March 26th, 2021
Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, BC, V5A 1S6

RE: [Letter of Transmittal] ENSC 405/440 Design Specifications for MNDL (Company14)

Dear Dr. Scratchley,

Our Company MNDL, has included with this letter, the Design Specification for Greg. Our system is designed to provide an autonomous watering solution that can be monitored and controlled remotely. Aimed at mid-to-large scale nurseries, we will be providing a solution that will both increase plant yield and aid in maintaining plant health. Our rail mounted system will be capable of attending to any plant type, soil composition, and pot size by administrating a calculated amount of water based on these parameters alongside soil moisture reading.

The purpose of this document is to provide detailed specifications of the design choices, reasonings, and formulations for Greg. It will cover the overall system design, hardware design, software design, test plan, and alternative design options. The design choices will be specific to our proof-of-concept prototype, which will be subjected to adjustments during the development with possible changes that were not included or removed for the prototype. These possible changes will be covered and described in the Design Option Appendix.

MNDL (company 14) is comprised of 4 Computer Engineering (Daniel Song, Steve Chen, Eric Huang, Leon Zou) and 2 Systems Engineering students (Mickey Kim, Jake Kim) that have gained various skills and expertise during their academic and industry experiences. We are confident of successfully delivering the system described in this document for our proof-of-concept.

Thank you for taking the time to review our design specifications for Greg. We hope to hear back with any feedback and improvements that could be made to our designs. If there are any inquiries or concerns, please reach out to me, Daniel Song, the CEO and CCO of MNDL at esa46@sfu.ca.

Sincerely

Daniel Song
Chief Executive Officer and Chief Communications Officer
MNDL (Company 14)
Esa46@sfu.ca

GREG: PLANT CARE SYSTEM

March 26, 2021

Design Specifications

Presented by MNDL (Company 14)
Daniel Song, Steven Chen, Mickey Kim, Jake Kim, Eric Huang, and Liangchen (Leon) Zou

Greg: Plant Care System

DESIGN SPECIFICATIONS

Abstract

The design specifications for Greg by MDNL includes a detailed explanation of the design overview for the proof-of-concept of an automated plant care system. The rail mounted operation box can deliver water to plants of varying species, pot size, and soil composition with an accurate calculated amount. This system will be efficient and effective at caring for multiple plants while also providing users a web application for registration, monitoring, and control of their system. The design choices and reasonings will be explained to provide a full understanding of the deliverable prototype for the proof-of-concept. A test plan and design options will be included in an appendix as well.

Revision History					
Revision Number	**Implemented By**	**Revision Date**	**Approved By**	**Approval Date**	**Reason**
V1.0	Daniel Song	03/26/2021	Steven Chen, Mickey Kim, Jake Kim, Eric Huang, and Liangchen (Leon) Zou	03/26/2021	Initial Design Specifications

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3. WATER DELIVERY SYSTEM AND OPERATION BOX

4. PLANT MONITORING SYSTEM

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2. SYSTEM OVERVIEW

3. WATER DELIVERY SYSTEM AND OPERATION BOX

1. INTRODUCTION

In our survey, nurseries reported that roughly 5% of all plants are discarded due to them not meeting certain commercial standards. The main reason for this is either underwatering or overwatering of the plants. Being able to accurately water a house plant greatly determines how well the plant will do. In a nursery, having large quantities and varieties of plants can be difficult to manage and training employees can take months due to the unique needs of individual plant species. Our solution Greg, aims to help these nurseries increase their yield, reduce training time for new employees, and be able to monitor their inventory remotely. The Greg system will register plants with sensor devices and place them in our rail mounted watering system to help monitor soil moisture levels and deliver catered care to each plant. Our web application will provide a platform to easily monitor and manage the system to exactly how they want. Once set up, the system will take care of everything related to watering for the user and will be able to notify them of any vital information.

1.1. Purpose

The purpose of the design specifications is to provide the explanation of the design choices and specifics for Greg. The individual sub systems will be described and a test plan with design alternatives will be given in the appendix.

1.2. Scope

The design specification covers the design choices for Greg based on our requirement specifications for the proof-of-concept and any design alternatives. The following will be covered in this document.

1. System Overview
2. Water Delivery System and Operation Box
3. Plant Monitoring System
4. Appendix:
    a. Test Plan
    b. Design Options

2. SYSTEM OVERVIEW

2.1. System Overview and User Interaction

Setup of the proof-of-concept for Greg will require construction of the rail system and mounting of the operation box in area 1-meter by 1-meter (i.e., table or floor). To review information of the rail system and operation box please refer to Water Delivery System and Operation Box. After setup of the operation box and Arduino sensor hub, they will connect it to the local Wi-Fi network. The user will be directed to register on the web application and connect the system for monitoring. Device registration will be done by generating a QR Code and mapping the area that is covered by the rail system in 3 by 2 grid (Reference Plant Identification and Mapping) and placing the plants in the area. These QR codes will be placed beside the device to identify the plant and assist for aiming the water delivery system.

Figure 2-1 displays the Use Case diagram of interactions of the user with the system for the proof-of-concept of Greg.

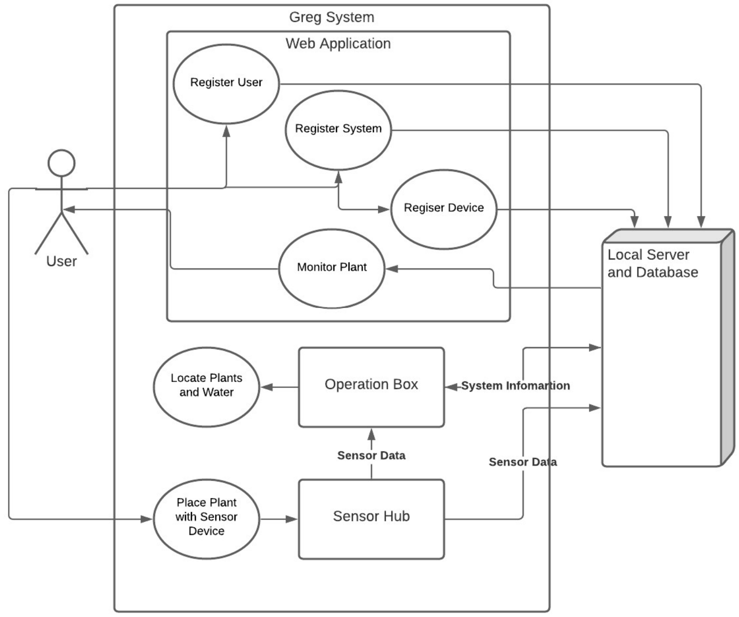

Figure 2- 1 Use Case Diagram

2.2. System Monitoring and Web Application

Data processing is important in the MNDL project. Data processing will help to collect useful information and process it for the further use. MNDL will choose MongoDB as the data storage as it is a document model which allows virtually any kind of data structure to be modeled and manipulated easily, is easy to scale, and will therefore provide more flexibility to the MNDL.

For the proof-of-concept, MNDL will set up a local backend server which will include the data and registration functions by using Node.JS. The local backend server will include user, system, and sensor registration. Users can register via the sign-up page shown in the Figure 2-2. In the prototype, MNDL will move backend from local to the AWS server. For more details about how to use the web application, please refer to Appendix B for the user interface. Table 2-1 will discuss the requirements related to the web application.

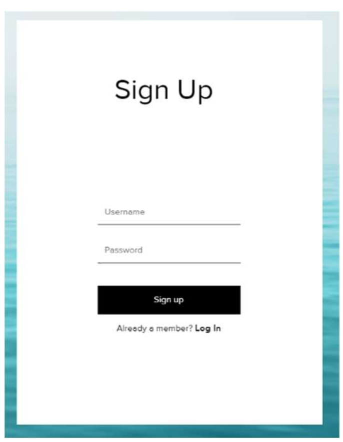

Figure 2- 2 User registration

Web app specifications	
Standards	Description
[Des 2.1.1-POC]	The user cannot sign up with an existing username in the database.
[Des 2.1.2-POC]	The user can only login with correct username and password.
[Des 2.1.3-POC]	The user shall be able to register a new plant via the web app.
[Des 2.1.4-POC]	The user shall be able to register a new device via the web app.
[Des 2.1.5-POC]	The user shall be able to see registered plants' status on the web app.

Table 2- 1 Web application specifications

As shown in the Figure 2-3, The sensor device hub will collect soil moisture level data from sensors embedded in potted plants. The sensor device hub will then send this data to MongoDB Atlas by calling the HTTP request. The backend data function will help to store the collected data into their corresponding collections. Operation box will send HTTP PUT requests to update the water tank level in the MongoDB database.

The MNDL website application for users can call HTTP request to monitor their plants and system. The backend data function will choose the required data to process, so that user can check the overall system information from the website application by clicking the plants status. The web application will allow the user to view general information of the system, which includes the water tank level, and registered plants' data and history [figure 2-4]. Selecting a plant through the interface will let users see each registered plant's image, current soil moisture level and daily moisture level shown in figure 2-5.

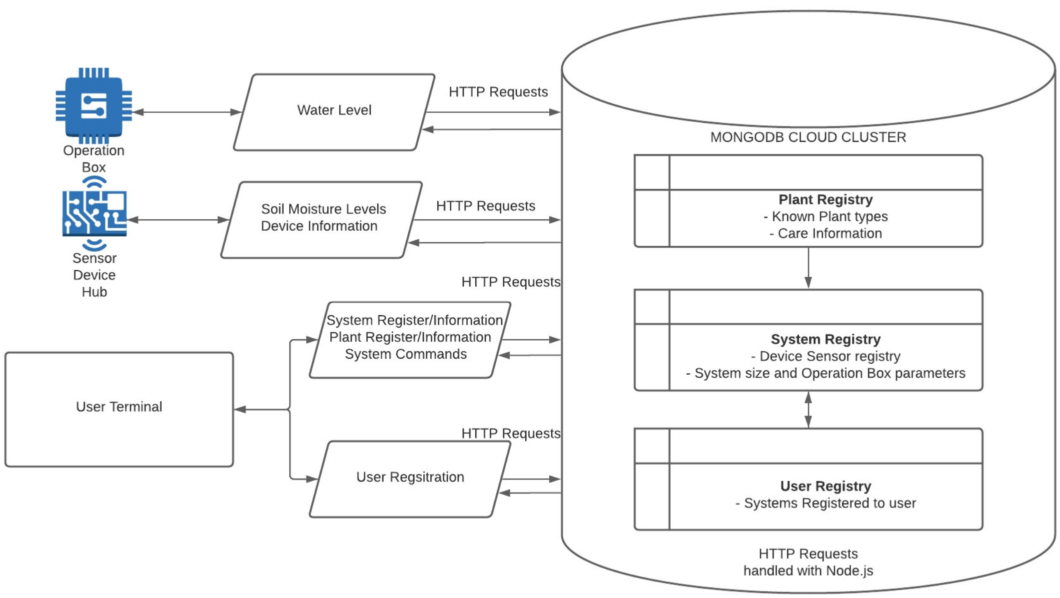

Figure 2- 3 Database transactions

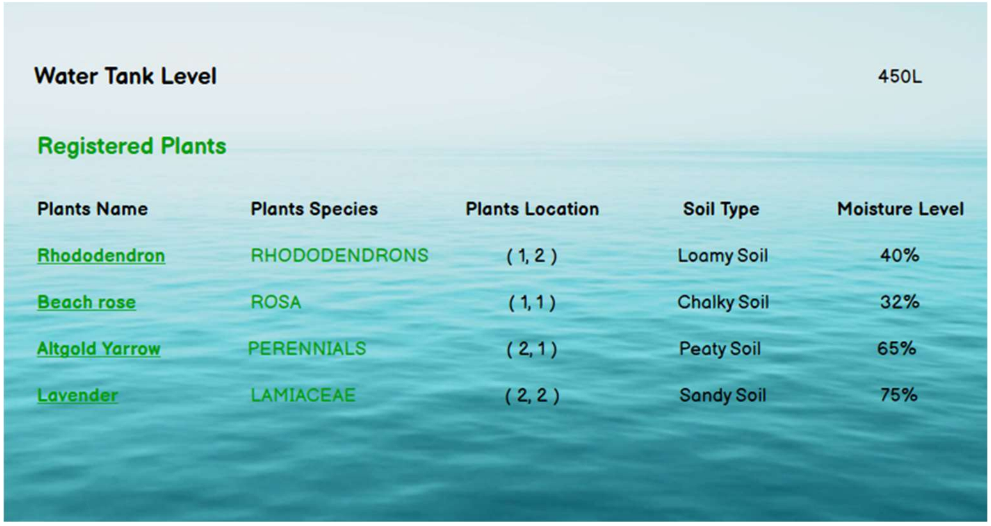

Figure 2- 4 Overall system information

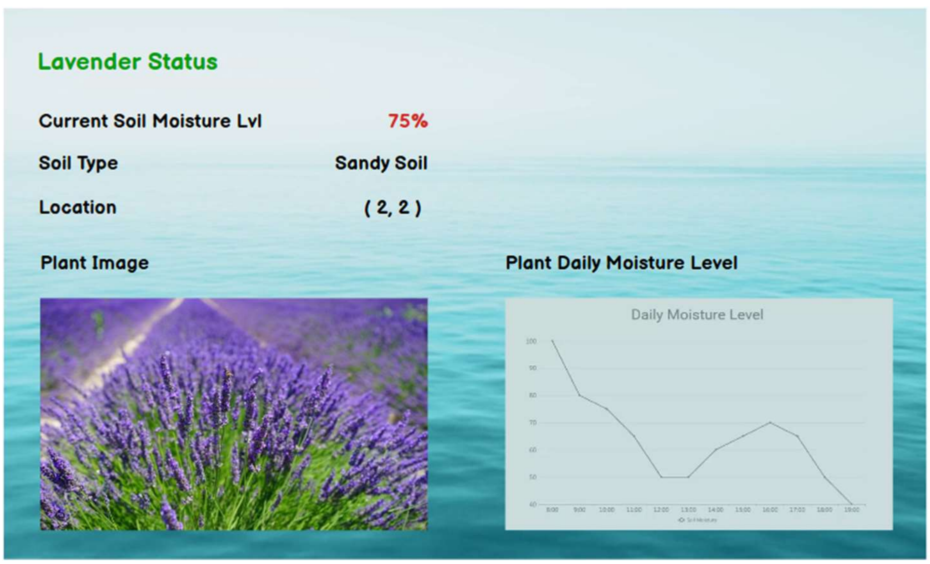

Figure 2- 5 Plant Status

Data Storage and Utilization specifications	
Standards	Description
[Des 2.2.1-POC]	MNDL Data processing shall store each registered system information in MongoDB system registry.
[Des 2.2.2-POC]	MNDL Data processing shall store each registered sensor information in MongoDB sensor registry
[Des 2.2.3-POC]	MNDL Data processing shall store soil moisture level data, water tank level, plants image to the MongoDB atlas.
[Des 2.2.4-POC]	MNDL shall process data using HTTP requests between devices on a local Wi-Fi network.

Table 2- 2 Data Storage and Utilization Specifications

3. WATER DELIVERY SYSTEM AND OPERATION BOX

These specifications describe the rail mounted operation box functions to determine how much water to deliver to each plant after locating them in the system. The following parameters will be used to determine how much water will be delivered.

1. Plant Species. (specify ideal soil moisture level)
2. Soil Composition.
3. Pot Size.

Soil composition is important for plant health and various plants will require different mixtures. Common soil mixes are perlite, vermiculite, peat moss, sand, wood fiber, and coconut fiber. This is to allow the soil to be more porous and allow proper drainage and distribution of water. However, this causes the potted plant to dry out quicker and requires more frequent watering. Additionally, some other types of soil mixes involve using limestone for pH control or fertilizer for growth. Depending on what kind of soil mix is used for the potted plant will also determine how much water will be required **[15]**. Therefore, if a plant's soil composition consists of a gritty mix which allows for quick drainage, it may require more frequent watering (but won't need large amounts of water at any given time). Likewise, a soil mix which retains more moisture will require a different watering routine.

Another attribute of how much water will be needed is based on the pot size. This will contribute to the base amount of water to provide to the plant and is given by multiplying the surface area of the open soil by 2.5cm **[16]**. For example, if a pot has a diameter of 20 cm and an area of 314 cm^2 then the amount of water to be given per week is 314 cm^2 * 2.5 cm = 785 cm^3, or 0.785 L of water. This scale factor will be adjusted accordingly with further development to give a better ideal baseline.

$$Area\ (cm^2) X\ 2.5\ cm\ =\ Volume\ of\ water\ weekly\ (cm^3)$$

This value will be divided by 7 for the number of days in a week and be the base amount of water that will be given when a plant falls below a user specified soil moisture threshold. Soil composition and pot size determine the amount of water to deliver, while the plant species will determine when the plant will be watered. For the proof-of-concept, the operation box will be servicing up to 6 plants in a 1m^2 area mounted on top of an operation box. [Refer to Hardware Design]

The autonomous steps are as described:

1. Soil moisture reading is received by a plant's sensor device.
2. Soil moisture level is compared to the threshold based on plant species/type. If level is below threshold:
    a. True: Add plant to watering queue.
        i. Operation box calculates how much water to deliver to the plant based on soil composition and pot size.
        ii. Operation box locates plants and delivers water.
    b. False: Next soil moisture reading is checked.
3. Wait for next soil moisture reading.

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The software system diagram is displayed in figure 3-1 to describe the logical flow of operations when the system is in operation. The system will periodically check the soil moisture readings from the sensor device hub at intervals of 4 hours and process the data in the operation box.

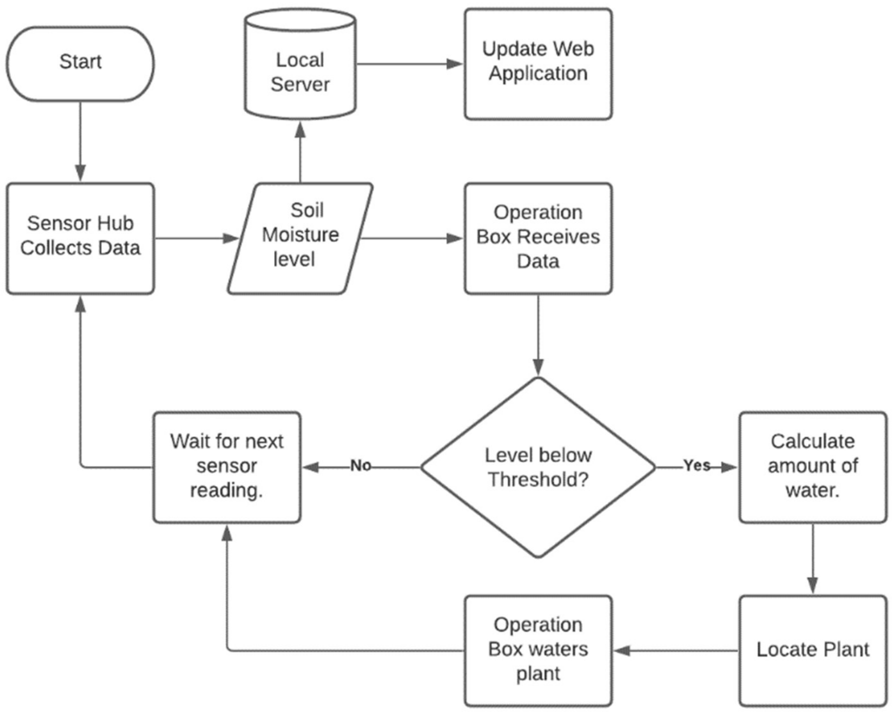

Figure 3- 1 Water Delivery System Diagram

Operation Box Watering System Design Specification	
[Des 3.0.1-POC]	The operation box will service up to 6 plants periodically and based on needs received by their soil moisture sensors.
[Des 3.0.2-POC]	Operation box delivers an appropriate amount of water based on plant species, soil composition, and pot size.
[Des 3.0.3-POC]	Operation box must recognize any plants that was registered and placed inside the system.
[Des 3.0.4-POC]	The operation box shall receive data from the sensor hub through a local Wi-Fi network about soil moisture readings.
[Des 3.0.5-POC]	The operation box shall calculate correct irrigation volume based on the equation.
[Des 3.0.6-POC]	The autonomous steps shall run smoothly without errors.

Table 3- 1 Water Delivery Design Specifications

3.1. Rail System Hardware Design

The rail system is built up with stepper motors, motor drivers, a microprocessor located in operation box and lead screw linkages. These linkages integrate to allow the operation box to locate the designated position and execute the order that receive from the server. Figures 3-2 and figure 3-3 giving an aerial and plane view of the system, respectively. Table 3-2 describes the dimensions that will be used to create the rail system for Greg. The labels of the axis are as follows:

- Y-Axis: Movement of the bridge across the frame.
- X-Axis: Movement of the operation box along the bridge.

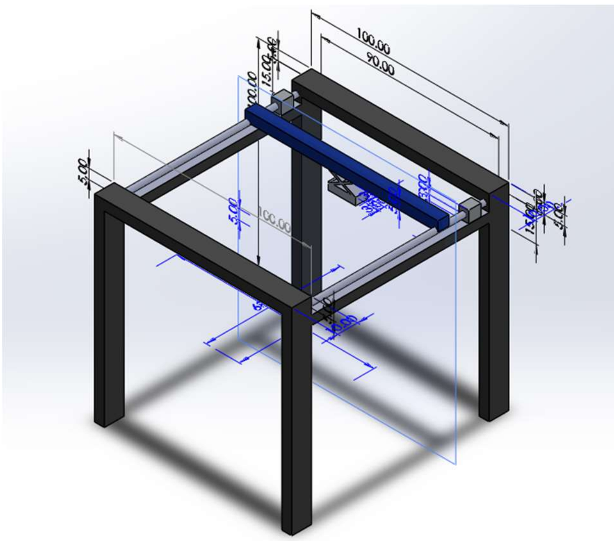

Figure 3- 2 Aerial view of rail system

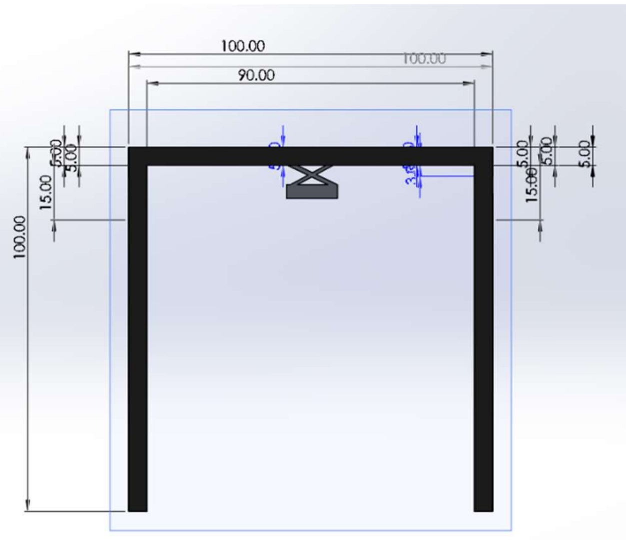

Figure 3- 3 Plane view of rail system

Item	Specification
Y-axis length	100 cm
X-axis length	100 cm
Frame height	100 cm
Lead screw length	90 cm
Estimate bridge weight (include operation box)	2 kg

Table 3- 2 Frame dimensions of rail system

Table 3-3 shows the design requirements for the Greg's rail system. The design requirements are set to reduce the potential of failure and unify the standards of the system building when implementing the scalability for the engineering prototype.

Rail System Design Specifications	
[Des 3.1.1-POC]	The motor driver and microprocessor shall be connected on the breadboard.
[Des 3.1.2-POC]	The motors that drive the bridge at Y-axis shall be install at the same end position of both trajectories.
[Des 3.1.3-POC]	The rail system shall have LED lights to indicate the status of operation.
[Des 3.1.4-POC]	The linear guide shall place along with the lead screw and the bridge shall install on it.
[Des 3.1.5-POC]	The linear guide's slide block shall be link with the lead screw's interlock.

[Des 3.1.6-POC]	The dual motor at Y-axis shall be enough torque to drive the lead screw to rotation.
[Des 3.1.7-POC]	The motor shall be driving the slide block at consistent low speed.
[Des 3.1.8-POC]	The motor shall be turned off when it in standby mode.
[Des 3.1.9-POC]	The motor driver shall be able to drive with required current/phase of the motor.

Table 3- 3 Rail system design specifications

For the design specifications of the rail system, we will be looking at the specification and performances of the motor and its drivers. We will verify the rail system can drive the operation box to the designated position. The following specification of motor and motor driver is designed for the proof of concept and engineering prototype. The performance requirement of the motor and motor drive is suspect to changes for the production environment after being tuned during the development.

3.1.1. 1.8° 42mm Hybrid Stepper Motor-NEMA17

Two NEMA17 stepper motor will be used to rotate the lead screw at both sides of the Y-axis rails on the frame, and the coupling nut on the screw will drive the slide block along the linear guide. It will move the bridge along the Y-axis. The bridge will have a similar mechanism but using single motor to drive operation box along the X-axis.

Figure 3- 4 42HS34-0404 motor [1]

42HS34-0404 Motor Specifications	
Item	**Specifications**
Model No.	42HS34-0404
Step Angle	1.8 (°)
Motor Length	34 (L)mm
Current/Phase	0.4 A
Resistance/Phase	30 Ω
Inductance/Phase	35 mH
Holding Torque	2.6 kg.cm
# of Leads	4
Detent Torque	120 g.cm
Rotor Inertia	34 g.cm
Mass	0.22 Kg

Table 3- 4 42HS34-0404 Motor Specifications [2]

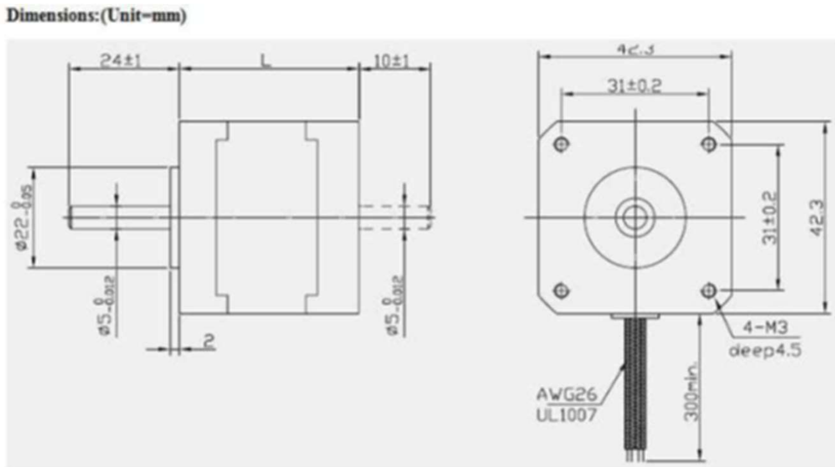

Figure 3- 5 42HS34-0404 motor dimensions [2]

3.1.2. A4988 Stepper Motor Driver Module

The A4988 [figure 3-6] is a mini stepper motor driver with a built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V and ±2 A. **[4]** Specifications and pin layout is included in table 3-5 and figure 3-7, respectively.

Figure 3- 6 A4988 Stepper Motor Driver

A4988 Driver Module Specifications	
Item	Specifications
Load Supply Voltage	8 to 35 V
Output Current	±2 A
Logic Input Voltage	–0.3 to 5.5 V
Logic Supply Voltage	–0.3 to 5.5 V
Motor Outputs Voltage	–2.0 to 37 V
Reference Voltage	5.5 V
Operating Ambient Temperature	–20 to 85 ºC
Current sense resistance	68 mΩ

Table 3- 5 A4988 Specifications [4]

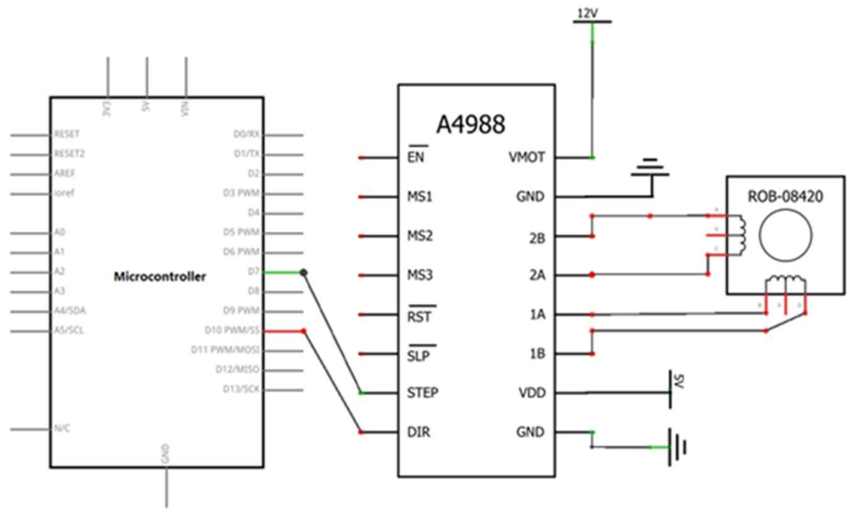

Figure 3- 7 Pin layout of A4988 [5]

3.1.3. Rail Motor Feasibility:

An approximate calculation will be done to verify that the chosen motor will satisfy design specification [Des 3.1.6-POC]. For the estimating the upper limit load of the rail system, the expect data are given below:

Item	Specification
Total mass of loads and table (per motor)	1kg
Friction coefficient of the guide (Lubricated Aluminum)	0.3

Table 3- 6 Load and linear guide specifications

Item	Specification
Diameter	8 mm
Total length	900 mm
Lead (pitch)	2 mm/rev
Efficiency	50 %
Material	Steel
Mechanism angle	0

Table 3- 7 Lead screw specifications

Item	Specification
Operating speed (Fixed)	15mm/s
Acceleration/Deceleration	2s

Table 3- 8 Operating conditions

From the motor sizing tool calculator [motor sizing calculator], we have the following result:

Item	Specification
Required Speed	450 r/min
Required Torque	3.1929e-3 N·m
Load Torque	2.0588e-3 N·m

Table 3- 9 Worst load requirements

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The required torque for the load item per motor is 3.1929e-3 N·m, or 32.5 g.cm. The 42HS34-0404 motor has a rotor inertia of 34 g.cm and is within our specification needs but ideally should have a wider torque margin for optimal operation. To satisfy the design requirement [Des 3.1.9-POC], the driver while supply the appropriate current to operate the motor correctly and safely.

The A4988 supports active current limiting using trimmer potentiometer and will be used to set an upper current limit. For Greg's design, each motor will need 0.4A/phase, and with 2 motors connected in parallel will need a supplied current of 0.8 A. As the A4988's specifies its current limit at 2A, this gives a safe margin from the upper limit of the motor. With the current known, the V_{ref} of the Y-axis dual motor driver is calculated as:

$$Vref\ (V) = Rated\ Motor\ Current\ (A) * 8 * Rsense(\Omega)$$

$$Vref = 0.8\,A * 8 * 0.068\,\Omega = 0.435V$$

Since the coils are limited to approximately 70% of the set current limit in full-step mode, it will need to set the current to be 40% higher, or 1.12A. Giving us an upper maximum of the V_{ref} as 0.610V **[7]**. To make sure we are not running the components at the maximum rating, we will provide a 10% safety margin giving a final V_{ref} value of 0.55V. Using the same method for the X-axis motor driver, the V_{ref} will be set at 0.274V.

3.1.4. Circuit Design

For the rail system design, we will use two motors on each side of the Y-axis frame railings. These two motors are run in the same direction and at the same speed to make sure the bridge moves at a smooth appropriate speed. The motor we chose to use is the NEMA 17 42HS34-0404 with a 0.4 A/phase. The maximum output of A4988 is 2A, so for the proof of concept we can use one A4988 to drive two NEMA 17 42HS34-0404 motor. And for the X-axis we use anther A4988 to drive the X-axis trajectory. The circuity for the proof-of-concept is shown in figure 3-8.

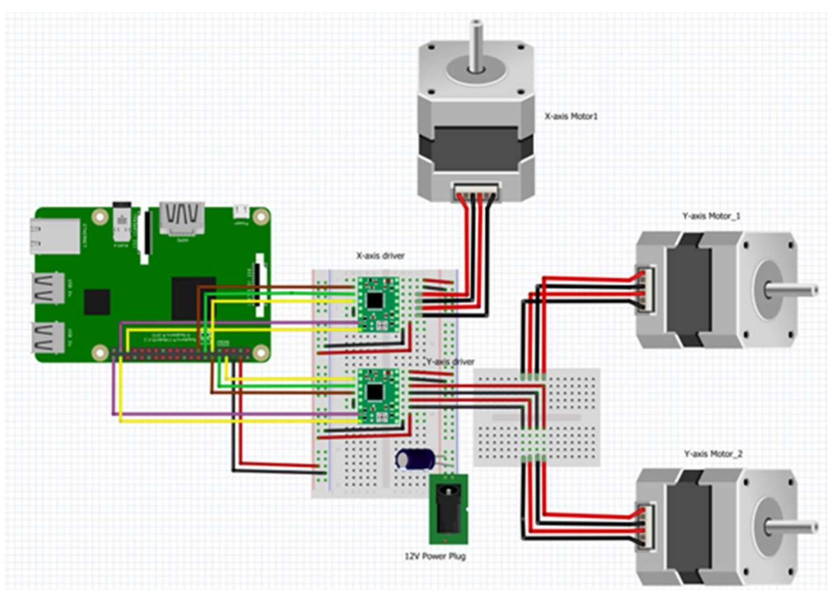


Figure 3- 8 Rail system circuit design

3.1.5. Design Alternative

An alternative for the lead screw linkage system for the rail system is to use a timing belt. The timing belt can manage long strokes, high linear travel speed, higher efficiency, lower input RPM and higher duty cycles. However, additional costs in vertical applications can be incurred due to gear reducers and motor fail-safe brake requirements, and the need for more input torque from the motors **[8].** This will require a more expensive and powerful motor. For the proof of concept, the lead screw system is the preferred choice for the size of our serviced area since it falls within our specifications and at a lower cost.

3.2. Operation Box Hardware Design

The Operation box will calculate the amount of water needed for the plants as specified in the introduction for section 3 and aiming the water pump with a spray or nozzle using the camera. The operation box hardware design is mainly divided into four components: the microcontroller, z-axis movement, and water pump. These components are critical for plant health and controlling the soil moisture levels of the registered plants. The microcontroller controls the z-axis movement, camera, and water pump to effectively keep things automated. Our product is fully autonomous without any human intervention once the setup is complete.

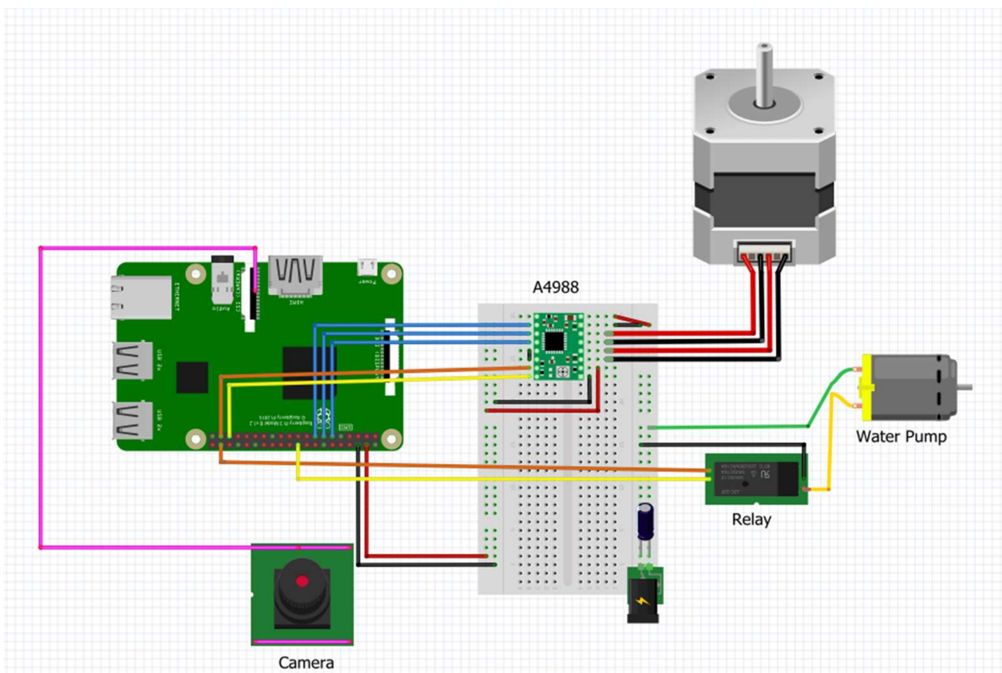


Figure 3- 9 Detailed circuit connection of the operation box.

3.2.1. Operation Box Microcontroller

Greg uses a Raspberry Pi 3 Model B+ to support various design specifications required by our product as it is easy to build with and has enough computation power for the needs of Greg. This microcontroller has numerous ports including camera, 4 USB 2.0, gigabit internet, supports PoE, Wi-Fi modules, Bluetooth 4.2/BLE and many more to support our design.

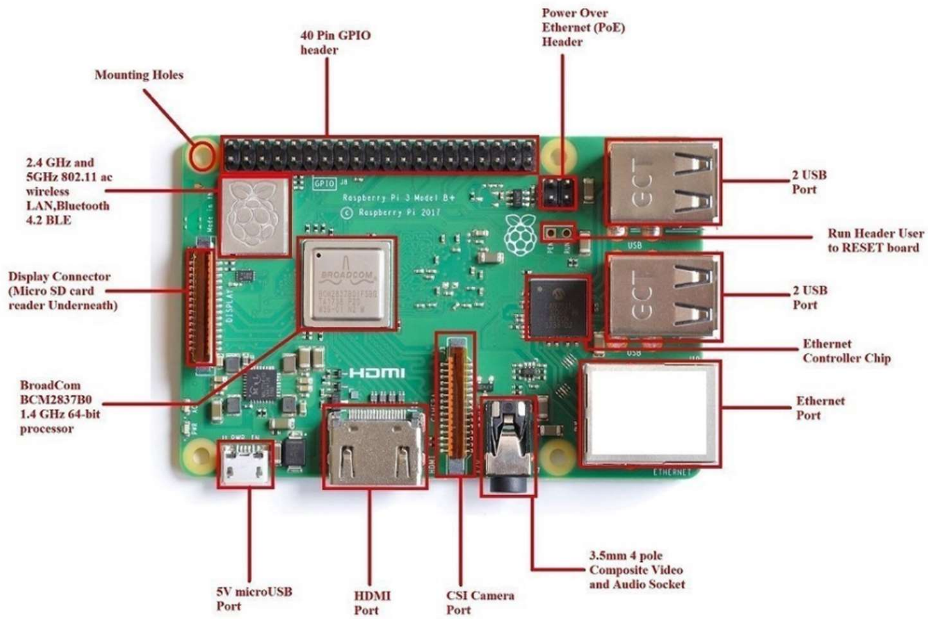


Figure 3- 10 Overview of Raspberry Pi 3 Model B+ [21]

Operation Box Microcontroller Specifications	
Standards	Description
[Des 3.2.1-POC]	The device must support Wi-Fi and Bluetooth 4.2/BLE modules
[Des 3.2.2-POC]	The device must have a camera port to plug into the controller
[Des 3.2.3-POC]	The device must be powered by 2.5A 5V micro-USB power adapter
[Des 3.2.4-POC]	The device must have a Micro SD of storage of at least 10GB to run the operating system

Table 3- 9 Operation box microcontroller specifications

3.2.2. Scissor Mechanism

The operation box uses a scissor mechanism along with a NEMA17 stepper motor to reach the soil and goes back to its original position. We chose this method to provide effective movement in the z-axis. We are planning to implement this mechanism by connecting to one end of the scissor mechanism to the stepper motor to make the scissor mechanism either shrink or expand.

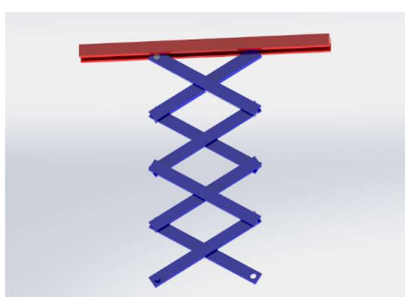


Figure 3- 11 Example of scissor mechanism for z-axis movement [22]

Scissor Mechanism	
Standards	**Description**
[Des 3.2.5-POC]	The operation box shall use scissor mechanism for z-axis movement
[Des 3.2.6-POC]	The operation box shall use NEMA17 stepper motor to move the operation box

Table 3- 10 Scissor mechanism specifications

3.2.3. Camera Module

The camera module plays an important role for the operation box. The camera tracks the plants, aims the plants to specific locations to provide a certain amount of water depending on the soil moisture level. To achieve this, we would need a camera with minimum of 5MP to support enough resolution and accuracy to aim the water to each plant. The camera we chose uses the OV5647 sensor to support a pixel count of up to 2592x1944 and video up to 1080p at 30fps using codec H.264. The camera has a 65-75 degrees angle of view and the camera size is 25x24mm.

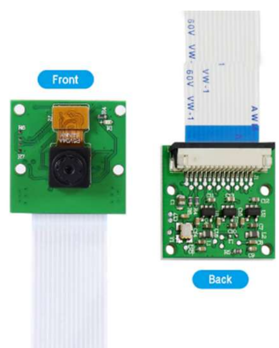


Figure 3- 12 5MP camera with OV5647 sensor

5MP camera with OV5647	
Item	**Specifications**
Angle of View	54 x 41 degrees
Field of View	2.0 x 1.33 m at 2 m
Full-frame SLR lens equivalent:	35 mm
Fixed Focus	1 m to infinity
Max frame rate	30fps
Material	Metal, Plastic

Table 3- 11 5MP camera with OV5647 sensor specification [10]

Camera Module	
Standards	**Description**
[Des 3.2.7-POC]	The camera must use OV5647 sensor to support 5MP resolution
[Des 3.2.8-POC]	The camera must have at least 65 degrees angles of view
[Des 3.2.9-POC]	The camera must be fully compatible with the microprocessor
[Des 3.2.10-POC]	The camera must be able to scan the QR code accurately

Table 3- 12 Camera module for Raspberry Pi

3.2.4. Water Pump

Greg uses a water pump along with the water tank to accommodate efficient watering system. We chose DC WATER PUMP 6-12V RS360SH, because it is cost effective and supports enough power to water each plant. Water tube is then connected to this water pump and has two channels. One channel is pumping the water from the water tank and the other channel is attached to the operation box to provide precise position to aim at the plant. We are using Liters per minute (LPM) measurement to calculate the water flow rate of the water pump.

We will then calculate the water tank water level with the use of ultrasonic distance sensor –HC-SR04. This sensor provides 2cm to 400cm of non-contact measurement with an accuracy level up to 3mm.

Figure 3- 13 DC WATER PUMP 6-12V RS360SH [23]

DC WATER PUMP 6-12V RS360SH	
Item	**Specifications**
Rated Voltage	DC 6-12V
Nominal Voltage	7.2V
Total Length	78mm
Main Body Size	27 x 35mm / 1" x 1.4" (D*L)
Pump Head Size	40 x 14mm / 1.6"x 0.6" (D*L)
Material	Metal, Plastic

Table 3- 13 DC WATER PUMP 6-12V RS360SH Specification [9]

Water Pump System	
Standards	**Description**
[Des 3.2.11-POC]	The water pump must have at least 6V to pump water from the water tank
[Des 3.2.12-POC]	The capacity of water tank must be between 3 to 15 Liters of water to accommodate efficient watering system
[Des 3.2.13-POC]	The water tank must have a sensor to calculate the water level
[Des 3.2.14-POC]	The user shall be notified to fill replenish the tank once the water is below 3 Liters of water

Table 3- 14 Water pump system specifications

3.3. Plant Care Software Design

3.3.1. Plant identification and Mapping

Plant identification is one of the most vital components for Greg, it will provide the operation box the location of plant which needs irritation. Greg will use a QR code as the way to identify the location of each plant. Figure 3-7 shows the structure of QR code. QR code is a fast and simple to use and will be sufficient for our proof-of-concept over using a plant identification API.

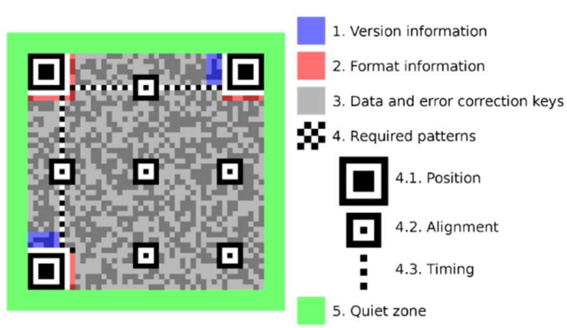


Figure 3- 14 QR code structure [12]

Plant Identification Specifications	
Standards	Description
[Des 3.3.1-POC]	MNDL Plant identification shall generate the QR code and store plant location.
[Des 3.3.2-POC]	MNDL Plant identification shall scan the QR code and get the plant location

Table 3- 15 Plant identification specifications

The plant identification system in software will be divided into two components. The first component is to use website application to generate QR code, store plant location into it and call HTTP request to save QR codes for the corresponding sensor registry. We can create a QR Code Image, by calling the following code (Figure 3-8) in the website application. In our proof of concept, we will divide the 1 meter by 1 meter area covered by Greg into 6 even spaces, marked as (0,0), (0,1), (1,0), (1,1), (2,0), (2,1) to be the plant location. This mapping will be done for the proof-of-concept to quickly service the registered plants. In the following example, we will change 'Some text' to the plant location and store it into the QR code. After creating a QR code .png file, we will print it and place it alongside the plant pot with its registered sensor device.

Example

```
QRCode.toFile('path/to/filename.png', 'Some text', {
  color: {
    dark: '#00F',  // Blue dots
    light: '#0000' // Transparent background
  }
}, function (err) {
  if (err) throw err
  console.log('done')
})
```

Figure 3- 15 Create a QR Code Image [13]

The second component is to use camera from operation box to scan the QR code beside the registered plant pots to get the identity of the plant. Greg will use the Raspberry Pi 3 and its camera module as a QR scanner. We need to attach the camera ribbon connector in the camera slot given in the Raspberry pi as shown in Figure 3-9 The plant identification system will grab a frame from the video stream and resize it to 400 pixels. Once it grabs the frame, call the *pyzbar.decode* function to detect and decode the QR code. Then decode the detected barcode into an "utf-8" string using the decode("utf-8") function and then extract the type of barcode using the *barcode.type* function. After that, save the extracted barcode data and barcode type inside a variable named text, and draw the barcode data and type on the image.

Figure 3- 16 Raspberry pi 3 and Camera [14]

3.3.2. Operation Box Stepper Motor Control

Moving the operation box is an essential function of Greg. It plays a significant role in cases that it needs to irrigate, locate, and read information from a plant. The logic of this function is as follows and heed the specifications described in table 3-16:

1. The operation box reads the desired coordinate from the database system when it is necessary to move the box.
2. Once the destination is fixed, the operation box does calculation to generate proper instructions sent to the motors and scissor mechanism.
3. Finally, the motor drivers work as instructed to send the operation box to a specific coordinated (x, y, z).

Operation Stepper Motor Control	
Standards	Description
[Des 3.3.3-POC]	The desired coordinate (x, y, z) is determined by the operation box.
[Des 3.3.4-POC]	The operation box sends correct instructions to the motors and scissor mechanism.
[Des 3.3.5-POC]	Motors and scissor mechanism move the operation box to the specified coordinate (x, y, z).
[Des 3.3.6-POC]	Parameters can be found in proper locations in the database.

Table 3- 16 Operation Box stepper motor control specifications

4. PLANT MONITORING SYSTEM

To allow the Operation box and the user to be able to monitor their plants in the system, the sensor devices will be periodically sending data every 4 hours. The soil moisture sensors will take readings from each plant and submit the data through the Arduino UNO sensor hub to their system database and operation box for its respective plant. If the reported soil moisture is below the accepted range of readings, then the operation box will find the plant and calculate the amount of water needed based on soil composition, plant species, and pot size. Figure 4-1 describes the pathway of the soil data being transmitted over Wi-Fi to the operation box and local server for the proof-of-concept. The process of collecting soil moisture data and transmitting to the local server is described earlier in Systerm Overview.

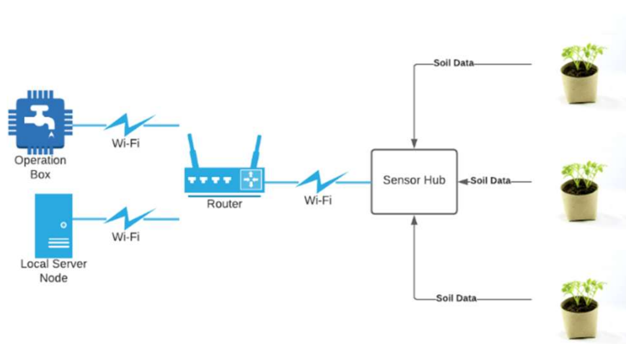


Figure 4- 1 Sensor System credits in ref [17]

Plant Monitoring Specifications	
Standards	Description
[Des 4.0.1-POC]	The sensors shall be able to grab accurate data of the moisture level of each plant's soil every 4 hours.
[Des 4.0.2-POC]	There shall be no risk of shortage from the circuit connection of within the hub and with the hub with the multiple sensors connected.
[Des 4.0.3-POC]	The hub shall have spare connectable ports for expansion purpose.
[Des 4.0.4-POC]	The hub shall support 1 sensor device per plant with up to 6 total plants connected.
[Des 4.0.5-POC]	The sensor devices shall connect to the hub via the GPIO pins of the Arduino UNO.
[Des 4.0.6-POC]	The sensor hub shall distinguish which sensor device is connected to which plant.
[Des 4.0.7-POC]	Sensor hub shall transmit plant data over a local Wi-Fi network to communicate with the operation box.
[Des 4.0.8-POC]	Sensor hub shall transmit plant data over a local Wi-Fi network to communicate with the database for remote monitoring.
[Des 4.0.9-POC]	Correct data is transmitted between the operation box and the plant monitoring system.
[Des 4.0.10-POC]	Correct data is transmitted between the database system and the plant monitoring system.

Table 4- 1 Plant monitoring specifications

4.1. System and Plant Monitoring Hardware Design

4.1.1. Microcontroller

Greg shall use the Arduino UNO with an integrated ESP8266WiFi module. This module is reliable, safe, and scalable to numerous applications which is why MNDL chose to use this microcontroller. Greg aims requires the microcontroller to be able to be scalable since we are targeting plant nurseries. It has built-in digital and analog I/O(input/output) that is adaptable to expansion of boards and scalability in which Greg requires. The board has 6 analog I/O pins, 14 digital I/O pins and programmable with the use of Arduino IDE (Integrated Development Environment) through a USB cable. It can be powered by an external battery in the range of 7V to 20V or by USB power. Arduino UNO is the ideal component that will act as the hub for the sensors that are in the soil of each plants per 1 meter by 1 meter structure of Greg. It has an operating voltage of 5V, which is considered low and perfect for Greg as a sensor device hub. Arduino UNO also has one UART, I2C, and SPPI.

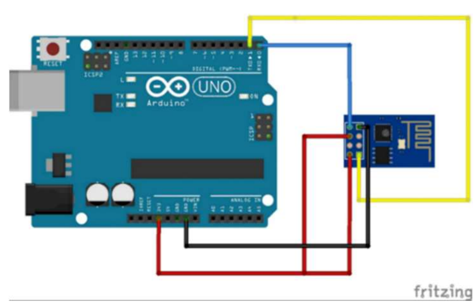


Figure 4- 2 Connection between Arduino UNO with ESP8266 Wi-Fi module

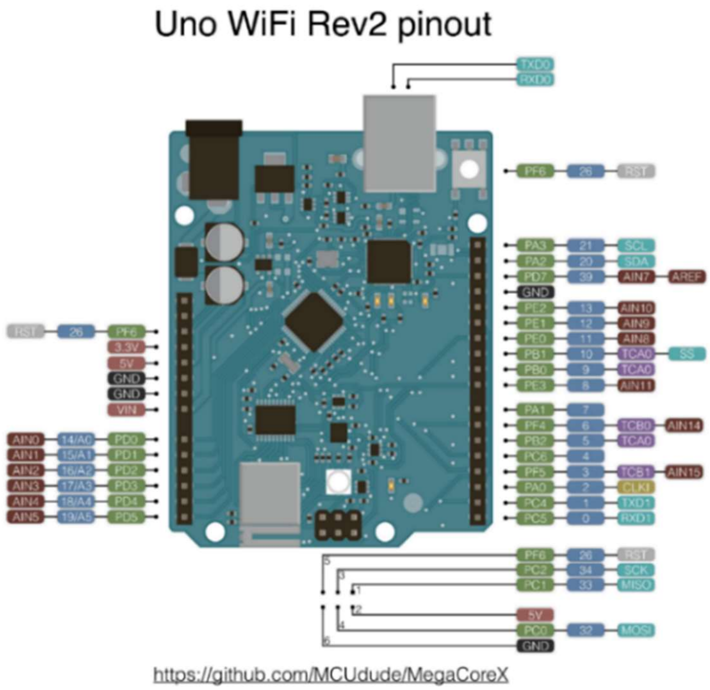


Figure 4- 3 Pin layout of Arduino UNO Wi-Fi Microcontroller [18]

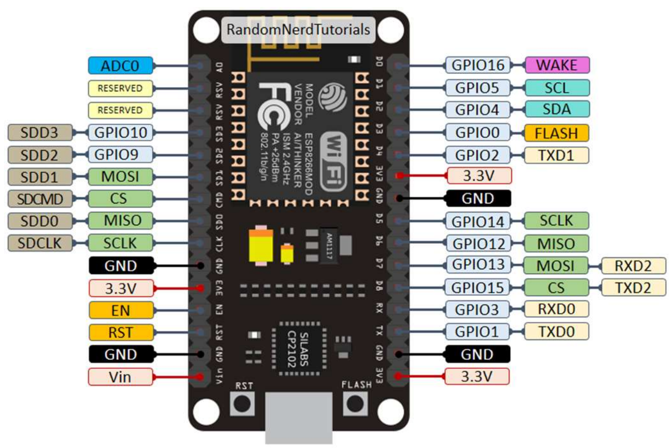


Figure 4- 4 Pin layout of ESP8266 Wi-Fi module

Sensor Hub Microcontroller	
Standards	Description
[Des 4.1.1-POC]	Microcontroller shall access the internet for data transmission through connection with ESP8266 Wi-Fi module.
[Des 4.1.2-POC]	Microcontroller must work with low voltage (7V-20V) batteries or by a USB cable.
[Des 4.1.3-POC]	Microcontroller must have multiple spare input pins for expansion.

[Des 4.1.4-POC]	The risk of shortage caused by water should be eliminated at the connectable ports of the sensor hub.
[Des 4.1.5-POC]	The sensor hub shall have spare connectable ports for expansion purpose.
[Des 4.1.6-POC]	The hub supports 1 sensor for each plant and 6 plants connected in total.

Table 4- 2 Sensor hub microcontroller specifications

4.1.2. Sensors

MNDL shall use a Capacitive Soil Moisture Sensor v1.2 as the main sensor to detect the moisture level of the soils in the plant pots. This sensor has a working voltage in the range of 3.3 - 5.5V. This was a perfect candidate for the purpose for the development of Greg since it is ideal for our low power microprocessor, ESP32. It has working current of 5mA and weight of 15g that can be directly inserted to the soil which is what Greg requires. Multiple of this sensor would be connected to the Arduino UNO. The sensors will be calibrated to get the most accurate real time data for Greg.

Figure 4- 5 Image of capacitive Soil Moisture Sensor v1.2 [20]

Capacitive Soil Moisture Sensor v1.2	
Item	**Specifications**
Operating Voltage	DC 3.3-5.5V
Output Current	±2 A
Output Voltage	DC 0-3.0V
Interface	PH2.0-3P
Size	99x16mm/3.9x0.63"

Table 4- 3 capacitive Soil Moisture Sensor v1.2 Specification [11]

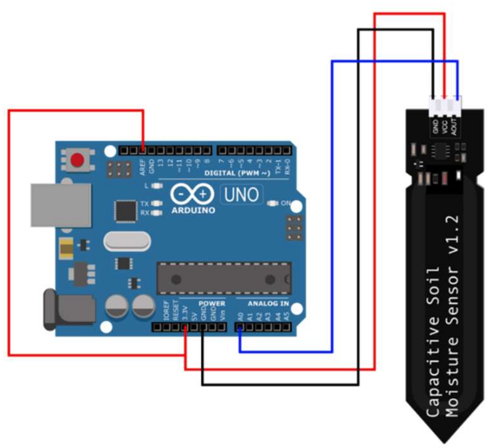


Figure 4- 6 Connection between Arduino UNO and the sensor

The sensors will get connected to the 3.3V, GND and in incrementing order from AIN0 to AIN# for the respective sensors. A jumper will be used on a breadboard for the connections to the 3.3V and GND pins of the sensors.

Capacitive Soil Sensors	
Standards	**Description**
[Des 4.1.7-POC]	Sensors must have a waterproof end where it can be directly inserted to soil.
[Des 4.1.8-POC]	Sensors must be able to be calibrated for accuracy of data.
[Des 4.1.9-POC]	Sensors must instantly read live data.
[Des 4.1.10-POC]	Sensors must be able to communicate with the microcontroller.
[Des 4.1.11-POC]	Sensors must have a low working voltage and should be light.
[Des 4.1.12-POC]	Sensors must have at least 2year of lifespan.
[Des 4.1.13-POC]	Sensors have working voltages in the range 3.3 to 5.5V, besides, the weight shall be around 15g.

Table 4- 4 Capacitive soil sensors

5. CONCLUSION

Greg is an automated and remote monitoring system that provides catered care to each plant that is placed in the rail mounted system. It helps monitors the soil moisture of plants and provide watering to plants as specified by the user based on plant type, soil composition, and pot size. Although Greg is relatively expensive due to the costly rail system, it is worth paying for Greg considering its high efficiency and accuracy of water delivery to boost yields and reduce costs from human error.

The design and the logic of our product is illustrated in this document, the following is a summary of our design specifications:

1. Web application and database system:
    a. Web app:
        i. Sign up/Login: The user can sign up or login on the web app.
        ii. Plants register: A new plant can be registered here.
        iii. Device register: The user can register a new device.
        iv. Plants' status: The status of all registered plants can be viewed in this page.
    b. Database:
        i. MongoDB: MongoDB is used as our data storage.
        ii. Node JavaScript: For PoC, node JavaScript is used to implement functions.
        iii. HTTP request: Data is transmitted by calling HTTP request.
2. Watery delivery system
    a. Parameters:
        i. Plant Species: Different species have different pre-set ideal soil moisture level.
        ii. Soil composition: The soil composition influences the water volume of irrigation.
        iii. Pot size: The bigger the pot is, the more water it needs.
    b. Software:
        i. Equation: This equation is to determine the amount of water that flows into the plant's soil when irrigation is needed.
        ii. Autonomous steps: Logic of watery delivery.
    c. Hardware:
        i. It requires almost all subsystems to work together to finish the watery delivery task, hardware needed includes web app and database system, rail system, operation box and plant monitoring system.
3. Rail system:
    a. Hardware:
        i. Stepper motor: Provides the torque to the lead screw linkages system.
        ii. Motor driver: Allows easy operation of stepper motors.
        iii. Lead screw linkage: Enables the operation box to locate the designated position.
4. Operation box:
    a. Hardware:
        i. Microprocessor: Deals with data input and send data to attached peripheral devices.
        ii. Camera: Tracks plants and help the watering system aim a specific plant.
        iii. Water pump: Irrigates plants by pumping water from water tank to a targeted plant.
        iv. Scissor mechanism: Let the operation box reach a certain height in z-axis.
    b. Software:

i. Plant Identification: The camera can scan the QR code sticker on the plants' pot, besides, it shall accurately aim the plant to let the pumped water flows to the correct position.
ii. Operation box moving function: The operation box sends instruction to motors and scissor mechanism, which allows the operation box to be located at a certain coordinate (x, y, z).

5. Plant monitoring system:
    a. Hardware:
        i. Microcontroller with Wi-Fi module: Accesses the internet for data transmission and allows the input from sensors.
        ii. Sensor: Reads the moisture of the soil.
        iii. Sensor hub: Provides a secure and waterproof environment for the microcontroller and allows the sensors to connect to the microcontrollers via some ports.
    b. Software:
        i. Sensor hub report system: The sensor hub periodically read the data input from sensors and then transmit the data to local server node and operation box over Wi-Fi.

APPENDIX A: TEST PLAN

A.1. Introduction

The test plan appendix shows the basic idea of how the testing will be done for every subsystem.

A.2. Web application and database testing

Tester Name:		Data:	
Web app and database testing			
Design Specifications	Test Description	Result (√ for Pass, × for Fail)	Comments
Web app			
[Des 2.1.1-POC]	Signup with an existing username shall fail.		
[Des 2.1.2-POC]	Correct username and password are required to log in.		
[Des 2.1.3-POC]	The user can register a new plant, generating QR code for it and storing information about it to database.		
[Des 2.1.4-POC]	The user can register a new device, storing information about the device to database.		
[Des 2.1.5-POC]	The user can see the report of registered plants' status.		
Database			
[Des 2.2.1-POC]	Information of registered systems can be found in MongoDB system registry.		
[Des 2.2.2-POC]	Information of registered sensors can be found in MongoDB sensor registry.		
[Des 2.2.3-POC]	Data including soil moisture level data, water tank level, plants image shall be stored in MongoDB atlas.		
[Des 2.2.4-POC]	MNDL transmits data using HTTP requests between devices.		

A.3. Rail system testing

Tester Name:	Data:
Rail system testing	

Greg: Design Specifications

Design Specifications	Test Description	Result (√ for Pass, × for Fail)	Comments
[Des 3.1.1-POC]	The breadboard connects the motor driver and the microprocessor.		
[Des 3.1.2-POC]	Motors shall be installed at the correct position.		
[Des 3.1.3-POC]	LED lights work properly to indicate the status of operation.		
[Des 3.1.4-POC]	The linear guide shall place along with the lead screw and the bridge shall install on it.		
[Des 3.1.5-POC]	The linear guide's slide block shall be linked with the lead screw's interlock.		
[Des 3.1.6-POC]	Enough torque is produced to rotate the Y-axis lead screw.		
[Des 3.1.7-POC]	The slide block is moving at a consistent low speed		
[Des 3.1.8-POC]	Motors shall turn off in standby mode.		
[Des 3.1.9-POC]	The motor driver works smoothly with required current and phase.		

A.4. Operation box testing

Tester Name:		Data:	
Operation box testing			
Design Specifications	Test Description	Result (√ for Pass, × for Fail)	Comments
Microcontroller			
[Des 3.2.1-POC]	The device is connected to Wi-Fi and Bluetooth.		
[Des 3.2.2-POC]	The device is connected to the camera.		
[Des 3.2.3-POC]	The power supply is a 2.5A 5V micro-USB adapter.		
[Des 3.2.4-POC]	The micro-SD works properly and has at least 10GB storage.		
[Des 3.3.2-POC]	After the camera scans the QR code, the microcontroller shall		

	identify the plant's location in the form of coordinate (x, y, z).		
[Des 3.3.5-POC]	The operation box shall be accurately moved to a specified location when it is necessary.		
Camera			
[Des 3.2.7-POC]	The camera uses OV5647 sensor to support 5MP resolution.		
[Des 3.2.8-POC]	The camera has 65 or more degrees angles of view.		
[Des 3.2.9-POC]	The camera works compatibly with the microprocessor.		
[Des 3.2.10-POC]	The camera scans the QR code correctly.		
Add-on requirement	The position of the camera is precisely adjusted so that it accurately aims the plant for the purpose of irrigating.		
Water Pump			
[Des 3.2.11-POC]	The voltage of the device is at least 6V.		
[Des 3.2.12-POC]	The water tank has a capacity of 3 to 10 Liters.		
[Des 3.2.13-POC]	The water level of the water tank can be read from a sensor		
[Des 3.2.14-POC]	Whenever the remained water is less than 3 liters in the water tank, the user shall receive a refill notification.		
Scissor Mechanism			
[Des 3.2.5-POC]	The operation box can move in z-axis using this device.		
[Des 3.2.6-POC]	The NEMA17 stepper motor functions properly.		

A.5. Plant monitoring system testing

Tester Name:		Data:	
Plant monitoring system testing			
Design Specifications	Test Description	Result (√ for Pass, × for Fail)	Comments
Microcontroller			

[Des 4.1.1-POC]	Data can be transmitted through Wi-Fi.		
[Des 4.1.2-POC]	The microcontroller works with 7V to 20V batteries or by a USB cable.		
[Des 4.1.3-POC]	Multiple spare input pins are provided.		
Sensors			
[Des 4.1.7-POC]	The sensor is partly or fully waterproof as required.		
[Des 4.1.8-POC]	Data read from the sensor shall be calibrated.		
[Des 4.1.9-POC]	Data read from the sensor shall be real-time.		
[Des 4.1.10-POC]	Sensors have working voltages in the range 3.3 to 5.5V, besides, the weight shall be around 15g.		
[Des 4.1.11-POC]	Sensors read the moisture level of plants' soil.		
Sensor hub			
[Des 4.0.2-POC]	The risk of shortage caused by water should be eliminated at the connectable ports of the sensor hub.		
[Des 4.0.3-POC]	The sensor hub shall have spare connectable ports for expansion purpose.		
[Des 4.0.4-POC]	The hub supports 1 sensor for each plant and 6 plants connected in total.		
[Des 4.0.5-POC]	Sensors are connected to the hub via the GPIO pins of the Arduino UNO.		
[Des 4.0.6-POC]	The sensor hub properly deals with the data input by sensors and keep the data organized.		
[Des 4.0.7-POC]	The hub transmits collected data to the operation box via Wi-Fi.		
[Des 4.0.8-POC]	The hub transmits collected data to the database via Wi-Fi.		

A.6. Post Water Delivery Safety testing

Tester Name:		Data:	
Post Water Delivery Safety testing			
Design Specifications	Test Description	Result (√ for Pass, × for Fail)	Comments
	Parameters		
[Des 3.3.6-POC]	Parameters can be found in proper locations in the database.		
	Software		
[Des 3.0.5-POC]	The operation box shall calculate correct irrigation volume based on the equation.		
[Des 3.0.6-POC]	The autonomous steps shall run smoothly without errors.		
[Des 4.1.13-POC]	Sensors have working voltages in the range 3.3 to 5.5V, besides, the weight shall be around 15g.		
	Sensor hub		
[Des 4.1.4-POC]	The risk of shortage caused by water should be eliminated at the connectable ports of the sensor hub.		
[Des 4.1.5-POC]	The sensor hub shall have spare connectable ports for expansion purpose.		
[Des 4.1.6-POC]	The hub supports 1 sensor for each plant and 6 plants connected in total.		
[Des 4.0.9-POC]	Correct data is transmitted between the operation box and the plant monitoring system.		
[Des 4.0.10-POC]	Correct data is transmitted between the database system and the plant monitoring system.		

APPENDIX B: USER INTERFACE AND APPEARANCE DESIGN

The automated plant watering system *Greg* by MNDL is an automated solution for medium-to-large nurseries to help take care of and monitor multiple plants with varying species, sizes, and needs. After setup, this operation can be used remotely by the user after setting up the system from our web application. The design of the Greg system is to be flexible and expandable by letting the user choose how large of an area to cover and what plants to take care of. The software system will be designed to allow minimal intervention from the user other than to set up and register plants. They will be able to monitor and control the system remotely through an application.

Purpose

The purpose of the User Interface Design Appendix is to provide a visual and analytical representation of the user interactions with the *Greg* system. It will provide specifics and design choices for our Proof-of-Concept and possible choices for the Prototype design.

Scope

The User Interface Design Appendix will discuss the following topics related to *Greg*.

1. User Analysis
2. Technical Analysis
3. Graphical Presentation
4. Engineering Standards
5. Usability Testing

B.1. User analysis

Our target market and audience for *Greg* are medium-to-large scale home plant nurseries and home plant enthusiasts with the need to water multiple plants precisely, automatically, and remotely. *Greg* is designed as a low-cost and flexible system. Our ideal user should have a basic to intermediate level of knowledge and experience on home plant species and the best way to care for them. If our user is familiar with a 3D printer or bridge crane system, then *Greg's* rail system will be similar but with watering, monitoring, and detection functions for plants *[please refer to Figure B-1 and Figure B-2]*. The operation box mounted on the rails will be used for mapping and delivering care to the plants *[Refer to Figure B-3]*. Additionally, to ensure the water pump of the operation box does not run dry, the user will be required to provide a sufficient supply of water and/or attach the system to a water source.

The system will need to have a stable connection to a Wi-Fi network to transmit updates and information to the server and database. To monitor the history and condition of their registered plants, users will need to register their system onto our web application with a sensor device *[Refer to Figure B-4]*. The web application will also be needed for registering sensor devices and calibrating the operation box for mapping. For registering a device, the user will need to print a generated QR code (Quick Response code) to identify a sensor device to its plant. When registering sensor devices, the user must set up the QR code to its appropriate sensor device and place it beside the pot facing upwards and visible to the camera on the operation box.

The user is expected to have a basic understanding of how the mechanical system works and will be provided an intuitive software application. Plant care can be done remotely but should not be expected as a perfect system that does not require any interference. The user will be provided as much information as possible by the system but will need to ensure the plant is properly taken care of themselves.

B.2. Technical Analysis

B.2.1. Discoverability

Discoverability, in the context of user interface design, is the degree of ease for the user to find all the elements and features when first introduced to the *Greg* plant watering system. For our proof-of-concept stage, we will have a website application that will display the system information and plant monitoring. [*Refer to Graphical Presentation*] Clicking into the plant's history will provide an updated picture of the registered plant, vital information, and their locations. The website application will be designed to be intuitive so that users will not have any difficulties adjusting to the system and utilize all features.

The main actions that will determine the Discoverability criteria of our system are as follows:

1. The operation box and rail system are set up in the desired area and provide a sufficient water source.
2. The user turns on the system through the operation box.
3. The user registers the system to the web application and registers plant sensor devices.
4. Sensor devices are placed in the setup area with the registered plant.
5. Use the web application to track and manage system and plant information.

To achieve those actions:

1. The rail system with the operation box can be assembled with ease by the user. The user can easily adapt a water supply to the water tank for the operation box with standard fittings.
2. The on/off switch will power on the system or power down the system safely.
3. The user can quickly configure the operation box to connect to a Wi-Fi signal and be registered on the web application when first setting up.
4. Plants can be registered using a generated QR code and placed with a sensor device in the system in a minimal number of steps.
5. The web application is intuitive, and users can quickly identify features to use them as intended.

B.2.2. Feedback

In *Greg*, feedback will be used to notify the user of statuses and warnings found in the system through the web application. The web application will be capable of providing notifications and displaying useful information regarding the system and the plants registered. For example, when a plant has reached below an optimal soil moisture level, the system will update the information displayed in the web application and send a request to the operation box to water the plant.

Web Application:

1. After the system waters plants, the website application will be updated and notify, the application will display when and how much the system water.

2. When the user clicks the plant status, the application will display a graph of the plants and detailed information about the plants.
3. If the water tank is not attached to the water source or there is an error, the system will notify the user through the web application with a notification warning them if the water tank is below a certain level.

Operation Box with LEDs to provide a status of the device:

- Blue(solid) – The Operation box is ON.
- Red(solid) – The water pump is OFF.
- Green(solid) –The water pump is ON.

Rail system with LEDs to provide the status of the motor:

- Green(solid) – Motors are operating.
- Red(solid) – Motors on standby.
- Red(blink) – Motor failure/error.

B.2.3. Conceptual Models

Conceptual models allow the users to intuitively understand how to use the device's features. These models would allow you to have similar experiences as other autonomic devices. In the case of *Greg*, it resembles a 3D printer or even a claw machine where people are familiar with how they are moving. In addition to this, users would be beneficial to have prior experiences with electronic devices to input correct data into our system. The software experience will be like using a smart home application and device.

B.2.4. Affordances

The affordances define the actions that are feasible for the device. We have designed a simple application to register plants to our system and once the initial setup has been done, the system will automatically detect the plants that have low moisture levels and give water to that specific plant. The user will not need to actively interact with the software for the system to be usable.

B.2.5. Signifiers

Signifiers are used to indicate potential and intended affordances. In the website application, plants' status will dynamically change according to the current data which was updated by the sensors. The application will signify any changes in the condition of the system and plants registered to it.

B.2.6. Mappings

The mapping is the relationship between control and effect. Therefore, in *Greg* the operation power on-off switch is explicitly labeled with on and off, allowing the user to know when the device is on or off. Besides, the website application will be updated once the operation box is done watering and allow the user to know when and how much the system watered. The mapping will be important for identifying what sensor device in the web application is registered to which plant and is operating in which system.

B.2.7. Constraints

Constraints limit the actions that can be performed by the users with the *Greg* plants watering system. Users must own a personal computer or a mobile device to register systems and plan, as well as access the plants' data. Users who want to check the status of devices or plants must have the system and themselves be connected to Wi-Fi, as no data will be transferred if there is no internet connection. *Greg* will use an external water tank to supply water and requires users to keep the water tank at a minimum level to be operational or have a water supply connected to the tank.

B.3. Graphical Presentation

B.3.1. Hardware

The following figures represent the proof-of-concept design and dimensions for the rail-mounted operation box with a camera. *[Figures B.1 to Figures B.3]*

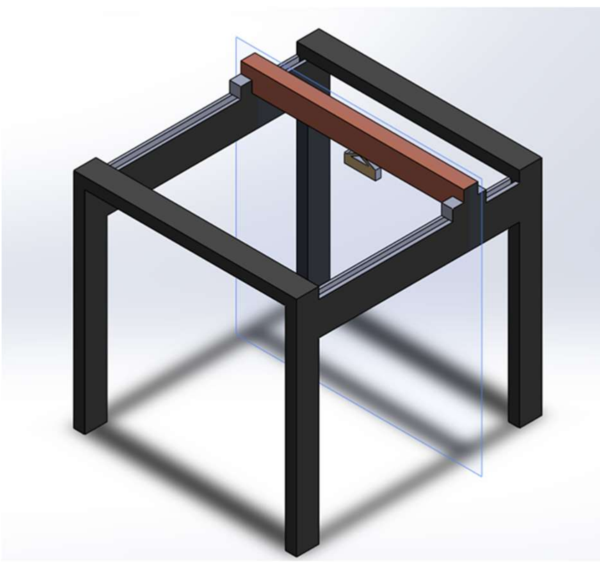


Figure B-1 Rail System (Isometric View)

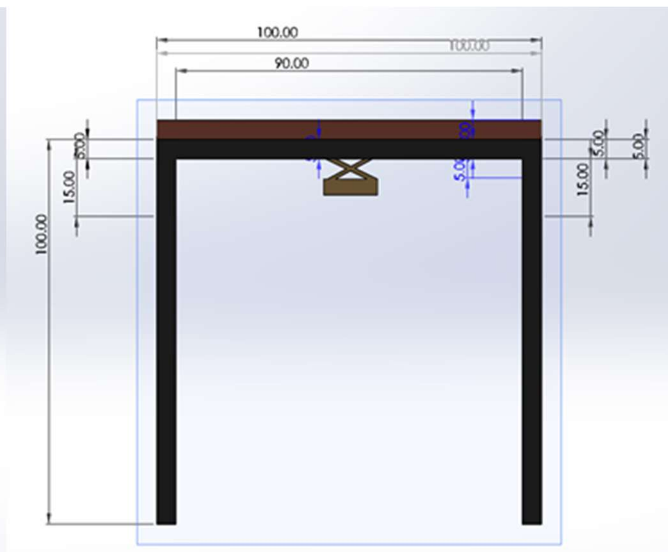


Figure B-2 Rail System (Front View)

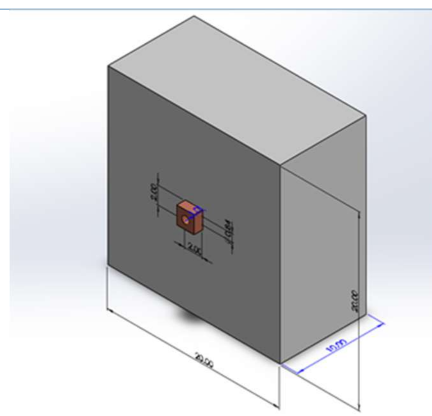


Figure B-3 Operation Box and Camera (Isometric View)

The next hardware figures relate to the sensor devices that will be embedded in the plants and the hub where they will be attached. *[Figure B.4 to Figure B.5]*

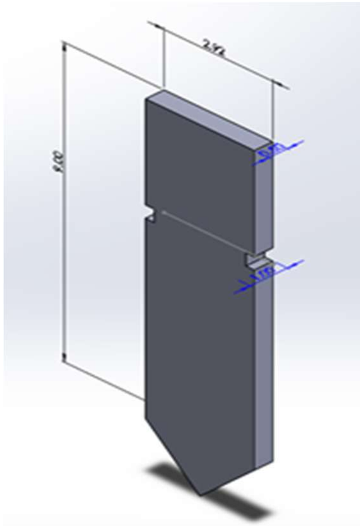


Figure B-4 Sensor Device

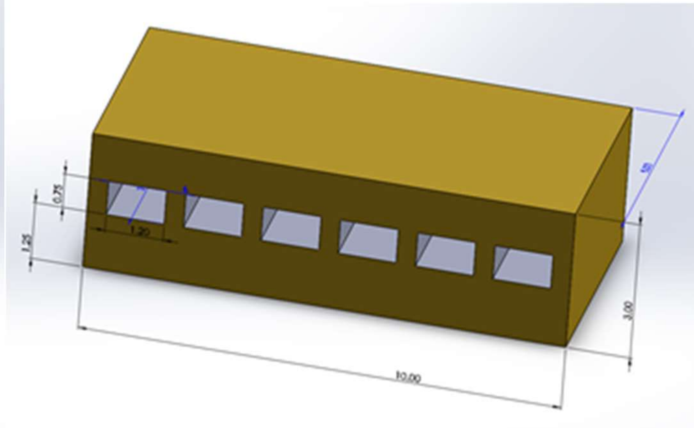


Figure B-5 Sensor Device Hub

B.3.2. Software User Interface

The following figures represent the user interface of the *Greg* web application. This terminal is where the user can sign in to register their system and plants. Figures B-6 to B-8 represent the current design mockup for the user and system registration for the proof-of-concept prototype.

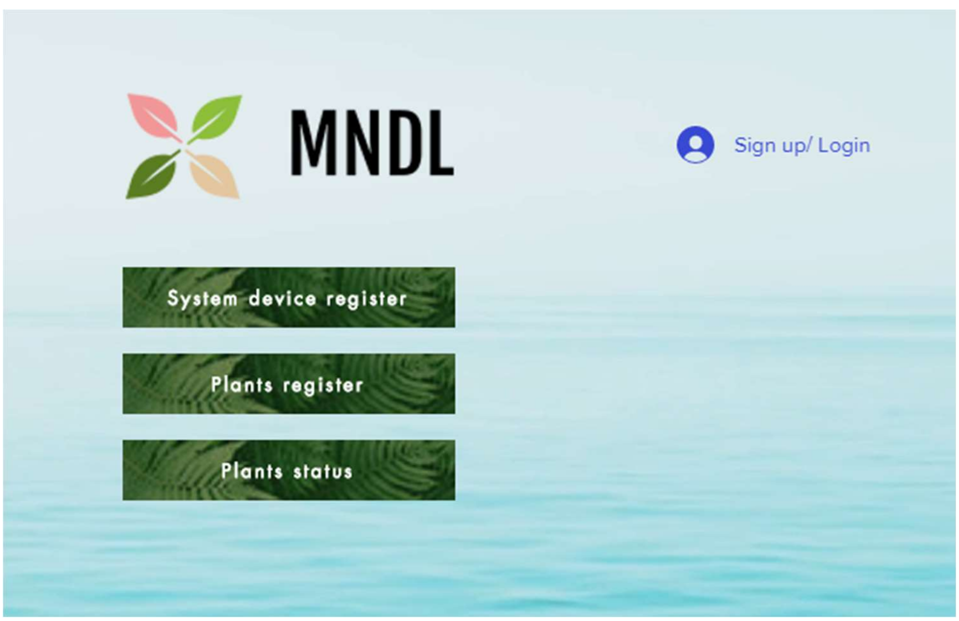
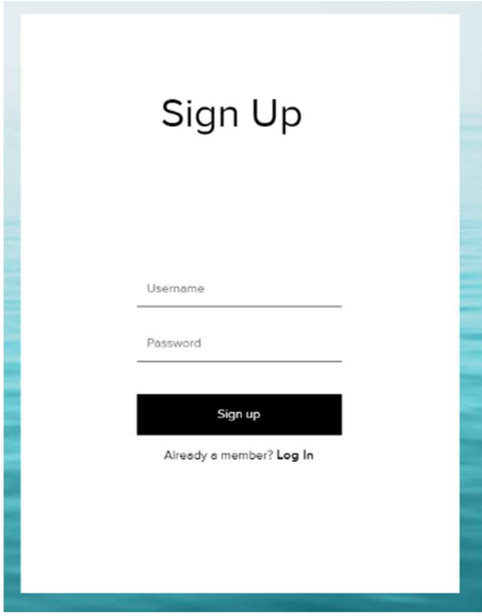


Figure B-6 Web application UI



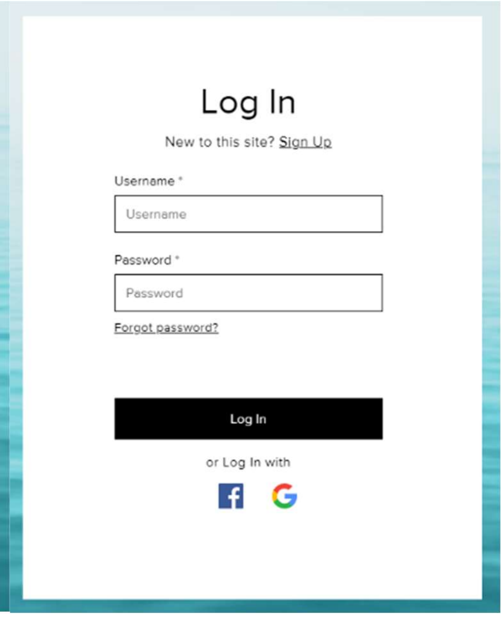


Figure B-7 Web Sign Up *Figure B-8 Web Log In*

Figures B-9 and B-10 represent the monitoring page where the user can view and check on individual plants. Various information such as the plant species, soil type, and soil moisture readings will be displayed for each plant. The user will also be able to see an updated picture of each plant and a graph displaying its soil moisture history.

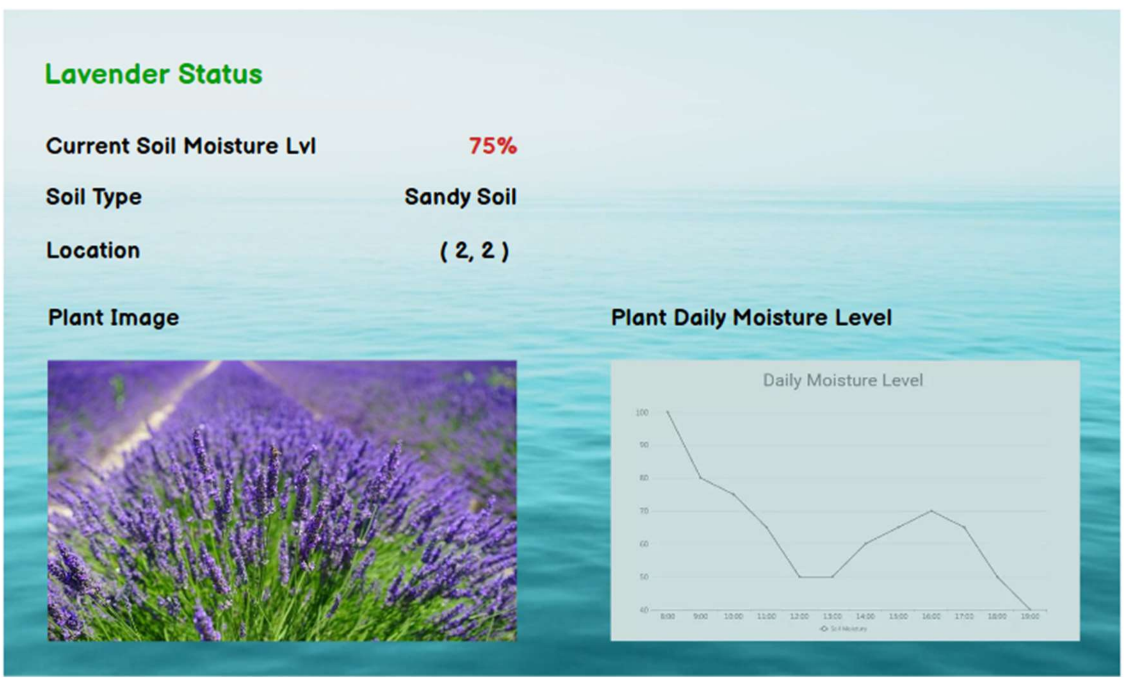


Figure B-9 Plant Status UI

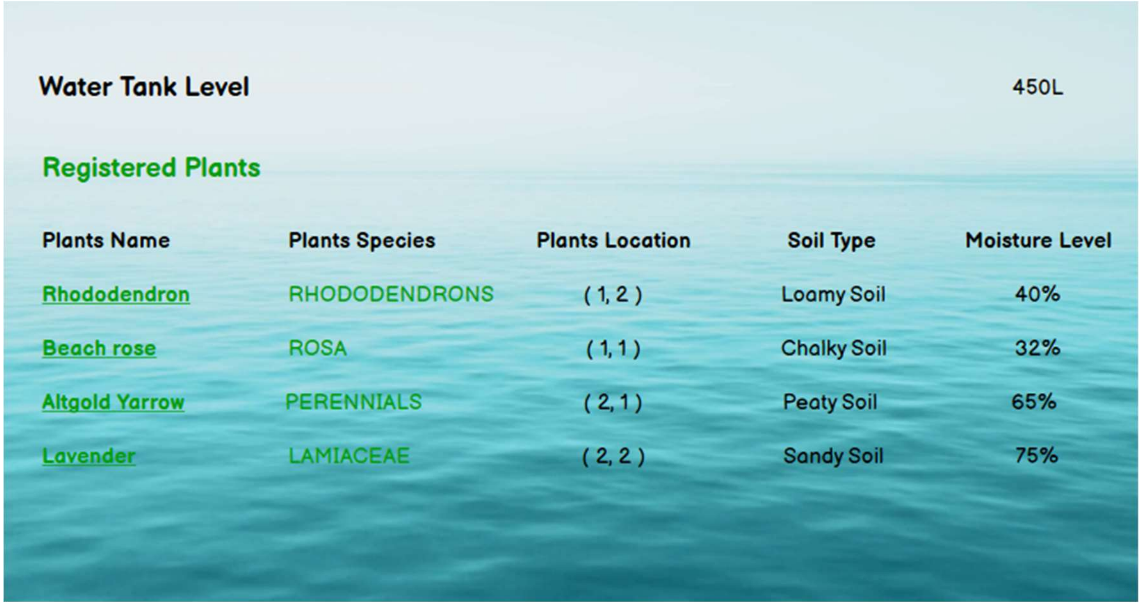


Figure B-10 System Overview

B.4. Engineering Standards

Table B-1 shows the Engineering Standards that chosen for the *Greg* system. To achieve the quality, intuitiveness, and safety of the user interface, *Greg* needs to follow the Standards make by CSA, IEEE, ISO, and IEC.

Standard	Description
CSA C22.1:21 14-406 [24]	Location of control devices
CSA C22.1:21 14-500 [24]	Operation of switches
CSA C22.1:21 14-704 [24]	Warning notices required - Suitable warning notices shall be placed
IEEE 1621 – 2004 [25]	User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments
ISO/IEC 29138-1:2018 [26]	Information technology - User interface accessibility - Part 1: User accessibility needs
IEC 61800-5-1:2016 [27]	Adjustable speed electrical power drive systems - Part 5-1: Safety requirements - Electrical, thermal, and energy
IEC TR 61997:2001-09 [28]	Guidelines for the user interface in multimedia equipment for general purpose use
ISO 13854:2017 [29]	Safety of machinery - Minimum gaps to avoid crushing of parts of the human body
ISO 21628:2020 [30]	Gardening machinery - Powered material-collecting systems – Safety

Table B-1 Engineering Standards for Greg

B.5. Analytical Usability Testing

The process for the analytical usability testing stage will review the user interaction with the system and usability of the design choices made. The usability testing will be conducted as a team on a single Proof-of-Concept prototype and will submit a report for each subsystem (operation box and rail system, sensor devices, and the web application). Reports will be reviewed and addressed as a team for improvements. To note, as testing is based on the Proof-of-Concept, testing methods and design choices are subject to change under development.

B.5.1. Designer testing

1. Set-up the rail system (1m X 1m) by a table with plants
2. Extend as needed to fit the different standards.
3. Connect the water system to the designated water tank.
4. Place the operation box to the rail system.
5. Place the Hub that has 4-6 sensors connected to it in the middle of all the plants in the 1m-by-1m parameter.
6. Make sure to insert to the required level of deepness for every capacitive soil moisture sensor to every soil in every pot.
7. Create a test account in the app created.
8. Log-in and register all the plants that are connected on the table.
9. Verify that the correct information of each plant is grabbed from the database.
10. Verify that the app shows the soil moisture level of every connected plant.
11. Verify that automation of watering different plants works.

B.5.2. Heuristic Evaluation

The heuristic analysis of the results from the designer testing will be reviewed by following the listed guidelines. Members of MNDL will be expected to ensure each subsystem is functional and follows the minimum requirements as a product for the Proof-of-Concept.

1. The rail system smoothly guides the operation box to a specified position.
2. The operation box identifies each plant correctly and delivers an accurate amount of water.
3. Sensor devices can be placed in the pots of plants.
4. Sensor devices can be registered on the web application.
5. Web application displays information of the system and each plant registered.
6. Soil moisture readings trigger an operation to water the plant when it hits a threshold limit.
7. Operation box initiates care protocol to find and water plants that are below soil moisture threshold.
8. Sensor devices update the database periodically.

B.6. Empirical Usability Testing

B.6.1. Internal Testing

At this stage, testing will occur within the MNDL team. The software team will rate the website and the database, team members are going to give short but precise feedback on the simplicity, comfortability, and reliability, the main goal here is to test how well the software interfaces operate. Meanwhile, the hardware team will test on the mock-up that has been built, team members will operate the machine and do some specific tasks such as irrigating, testing moisture of the soil, and moving the operation box in x, y, and z-direction. The hardware team will give feedback on the functionality, efficiency, reliability, and even more. In the end, the final product will allow the MNDL team to successfully sign up and log in to the website, register one plant, check the status of that plant, and do operations like irrigation and moisture testing to the plant via the mock-up.

B.6.2. End-User Testing

MNDL will aim to prioritize the safe operation of *Greg* and the intended users of nursery workers. Users who have no prior knowledge of this kind of automation would be nominated to test our system. After a trial period, the users will provide feedback on features to be improved upon.

Survey: Users who get to try using *Greg*, will be provided a questionnaire where they can rate from 1 to 5 (1 being the strongly negative and 5 being greatly positive) and have a section to write suggestions:

1. Was the device easy to setup (Hardware - structure)?
2. Was the device easy to setup (Software – app)?
3. Did the device make your work easier?
4. What was your first impression of the device?
5. Was the app intuitive to use? If not, any suggestions?
6. Would you recommend *Greg* to other plant nurseries?

Additional survey question for the owners:

1. Would this be something that you want to invest in?
2. Would this system help you reduce the nursery's operation cost?

B.6.3. User Feedback Form

The following figure is an example feedback form that will be completed by the user after reviewing the proof-of-concept. *[Figure B-11]*

MNDL

User Feedback Form

Test Environment: Please list during What occasions the device was used.

Rating Scale: 1-10(1: bad and 5: Excellent)

Questions:	1	2	3	4	5
First impression of Greg	○	○	○	○	○
Ease of hardware setup	○	○	○	○	○
Ease of website setup	○	○	○	○	○
How comfortable and safe is it to use the product?	○	○	○	○	○
How did the device help your work?	○	○	○	○	○
Was the product intuitive to use?	○	○	○	○	○
Would you use the device for your daily work?	○	○	○	○	○
Questions for the owners:					
Would this be something that you want to invest on?	○	○	○	○	○
Would this system help you reduce the nursery's operation cost?	○	○	○	○	○

Additional Comments:

Figure B-11 User Feedback Form

APPENDIX C: DESIGN OPTIONS

C.1. Rail System component Alternatives

Since we do not have an exact weight number of the X-axis bridge and the operation box, it is difficult to accurately determine which motor model to use. Based on the design requirements [Des 3.1.6-POC], the motor should output enough torque, low power demand and reasonable price. The major specifications of the options are shown below:

Option	Model	Current/Phase	Holding Torque	Detent torque	Motor Length	Price
1	42HS34-0404	0.4 A/phase	2.6 kg.cm	120 g.cm	34 mm	$25
2	42HS40-0404	0.4 A/phase	4.0 kg.cm	150 g.cm	34 mm	Unknown
3	57HS56-2504	2.5 A/phase	11.2 kg.cm	350 g.cm	57 mm	$35

Table C- 1 Motor options

There are three options of motor that consider for our rail system. The option 2's spec is the most practical for the design which has enough of holding torque and low power demand. However, the option 2 is unable to purchase from the local electronic store or online store. And for the option 3, the motor has enough of torque. However, the power demand of option 3 is too high for the proof-of-concept design. The option 1 is much less holding torque than the option 3, but it still capable to drive the 8mm lead screw with dual motor setting on the Y-axis movement. And the dual motor can drive by a single A4988 motor driver with its low power demand.

However, consider the prototype and the production stage, the option 3 might be use for heavier material and add up component of the bridge and operation box.

C.2. The Motor Driver

Based on the design requirement [Des 3.1.9-POC], the motor driver should drive the motor with the same required current, size, and pinout at a reasonable price. There two options of driver are shown below:

Option	Model	Load Supply Voltage	Output Current	Min step resolutions	Min Step plus duration	Price
1	A4988	8 to 35 V	2 A	1/16-step	1μs	$7.95
2	DRV8825	8 to 45 V	2.5 A	1/32-step	1.9μs	$11.50

Table C- 2 Motor driver options

Comparing options 1 and 2, the second option has more advantage of driving a higher spec motor. However, the option 2 (DRV8825)'s specification is excessive for the current design. And the cost is higher for the design that needs 2 drivers for simultaneously running.

Option 1 (A4988) should also use for the prototype and the production stage. And for the Y-axis trajectory, each motor shall use one driver to drive (The higher spec motor require higher current).

C.3. Water pump alternatives

Having a water hose connected directly to our rail system would be an alternative in our rail system design. Mid-to-large size nurseries would have water hose system already in place which would mean we can use the water hose in our design. With the use of water pressure relief valve, we can connect the valve with our microprocessor from available water hose to control the flow of the water and the water will never run out, because it constantly carries water to our plants.

Option	Model	Voltage	Working Pressure	Price
1	PURO-XD-12	12V	0Mpa-0.8Mpa	$33.75
2	BZW-20-12VDC	12V	0Mpa-0.8Mpa	$46.95
3	K-Rui-Valve	12V	0.02Mpa-0.8Mpa	$19.95

Table C- 3 Water pressure relief valve options

Out of all the options, we should choose option three, because it is cost effective and provides enough working pressure to water each plant. Other options are more expensive due to its materials made with brass and steel. The third option uses hard plastic material, and it would be perfect for our prototype for the cost and its effectiveness. We can then upgrade it to use a better and more expensive material as the product launches.

C.4. Sensor alternatives

Based on the design requirement [Des 4.1.8-POC], sensors that we require must have a lifespan of more than 2 years. The two options that we considered are as listed below:

Option	Model	Accuracy	Life Expectancy	Measurement Zone of Influence	Require Calibration	Price
1	Capacitive Soil Moisture Sensor v1.2	Great with calibration	2 to 5 years	<1cm from sensor	Yes	$4.67
2	SPARKFUN SOIL MOISTURE SENSOR	Good with calibration	1 month to 1 year	Between the two probes	Yes	$7.99

Table C- 4 Soil moisture sensor options

Based on the given values above, both options for the sensors require calibration to get more accurate set of data. However, option 1 has better accuracy from the difference in technology behind them. Option 1 uses the capacitive moisture sensing technology of <1cm around the sensor. On the other hand, option 2 uses resistive moisture sensing technology between the two probes of the sensor which potentially leads to corrosion of the sensors which shows in the life expectancy value of 1month to a year. However, option 2 has a life expectancy of 2 to 5 years which is more ideal for the plant nurseries in need. Also, option 1 has a lower price than option 2 making it a better option that we have chosen.

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