.

12. Safety Design

In general, the safety specifications of the device require the following precautions to be considered:

- Proper insulation of all interconnects [R36]
- Proper grounded of all electrical components [R39]
- Proper smooth of all edges [R44]
- Proper sealed the most electrical components [R40]

Gaia has incorporated some special designs to protect its electrical components from being damaged and to prevent people from getting harmed. Table 15 shows the design specifications of Gaia's safety features.

Table 15: Safety device table

Device	Door Release Button	Water Tank Level Indicator	Circuit Breaker	Power Relay
Quantity	1	3	3	9
Operating Voltage	N/A	5V	36V (max)	12V
Threshold Current	N/A	N/A	8A/6A	N/A
Control type	user control	voltage control	current control	signal control

As a safety measure, we designed the watering system to shut down when the door is opened. As shown in Figure 34, a push button is placed in the watering system circuit and acts as a switch. When the door is closed, the door pushes the button which means that the circuit is closed. The water pump pumps the water as normal. When the door is opened, the door releases the button, making an open circuit. At that time, the water pump does not respond to any commands. This way, when users open the door to check on the enclosure, refill the water or replace the pot, water will not be spilling everywhere.

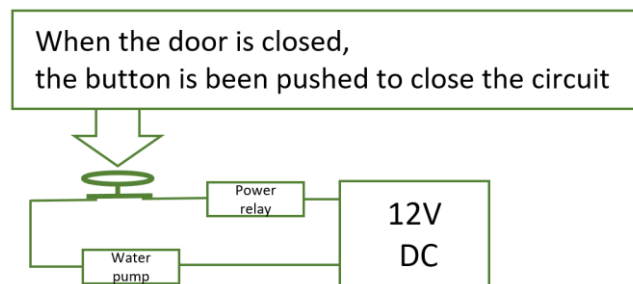*Figure 34: Watering system shut down design*

To prevent the electronic components from getting damaged from pumping the water or turning on the humidity fan when the tank is empty, we designed a simple circuit to measure the water level of the water tank by using a couple of resistors and wires. As shown in Figure 35, three pairs of wires are set to different heights corresponding to three levels of water: 50%,

20%, and 0%. Because water is conductive to electricity, when the water level is high enough to connect a pair of wires, the microcontroller receives a digital high signal. When the water level is below 50%, the circuit where the tank is at 50% becomes an open circuit, and the microcontroller receives a low signal. We designed the system in such a way that the water pump will be disabled when the water tank is empty to prevent overrunning of the water pump.
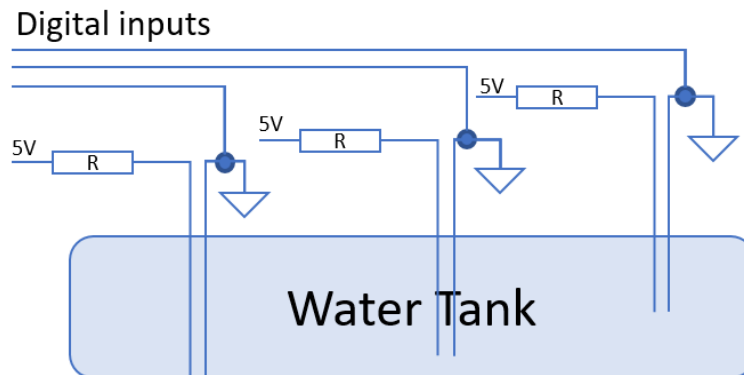

Figure 35: Water tank level warning for pump

To prevent any electronic components from receiving damage when the device is drawing too much current or is running super hot or if water is causing a short circuit, we use a current-limited circuit breaker to protect the system. From summing the current requirements of Gaia, 6.34A is the maximum current the system will draw when all functions are turned on. If the current goes above 6.34A, it means that there is a system failure. We use 8A as the threshold number to stop the system since eight is the closest number commercially available to prevent it from further damage. Also, the temperature control subsystem needs two 6A circuit breakers, one for the thermal heater and another one for the cooler to prevent them from drawing too much current and overheating the device or burning the user.

To prevent the electronic components from damage from disturbances from other system devices, we wire all electronic components in parallel using power relays. There are some advantages in using the power relay instead of not using it, and safety is the most important reason. The idea of the power relay is to use a small current to control a large current device, and the current will not flow backward to damage the microcontroller. As shown in Figure 26, the microcontroller uses a 5V signal to activate the power relay, and then the thermal heater operates on 12V and 5A which the voltage is coming from another power source. The power relay can also control the current flow by only providing the current that the device needs.

Because the design of the device involves electricity and water, water flow shall be designed to avoid most of the electronic parts. We use a sponge to absorb the water instead of using the water source directly to increase the air humidity, we use a grommet to prevent water overflow from the water tank, and we use a second wall as a segregation board between the control unit and water tank.

13. System Test Plan

13.1.   System Testing

Light
- Case I:
  - Purpose: To test the microprocessor's function of turning on one white LED strip.
  - Condition: Light intensity is low in the day.
  - Expected Outcome: One white LED light strip will be turned on when the microprocessor determines that the light intensity is low during the day.
- Case II:
  - Purpose: To test the microprocessor's function of turning on two white LED strips.
  - Condition: There's no light in the day.
  - Expected Outcome: Two while LED light strips will be turned on when the microprocessor determines that the light intensity is dark during the day.
- Case III:
  - Purpose: Can turn on blue/red lights via phone app when the device is in manual mode.
  - Condition: Users turn on blue/red LED lights via phone app.
  - Expected Outcome: blue/red lights will be turned on.

Watering System
- Case I
  - Purpose: Check if system will water soil if soil moisture is not within threshold.
  - Condition: Soil sensors are placed in wet soil.
  - Expected Outcome: No water is pumped.

- Case II
  - Purpose: Check if system will water soil if soil moisture is within threshold.
  - Condition: Sensors are placed in dry soil.
  - Expected Outcome: Water is pumped to the soil. The detailed process is shown in the flowchart in Figure 19.

Humidity System
- Case I:
  - Purpose: Test if can raise air humidity by +5% within 25 minutes.
  - Condition: Air humidity is lower than the threshold value.
  - Expected Outcome: Humidity fan is turn on. Air humidity has increased by +5% within 25 minutes.
- Case II:
  - Purpose: Test if can turn off the humidity fan.
  - Condition: Air humidity is higher than the threshold value.
  - Expected Outcome: The humidity fan is turned off.

- Case III:
  - o Purpose: Test if Arduino sends warning to app if air humidity system is suspended.
  - o Condition: Water level is below 20%.
  - o Expected Outcome: Humidity system is suspended. Arduino sends a warning message to app.

Temperature System
- Case I:
  - o Purpose: Test if can raise air temperature of device at least 2°C within 20 minutes.
  - o Condition: Air temperature is lower than the threshold value.
  - o Expected Outcome: Heating thermoelectric device is turned on, fan is turned on. Air temperature has increased at least 2°C within 20 minutes.
- Case II:
  - o Purpose: Test if can lower air temperature of device at least 2°C within 20 minutes.
  - o Condition: Air temperature is higher than the threshold value.
  - o Expected Outcome: Cooling thermoelectric device is turned on, fan is turned on. Air temperature has decreased at least 2°C within 20 minutes.
- Case III:
  - o Purpose: Test if Arduino sends warning to app if temperature within device is above 30°C or below 10°C.
  - o Condition: Temperature has reached extreme values.
  - o Expected Outcome: No devices are turned on. Arduino sends warning to phone app.

User Interface – App
- Case I:
  - o Purpose: Test if can select plant species and Arduino changes settings to that species.
  - o Condition: Device is turned on for the first time or the plant species is changed.
  - o Expected Outcome: After plant species is selected, LCD monitor and app display will update to new species.

- Case II:
  - o Purpose: Test if manual mode function will update Arduino settings.
  - o Condition: Starting from auto mode and switching to manual mode on phone app.
  - o Expected Outcome: Can turn watering and red/blue lights on and off from app.

- Case III:
  - o Purpose: Test if auto mode function will update Arduino settings.
  - o Condition: Starting from manual mode and switching to auto mode on phone app.
  - o Expected Outcome: Manual mode controls are unavailable on app, pressing buttons does not affect device.

User Interface – LCD Display

- Case I:
  - Purpose: Test if can input network name and password.
  - Condition: Device has been turned on for the first time or has lost Wi-Fi connection.
  - Expected Outcome: Network name and password selected are displayed on LCD.
- Case II:
  - Purpose: Test if inputting network name and password from LCD will allow Arduino to connect to Wi-Fi.
  - Condition: Device has been turned on for the first time or has lost Wi-Fi connection.
  - Expected Outcome: Arduino is successfully connected to Wi-Fi.
- Case III:
  - Purpose: Test if LCD can display sensor data from Arduino.
  - Condition: Species of plant has been selected on app and Arduino has been updated.
  - Expected Outcome: LCD will display sensor data, data is updated periodically.

13.2. Integration Testing

Case I:
- Purpose: Test the setup process flow for new plant in auto mode.
- Condition: Device is turned on and setup process for new plant is started.
- Expected Outcome: Able to perform system setup and select plant species successfully through phone app and LCD screen, phone app manual mode options are deactivated.

Case II:
- Purpose: Test the setup process flow for new plant in manual mode.
- Condition: Device is turned on and setup process for new plant is started.
- Expected Outcome: Able to perform system setup and select plant species successfully through phone app and LCD screen, phone app manual mode options are activated.

Case III:
- Purpose: Check that opening the door of device shuts off watering system.
- Condition: System is setup and running.
- Expected Outcome: Watering system will not be activated no matter the mode.

Case IV:
- Purpose: Low tank level warning shows on phone app and in LED indicator lights on device.
- Condition: Water tank level reaches 50%, 20%, and 0%.
- Expected Outcome: Warnings will show on phone app for all levels, LED light is on at 20%.

Case V:
- Purpose: Check that low tank level stops humidity and watering systems.
- Condition: Water tank level is low.
- Expected Outcome: at 20% humidity system is disabled and at 0% watering system is also disabled.

13.3.   Validation

Gaia will be able to meet the following criteria for which the end user will expect during intended usage. The following test cases are outlined in the test sheet in Appendix C: Test Sheet.

Case I:
- Purpose: System should consistently switch on and let user know otherwise confusion may occur as to when to use it.
- Expected Outcome: Switching on Gaia will activate it and prompt user when ready.

Case II:
- Purpose: Wi-Fi connection needed for app use.
- Expected Outcome: Connection to Wi-Fi can be manually set and auto connects.

Case III:
- Purpose: Gaia can control temperature, lighting, soil moisture, humidity parameters.
- Expected Outcome: During automatic mode, Gaia will regulate soil moisture, temperature, humidity, and lighting based on detected parameters.

Case IV:
- Purpose: Allows user set parameters and alter Gaia behaviour.
- Expected Outcome: Gaia will appropriately respond to commands sent through app.
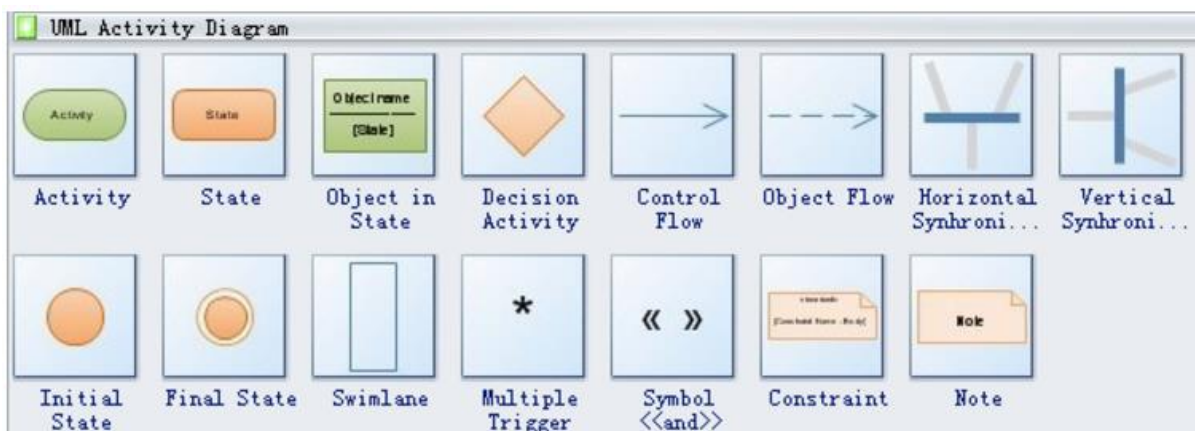
14.   Conclusion

This document covers the design solutions proposed to meet the requirements of Gaia. During the development of the proof of concept and prototype versions of Gaia, these specifications will be followed as closely as possible to ensure that Gaia will have the required functionality specifications. Also included are the system test plans. Using these tests as a reference, we can evaluate the performance of Gaia and its functionalities. The design specification presents the basic designs for the development of Gaia.

Appendix A: Basic Flowchart Shapes [9]
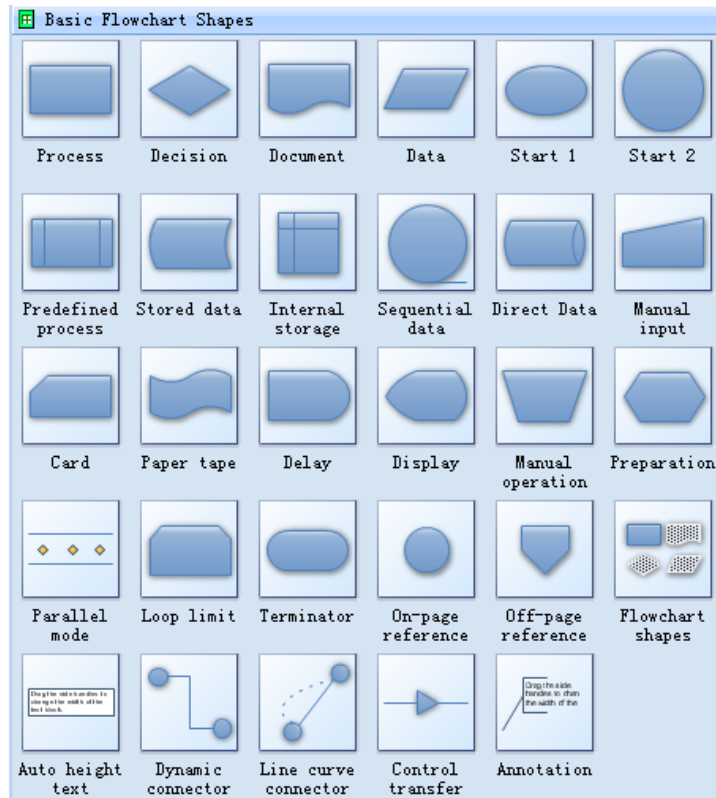
Appendix B: UML Activity Diagram Shapes [10]

Appendix C: Test Sheet

Team 10 Applied Agriculture Innovation	
Test Sheet	
Tester Name:	Date :
Validation	
1. System on/off Is the system on consistently? ☐ Yes ☐ No	Comments :
2. Wi-Fi Can the Wi-Fi connection be set automatically and Manually? ☐ Yes ☐ No	Comments :
3. Auto mode Will Gaia regulate soil moisture, temperature, humidity, and lighting , based on detected parameters, during the automatic mode ? ☐ Yes ☐ No	Comments :
4. App Will Gaia respond to commands sent by users through app appropriately ? ☐ Yes ☐ No	Comments :

15. UI Appendix

15.1. Introduction

The UI Appendix provides an analysis of the education and background knowledge of the typical user who might be familiar with products that operate similarly to Gaia, the seven elements of UI interaction in regards to Gaia, the engineering standards our device should

follow, and the analytical and empirical usability testing our device. This will be referenced to during the development of the prototype and the testing stage of the device.

15.2.   User Analysis

Gaia is an intelligent, luxury growth chamber for plants with a physical device and a phone control app. As expected from the user, the device is designed for taking care of plants with minimum maintenance. The device is reliable and safe to operate in the house and will not make excessive noise. The phone control app is designed for ease of use and understanding. To achieve that goal, the control steps from the app are simple with helpful guidelines. Also, the app is reliable and secure to prevent the loss of control or other internet issues.

Even the system and device is designed to simplify the control step, but there are certain things the user should know to operate the device successfully. The device follows common conventions of similar technologies.

The user needs to know how to power on the device just like other home equipment by plugging the power line into wall outlets and pressing the on/off button. To start the system, the user should know how to setup a Wi-Fi connection just like the setup of a wireless printer. Even if the user does not have that kind of experience; the user manual has clear and detailed information about how to setup the Wi-Fi connection. Also, the user should know how to download an Android app using an Android device.

Gaia has some user's restrictions. For example, the user does not have the control of temperature and humidity and can not control the subsystem from the LCD and buttons. Considering the size of Gaia, the user can not put two or more pots inside the device and only accept certain sizes of pot.

15.3.   Technical Analysis

Feedback [11]

Gaia mainly provides feedback through its phone app. The app will display information about the environment inside of the enclosure and the current state of the device. This way, users will be aware of changes to the temperature, humidity, and other environmental elements. If changes are made to the operation of the device, the app will show this in its menu. Such operations include changing the plant species inside of Gaia. If a different species is chosen then the data display on the app will change to reflect this. Changing the mode of the device will be shown on the app. The device will also use the app to show warnings if the water tank level of the device is at 20% and at 0%.

On the device itself, there will be a control panel on the side with a LCD screen and some basic operating buttons. During the initialization process of Gaia the LCD will display a list of detected Wi-Fi networks for the user to choose from. After selection, if applicable, the screen will ask for the network's Wi-Fi password and selectable numbers and letters will be displayed instead. With the successful selection of a character, the characters selected will be displayed on the top line of the LCD, allowing users to see what they have input into the device. Cancelling a character will update this line to reflect the changes. Once a Wi-Fi connection has been

established the display will prompt the user to open the phone app to finish the rest of the configurations. Upon the completion of the setup process the LCD screen will begin to display the species chosen and the temperature and humidity of the environment.

Other than the LCD and buttons the control panel will also have some LED indicator lights and a scale showing the level of water in the tank. One light indicates when the temperature system is on while the other is for when the water tank level is at 20%.The scale is a visual measure of the water level in the tank.

Affordances

Gaia has many features and many actions are possible because of these features. There is a door to the enclosure so that users can put in and take out their plant or clean the inside of the enclosure if desired. The grommet inside of the enclosure allows users to easily refill Gaia's water tank. Because the user has access to the pot and the water supply, they can add fertilizer to their plant too. The LCD and phone app allows users to see what the environment is like inside of the enclosure. The phone app also allows users to change the type of plant Gaia is taking care of and change the mode it's operating in between manual or auto. The manual mode gives the user control over the watering frequency and control over the red and blue lights of Gaia. There is a power switch that can turn Gaia off and on at will. The pot containment hole of Gaia can contain pot sizes from 12 to 18 cm in diameter. The hole will also allow for any excess water to drain directly from the pot back into the tank.

Signifiers

The control panel of Gaia has four buttons. They are labelled and colour coded so that their functions of up, down, select, and cancel are easy to determine. To the side of the base of Gaia will be the power switch, a rocker switch labelled on and off. The LCD screen is also used to give instructions to the user during the setup process, making it easier to follow. The various holes and vents inside of the enclosure are labelled and have warning signs if applicable. The grommet will be visually different from the netting covering the humidity and temperature channels so it's easy to tell that it has a different function. The pot containment arms and the hole itself serve as visual signifiers for users to indicate where the flower pot is placed. Within the phone app there is a menu to change the mode of the device that be apparent to the user that they can only choose one of the two options. Selecting the manual mode will make the manual watering, and red and blue light control buttons appear, labelled and with short explanations on their operation underneath. Any warnings such as a low water level will also be displayed by the app for users.

Mapping

Gaia includes a LCD and control panel. The control panel is for connecting Wi-Fi and powering the device. There are four buttons in the control panel as shown in Figure 32. They are up, down, select, and cancel. The up and down buttons are used to select the Wi-Fi connection, which is displayed in the LCD screen. The up and down buttons are positioned in a logical way.

The up button is above the down button. The select and cancel buttons are positioned to the right of the up and down buttons.

Constraints

Gaia has many features and most of these features have their own constraints. Gaia only provides one door for users to open the enclosure and place their plant. Users are not able to open the enclosure in any other way. Also, Gaia will stop the watering system's pump when the door is opened for safety purposes.

There are physical and logical constraints for identifying the water refill, air humidity, and air circulation. The location for refilling the water tank will be a circular shape and the locations for air circulation and air humidity will be in the shape of a square as a logical way to differentiate them. The water hole is also closest to the door, so it will be more inconvenient to fill the water through the air circulation and air humidity vents. Also, there are air outlet covers on the air circulation and air humidity openings, as physical constraints.

The water tank has a few logical constraints. The water tank is transparent, so users are able to determine the water level easily. Also, the water tank has a scale on it, so user is able to determine the percentage of water level. The red LED light will be turned on when the water level is below 20 percent and empty.

Gaia includes the logical constraints when users use the Gaia for the first time. Gaia provides instructions which are displayed on the LCD screen during the initial setup process. When users turn on Gaia at the beginning, the system will remind users with the LCD to download/use the app before using Gaia. Gaia will not be functional if it is not connected to the Wi-Fi.

There is a physical constraint for safety purposes, Gaia has a cover on the heat sink, shown in Figure 36. The heat sink may become very hot and might harm users when the system is working. In order to prevent users from touching the heat sink accidentally, placing protection over the heat sink is necessary.
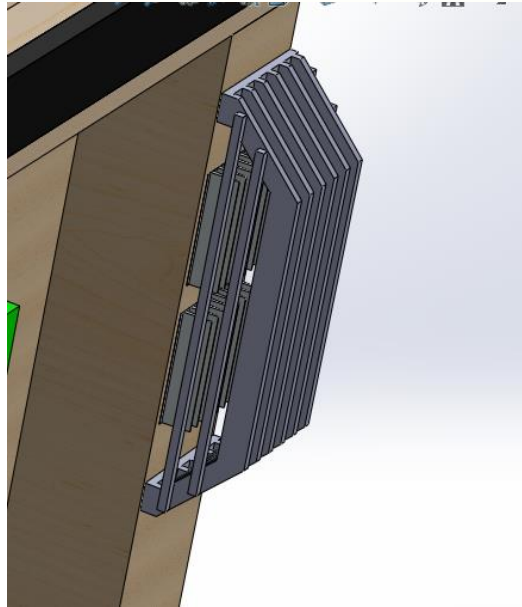
Figure 36: Solidworks model of the protection over the heat sink

Conceptual Models

Gaia is a device which can take care of a user's plant and allows the user to monitor the current status of the environment on their phone via Wi-Fi. Gaia provides many features which are very important for growing healthy plants. The main features are the lighting system, watering system, temperature system, and humidity system. Gaia monitors the environment of the plant and if there is anything about the environment that is not ideal for the plant's species, Gaia will activate the appropriate systems and adjust the environment until it reaches the ideal conditions. In general, Gaia is a device which allows a user to place their plant inside of the device and have Gaia take care of everything that the plant might require.

Discoverability

Gaia is designed to be easy for users. There is a power switch on Gaia. The system will be turned on after the user presses the power switch. At this stage, the LCD will show a message to remind users to choose the Wi-Fi connection. The buttons on the side of the LCD are visible and easily accessible to users. Once the user successfully connects the device to the Wi-Fi there is a message shown on the LCD screen to remind users to turn on the app on the phone. Users will need to follow the instructions provided by Gaia's app. After users have followed the instructions and placed their plant in the pot containment hole, the app will show a warning message telling users to close the door if they forget to close to the door. After that, users are able to enjoy the full functions of Gaia. Once the device is in operation the LCD will display the plant species and the temperature and humidity of the enclosure. The only time the LCD goes back into the initial setup mode is if the internet connection has been lost. The phone app, on the other hand, will have a more detailed display screen as well as another panel where the user can select a new plant species or change the operating mode of the device.

15.4. Engineering Standards

Engineering Standards	User interfaces for the device or system
IEC TR 61997:2001 Guidelines for the user interface in multimedia equipment for general purpose use [12]	The design of door, buttons, LCD screen, power switch, power plug would not cause any problem for the first time use without any special previous training.
ISO/IEC 13251:2004 Collection of graphical symbols for office equipment [13]	The device has symbols for four buttons (up, down, select and cancel), power switch like most office equipment.
ISO/IEC TR 30112:2014 Information technology -- Specification methods for cultural conventions [14]	As in many cultures, the door is opened from the left and buttons are on the right side.
ISO/IEC TR 19765:2007 Information technology -- Survey of icons and symbols that provide access to functions and facilities to improve the use of information technology products by the elderly and persons with disabilities [15]	The size of icons on the app is large enough for elderly to see clearly. Color blind people are able to use the app by sufficient color contrast.
ISO 9241-11:1998 Guidance on Usability -- The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. [16]	The design of auto and manual modes allow users to control the water pump, blue and red LED light to satisfy their needs.

15.5. Analytical Usability Testing

Cognitive Walkthrough [17]	
Purpose	Identify usability problems, focusing on the interaction between new users and the system as they use Gaia
Evaluator	3-5 designers/experts
Method	Walk-up-and-use Answer the following 4 questions. <table><tr><td>Question 1</td><td>Will the users notice that this subtask is needed to achieve his/her goal?</td></tr><tr><td>Question 2</td><td>Will the users know that the correct and wanted action is available?</td></tr></table>

	Question 3	Will the user understand that the needed subtask can be achieved by the action?
	Question 4	Will the user get any feedback?

Task List			
		Task Name	Things to Focus On
	Task 1	System setup	• Wi-Fi setup • Plant selection
	Task 2	Mode switch	• Auto to Manual • Manual to Auto

Evaluation Measure	Summarize by listing problems identified in each task and rate them for severity Severity can be ranked on the following scale: ✢ 0 = not a problem ✢ 1 = cosmetic ✢ 2 = minor, low priority to fix ✢ 3 = major problem ✢ 4 = catastrophe, must be fixed before product is released

Heuristic Evaluation [18] [19]	
Purpose	Have experts go through Gaia to discover common usability problems
Evaluator	3-5 designers/experts
Method	walk-up-and-use
Evaluation Measures	

Y/N	Name	Description
	Visibility of System Status	The system provides feedback to inform users what is going on.
	Match between System and the Real World	The system speaks the user's languages and reflects real-word conversations.
	User Control and Freedom	The system has "emergency exit" for users to exit unwanted state when they make mistakes.
	Consistency and Standards	Words, situations, or actions should follow platform conventions. Users should not be confused.
	Error Prevention	The system presents users a confirmation option before committing to anything.
	Recognition rather than Recall	The instructions for users are easily retrievable. Users should not need to memorize too much information.
	Flexibility and Efficiency of Use	The system is friendly and efficient for both inexperienced and experienced users.
	Aesthetic and Minimalist Design	Dialogue contains only relevant and needed information.
	Help Users Recognize, Diagnose, and Recover from Errors	Error messages indicate the problem and provide a solution.
	Help and Documentations	The product comes with documents which is easy to follow.

Safety Standards		

Labels

Y/N	Description
	Label all the buttons
	Label where the to pour water into the water tank
	Label "Download App: AAI- Gaia"

Warnings

Y/N	Description
	"Caution Hot!" labels near thermoelectric devices.
	"Caution Tip Over Hazard" labels near the top of the device.

15.6. Empirical Usability Testing

EU Test: Setup	
Objective	Can users safely and properly set up the device with the given instructions
User Profile	Age:15-75 Gender: 50%F and 50%M Technology Skills: Average smartphone user Background: Busy person with interests in plants
Method	• Focus on live tests (fewer subjects, greater quality of information) • Users given single prompt with objective and left to do what they can • Identify all issues seen during test • Supplement observed issues with user feedback
Task List	

Description	"Here is a device for automated plant care, please set it up for it to work for the provided plant. You may use any item provided including this set of instructions"

	Environment/Machine State	Device: Out-of-the-box, unplugged, no prior Wi-Fi connection saved, water tank is empty. Environment: Wi-Fi is available, potted plant provided with species known to user, app available online, power source available.
	Successful Completion	• Gaia is connected to app through Wi-Fi • Plant environment setting is set to species of provided plant. • Water Tank is filled to specified capacity • Soil moisture sensors plugged into soil evenly

Evaluation Measures	Quantitative
	    - Time to completion of overall setup
	    - Number of times user refers to instructions manual
	    - Number of times user redoes a step or needs to revert
	    - Missing steps
	Qualitative
	    - Completing more than given objective
	    - Mood of user from beginning to middle to end
	    - Looks of confusion or anger
	    - Questions asked by user during testing (respond with neutral answer)
	User comments and feedback
	    - Entry survey to record technical and science background
	    - Questionnaire with user experience ratings
	    - Open-ended question on thoughts/comments and questions	

15.7. Conclusion

The UI appendix outlines the different aspects of Gaia. It covers the expected experiences and knowledge of our users and the different elements of UI interfaces of Gaia. Meticulously designed test plans deeply regard the core interface and user interaction and strengthen the overall quality of the final design. This appendix will be referred to during the development and testing of Gaia.

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