Oasis: Final Report

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Contents

1 Executive Summary

Busy terms at Dartmouth make keeping track of numerous obligations, including classes, clubs, and watering plants, challenging. Dartmouth students reported forgetting to water their plants, evidencing that a busy term detracts from taking care of their plants.

Oasis was designed to automate the watering process of succulents, alleviating students' responsibility to water their plant. Current state of the art products allow for hands off watering of plants such as herbs and greenery but do not effectively water succulents, which are the most popular type of plants on campus. Our product is specifically designed for succulents and Dartmouth dormitories, which current state of the art devices do not address.

Our product automatically waters a user's succulent where the user only has to plant their succulent in the pot, plug in the device, and occasionally refill the water reservoir when needed. There are two main components to Oasis, the pot and the circuit that controls the automated watering cycle. Oasis is designed with three separate sections: the water reservoir, pot, and electronics. Each section is separated from the others, but allows for passage of tubing and wires to monitor and water the succulent. The circuit makes use of a water pump, Raspberry Pi, soil moisture sensor, relay, and 9V battery, and is powered through a wall outlet. Using these components, the code that was developed controls when the plant is properly watered every 10-14 days by the water pump.

Oasis is able to water the succulent according to the recommended cycle and, through analysis, was shown to provide enough water for the soak and dry method. The soak and dry method involves wetting the soil thoroughly and then allowing it to dry entirely before watering the plant again. Testing proved that Oasis will last for the entirety of a student's career at Dartmouth, with each individual component lasting significantly longer than four years.

Since Oasis is designed with Dartmouth students in mind, safety, automation, efficiency and size were highly considered in our iterative design process. Our product efficiently waters succulents with an automated watering cycle, and is lightweight and small enough to be easily moved around a dorm room. Moreover, since our device encompasses both water and electronics, it is important to keep these components separate to ensure the user's safety. Although Oasis is safe to use, users should be aware of potential dangers our device presents.

Looking toward the future, our device will be improved through the integration of an app or website interface that indicates when the user needs to fill the water reservoir and allows selection of the ideal watering cycle given the type of plant. This would allow Oasis to become a more generalized smart plant pot. Furthermore, using a more aesthetically pleasing design and developing multiple options will make Oasis enticing to more college students, and potentially buyers outside of Dartmouth.

2 Problem and User

College is an important chapter in the lives of many students because it is more than just a place of learning, it is also a place to call home. For many students at Dartmouth, that home includes a plant. However, that is not always practical for students living in dorms on campus. From participating in classes and extracurriculars, to learning how to live independent lives as young adults, Dartmouth students are preoccupied by many activities. Adding the care of a plant is often another ball thrown into the juggling act students do in order to maneuver throughout the term. So, the plants usually end up dying in the student dormitories. Moreover, a recent study shows that having a plant in your room improves one's mental and emotional health by reducing stress and anxiety, decreasing depression, improving self-esteem, and enhancing productivity[1]. That is why it is important to address this problem, especially now in the time of COVID-19 when students are usually isolated in their dorms.

When we surveyed Dartmouth students to identify the prevalence of the issue, 69% of those who own plants reported that their plants had died in their dormitories at some point during a term. As shown in *Figure 2.1*, they attributed lack of water and lack of light as the leading contributing factors. However, our benchmark testing discussed later in this paper shows that even in minimal light, the plant survives. From this, it can be inferred that lack of water is the primary issue, not lack of light. This finding is further supported by the vast majority of students who own plants indicating they have forgotten to water their plants at some point, and could be the combined issue of lack of water and light that led to the plant death, as shown in *Figure 2.2*. We also recognized that different plant types thrive in different conditions. As shown in *Figure 2.3*, succulents are by far the most popular type of plants among Dartmouth students. Using this information, we narrowed down our problem statement to become:

Problem Statement: 69% of Dartmouth Students who own succulents claimed that their plants have died at some point in their dorms.

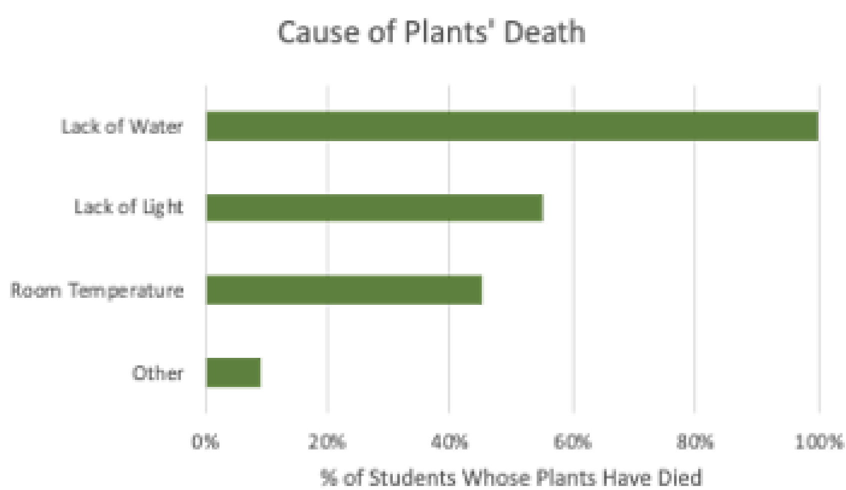


Figure 2.1: Leading cause of death in dorm room plants (from a survey of 48 students)

Dartmouth students will be the users and buyers of the product that we've developed. Roberts Flowers of Hanover, a local florist shop, issues free plants to first-year students in the beginning of each Fall term. We plan to sell our product directly to the consumer as well as to the florist shop as the middleman, as is discussed in our business plan.

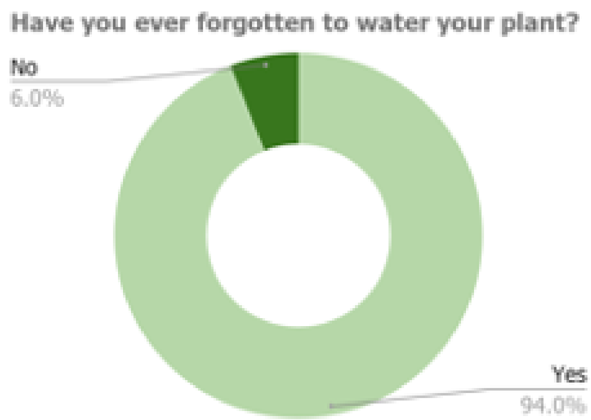


Figure 2.2: Responses from 33 Dartmouth students who own plants

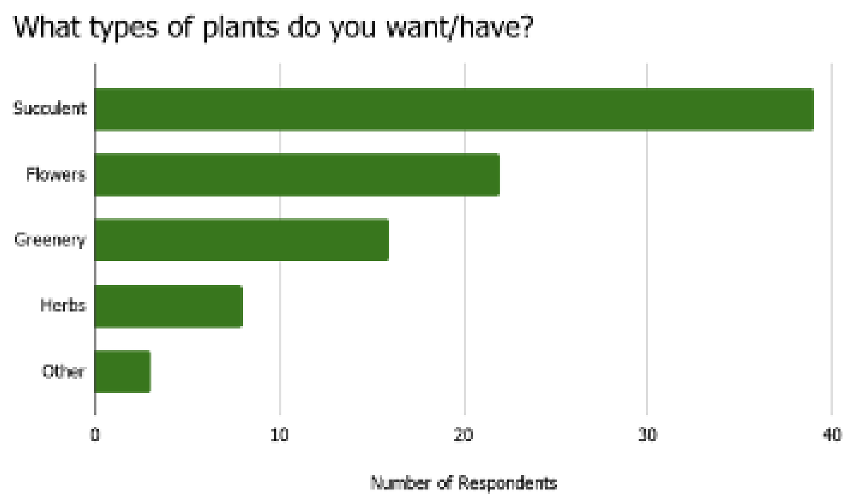


Figure 2.3: Dartmouth students who've owned or prefer certain plant(s); 47 students surveyed

3 State of the Art

While several patented solutions, including a watering system through capillary action [2] *(Figure 12.1)*, watering spike [3] *(Figure 12.2)*, and hydroponic growing system [4] *(Figure 12.3)*, have addressed this very problem with regard to herbs, no such solutions have been innovated for succulents. These patented and existing products are all passive watering systems that keep the soil wet or grow the plant in water. The watering system through capillary action and the watering spike are low-cost and low-tech solutions that are ideal; however, it is this passive component that is the issue. While the hydroponic system that has been listed, and many other systems on the market, take care of the water, light, and nutrients of the plants, all such products are incredibly expensive and grow the plant in water instead of soil. Taking all of this into consideration, it is reasonable to claim that there is no solution that directly addresses the problems associated with taking care of succulents, especially with the potential user being Dartmouth college students.

Therefore, our product Oasis addresses the needs of succulents in particular, accounting for the location they should be watered in, how frequently they must be watered, and the soak and dry method by which they should be watered. The recommended soak and dry method includes watering the succulent every 10 to 14 days with approximately half of the soil volume in water and allowing the soil to dry completely before watering again [5, 6]. This method allows for strong root development. If the succulent was watered more or less frequently, it could still be alive but would be less healthy than if the recommended soak and dry watering method was followed. In regards to location, the succulent would be indoors in a dorm room that might not have a lot of space available to dedicate to plant care. Therefore, the larger hydroponic systems and messy refill of the watering spike are not suitable for this location. Since all of these factors vary from proper care for herbs, an herb watering system is not an acceptable substitution for succulents. Instead of providing the regulated watering cycle they need, it drowns them in constant water and ultimately kills them. Since no state of the art product exists addressing this complex problem, our product, Oasis, is truly novel.

4 Specifications and Problem Solving Method

4.1 Specifications

In creating our solution, we first ensured that all potential solutions we considered were safe, ethical, and legal. After those criteria were met, we began thinking about how our solution should address succulents in particular. In order to satisfy this need, we decided that specificity—the ability to adjust the system to account for the type of plant it held—needed to be an integral part of our design. We also aimed to create a pot which collected and recycled the water which was cycled through the pot and which other pots neglect.

Finally, we prioritized the automation of our product. Succulents generally require a lot of care to ensure they receive adequate sunlight and water. However, we had a goal to create a product which the user could set up (plant, fill up with water, and plug in) but then would function almost entirely independently. The user would need to refill the water reservoir at infrequent intervals but would have very little intervention in the process of caring for the plant. However, if the student wishes to have more control over caring for the plant, the specificity of the system allows for that leniency. The automation of our system is particularly useful for students who are unable to bring plants home over long breaks and periods of time when they are away from school, such as the interim period from late November until January. This break often proves fatal for dorm room succulents as they are left unwatered and without sufficient sunlight for far too long.

Furthermore, we included six other specifications (included in *Table 4.1*) in order to ensure we created a product that targeted the problem and would be the best option for the student to use.

These included size, portability, lifetime of the product, modularity, cost, and aesthetic appeal. We continued to take all specifications into consideration throughout the process, with particular emphasis on the three key specifications: specificity, automation, and efficiency.

Specification	Justification	Quantification
Specificity	User interface to specify what type of conditions are desired for the plant	4 options for type of watering cycle
Automation	Allows user to be completely hands off and not worry about leaving plant for extended period of time	Watering cycle that occurs for 6 or more weeks without user input
Efficiency	Reduces waste produced by the product (smaller environmental impact)	Minimum of 95% of water inserted by the user goes into the plant
Size	Small enough to not take up a lot of space in dorm room	Windowsill ledge: 3" wide
Portability	Needs to be able to be moved within the dorm room, is not big/bulky that it has to stay in one place	<5 lbs; Within size limits; No excess wiring
Lifetime	Lasts for at least the students' time at Dartmouth	>4 years durability
Modular	Separable parts make the system easier to use	2 or more physical parts built to be sold individually as well as together
Cost	Lower cost would be better for Dartmouth students	$<\$40$
Aesthetics	People are more likely to use it if they like how it looks	One color scheme

Table 4.1: Specifications Matrix for Oasis

4.2 Problem Solving Method

Our problem solving process began with a solutions and alternatives matrix, the updated version of which is shown in *Figure 4.1*. We used the matrix to gauge which of our solutions might be the most effective, given our specifications and how important they were. After initial feedback from our original solutions and alternatives matrix not effectively representing the problem and the variety of potential solutions, we added the important specification of automation to the matrix to reflect explicitly evaluating the potential solutions in regards to this hands-off aspect. Additionally, we added a phone application solution which reminds the user to water the plant, as well as a "Thirsty Plant Kit" in reference to a system which contains parts that would allow for notification of when watering needs to occur but does not have the automated aspect.

The solutions and alternatives matrix, with the selected weighting of more important specifications over others, resulted in the top two solutions being a timed light and water system and artificial sunlight for winter months. With these two potential solutions coming the closest to addressing the actual problem of Dartmouth students, we were able to narrow down the scope of this project. However, since this timed light and water system would include artificial light, potentially from an LED, the solution for artificial sunlight for winter months becomes embedded into the first proposed solution. Therefore, the prototype we decided to pursue was the timed light and watering system.

Since lack of light in our initial survey *(Figure 2.1)* trailed significantly behind that of lack of water, and, as discussed later in benchmark testing, differences in light had minimal effect on the succulent, the timed light and watering system became just a timed watering system. However, there is still potential to add the timed lighting component in the future.

Specifications / Solutions	Ethical, Legal, and Safe	Automation	Specificity	Efficiency	Size	Portability	Lifetime	Modular	Cost	Aesthetics	Total
Weighting (1-5 or Y/N)	Y/N	5	5	4	4	3	3	2	1	1	N/A
Timed Light and Water System	**Y**	**25**	**23**	**18.4**	**13.6**	**14.4**	**10.8**	**8.8**	**1.6**	**3.6**	**119.2**
Artificial Sunlight for Winter Months	Y	23	20	16	18.4	13.2	10.2	6	2.2	4.4	113.4
Temperature Control Plate	Y	22	18	8	16.8	12.6	11.4	2.4	2.6	3.8	97.6
Thirsty Plant Kit	Y	10	16	16	14.4	14.4	10.8	3.2	3.6	2.2	90.6
Phone Application that Reminds User to Water Plants	Y	6	17	8.8	19.2	13.8	14.4	2.4	1.2	4.4	87.2
Passive Water Collector	Y	15	17	17.6	4	4.8	10.2	4	2.2	2.2	77
Automatic Blinds Temperature Regulator	Y	24	19	4	6.4	3	12.6	3.2	1.2	2.4	75.8

Figure 4.1: Updated Solutions and Alternatives Matrix

5 Prototype

Closely considering the actual problem that Dartmouth college students had in regard to taking care of their succulents, the lack of an existing product geared toward succulents, and our identified specifications, we started developing prototypes. Oasis was divided into two main components: the pot that holds the plant and the electronics, including the circuit, that controls the automation of the system. This allows a differentiation into a looks-like and works-like prototype.

5.1 Looks-Like Prototype

Oasis is designed for a Dartmouth student living in a campus dorm. Therefore, it must be lightweight and small in size, allowing the user to move the pot around the dorm with ease. Since our current prototype does not have an automated light component, the pot is small enough to fit on or by the windowsill inside dorm rooms, where the succulent receives sufficient light for survival. Based upon the specifications, the pot needs to promote automation and efficiency. This allows our product to be low maintenance as the user only has to fill the water reservoir occasionally.

The first pot prototype is the orange 3D-printed pot used in the works-like prototype, for which the SolidWorks model can be seen in *Figure 5.1*. For this prototype, a three compartment approach was used. One section is for the electronics (right section), the middle chamber houses the succulent, and the final chamber is the water reservoir, which also contains the water pump (left section). There is a hole for drainage at the bottom of the central chamber, and another hole between the water reservoir and middle section. This second hole is for tubing, which is passed through the wall and is used to water the succulent (for more detail see the Fluid Flow analysis section). In this design, the electronics and water are sufficiently separated, it is light and small enough for dorm life, and it provides a solid structure for our works-like prototype. However, this prototype did have significant drawbacks. The wires from the water pump to the Raspberry Pi were left exposed, which is not aesthetically pleasing, especially if students are to display our product in their dorm rooms. Secondly, the pot was too deep where the succulent sits far below the upper rim, making watering incredibly difficult. A piece of cardboard was used to bring the plant up to proper height, but that removes the ability for the succulent to drain properly. Finally, the placement of the hole between the water reservoir and the middle section is in the upper center of the dividing wall. This placement did not easily permit the tubing used to water the succulents to pass through and then go around the circumference of the plant. Recognizing these problems, our next design addressed these flaws while still meeting the specifications.

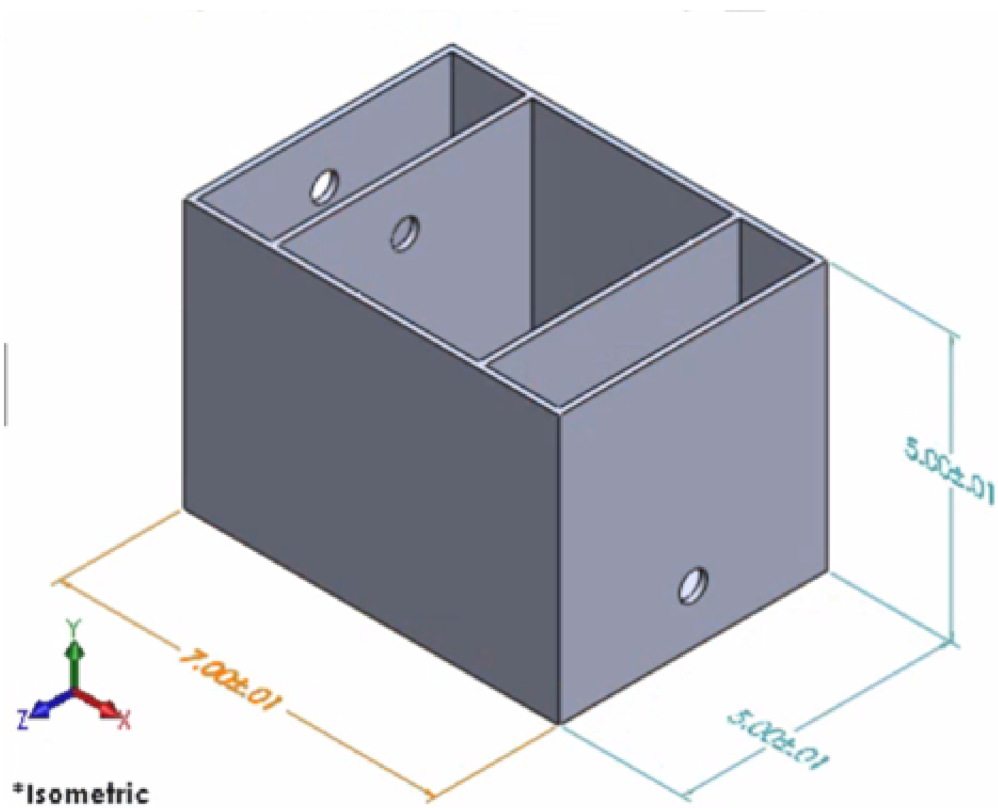


Figure 5.1: SolidWorks model of first pot prototype

A final SolidWorks looks-like prototype was designed to improve our product, as can be seen in *Figure 5.2*. This product is still small and light enough, even with a full water reservoir and a succulent. The water reservoir is the taller rectangular structure, which holds approximately 1.5L of water, which is enough water for 6 weeks, or a bit more than 4 watering cycles (see more in the water pump analysis section). The cylindrical structure houses the plant, and there is a drainage hole at the bottom to prevent overwatering and allow the soil to dry out. Beneath the cylindrical structure is a hollowed out area to house the Raspberry Pi, relay, wires, and allow the power cord to exit to a wall outlet. The drainage hole is sealed off from this area and passes down the center of it. There are then four holes allowing components of the works-like prototype, such as wires and tubing, to pass between sections of the pot. The hole on the upper part of the rectangular section allows the tubing to run from the water reservoir to the succulent at a better angle than our first pot prototype. The hole on the side of the cylindrical structure and the hole on top of the hollow area beneath it allow wires to pass from the Raspberry Pi to the soil moisture sensor, which is embedded in the soil, allowing moisture in the soil to be monitored by our program. Finally, the hole between the water reservoir and the hollow area underneath the cylindrical structure permits wires to pass from the electronics to the water pump.

All of these holes will be sealed to prevent any water from leaking between the sections as mixing water and electronics is incredibly dangerous. This final prototype, although not 3D printed, fixed the design flaws of our previous prototype: the tubing is now able to more easily pass from the water reservoir to the plant, the pot is the correct height so the succulent does not sit too deep, and the wires will no longer be as exposed. The previous three chamber pot is used in the works-like prototype, ensuring our product works on a practical level and provides a rudimentary demonstration of the combination of the looks-like and works-like aspects.

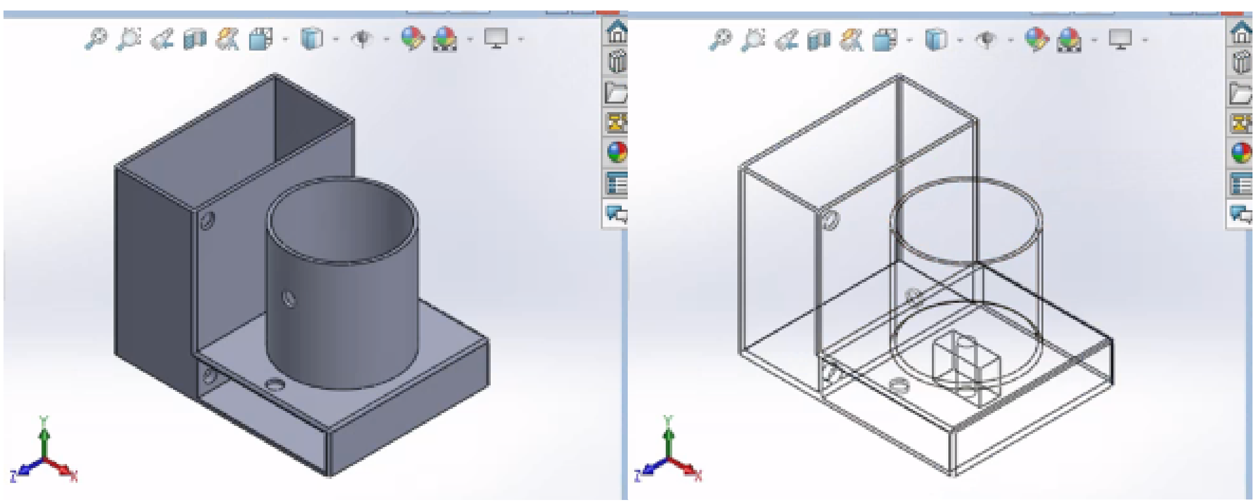


Figure 5.2: SoildWorks models for the final pot prototype in both Solid and Wireframe

5.2 Works-like Prototype

The automation of the watering of the succulent is controlled by the Raspberry Pi Zero W, which is powered from the wall outlet. There are three important aspects that are part of the automated aspect of the circuit: the soil moisture sensor, the submersible water pump, and the relay that allows control of the water pump *(Figure 5.3)*. The soil moisture sensor provides analog measurements of the soil moisture content through capacitive touch measurements (see Soil moisture testing section for more details). The water pump's motor is powered by 3V and can be controlled when it is powered on and off by use of the relay. One side of the optically isolated relay is powered by 5V from the Raspberry Pi, the other side of the relay is powered by an external power source (i.e. the 9V battery pictured in the circuit). The need for power sources on both sides of the relay is because it is optically isolated to ensure there is no damage to the Raspberry Pi. On the side of the relay powered by the battery, the water pump is connected to the normally open circuit. Since the relay is triggered on high, this allows for the water pump to only turn on when the input signal is set to high from the Raspberry Pi. Using these physical components and understanding how they work, the Python code was able to be written.

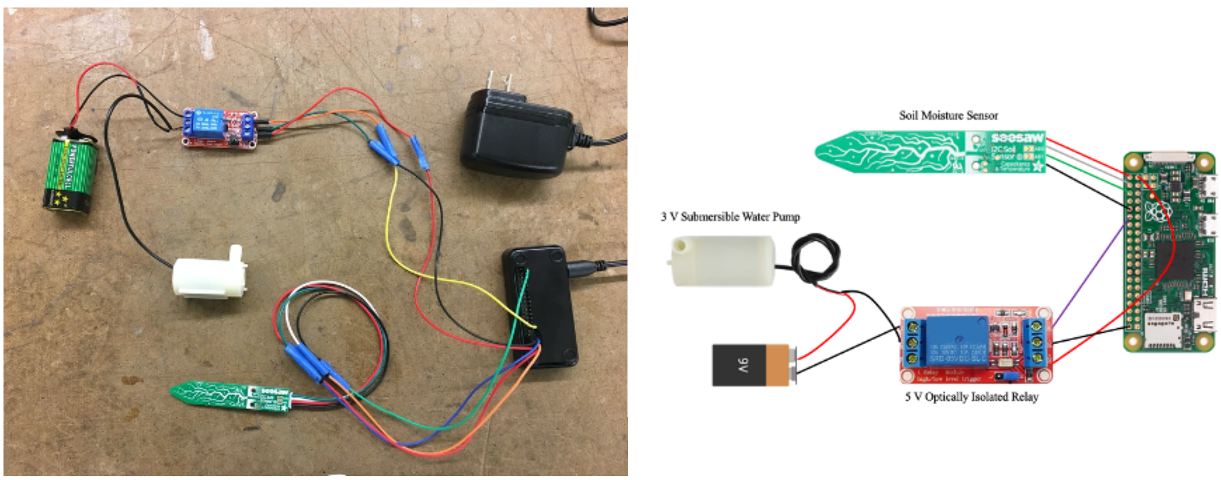


Figure 5.3: Actual and digital representation of the circuit for the prototype

Since Oasis is designed for succulents, the recommended watering cycle described above must be followed in the automated system. When the Raspberry Pi was plugged in and finished the 15 second boot up, the soil moisture sensor began collecting data. Two moisture data readings are taken each day, with a 12 hour wait time between measurements. When the second reading on the 10th day is taken, the measurement is checked to determine the water content of the soil. If the measurement is below 400, the soil is dry and the water pump turns on for 20 seconds. The program would then return to "Day 1" and begin the cycle again. If the measurement is above 400 on the 10th day, the soil moisture sensor continues to take measurements and the succulent is watered after the 2nd measurement of the 14th day. Then, the program returns to "Day 1" and the cycle starts again (see *Appendix 12.1* for code). This code was tested and run for multiple cycles by simulating the 14-day period in 30 seconds.

The first prototype *(Figure 5.1)* was able to be 3D printed and was used as a demonstration for how the electronics and the watering system would fit into the pot. Given that in this prototype, the water pump, relay, and battery were too close to each other and would then be too close to the water, the works-like and looks-like prototypes could not be fully assembled due to safety concerns. Therefore, *Figure 5.4* shows how the plant would be potted in the middle section with the soil moisture sensor either being in the soil or embedded into the plant pot. The wires that are seen outside the plant pot would ideally be embedded in the pot itself, where the only external aspect of the circuit that can be seen is the cord used to plug into the wall. This would be able to pass through the hole cut in the bottom of the pot *(Figure 5.1)*. In regards to how the soil is watered correctly, the water pump is located at the bottom of the water reservoir *(Figure 5.5)* and a tube runs up and then around the perimeter of the plant. The section of the tube surrounding the plant has 3mm diameter holes that allow the water to flow out in multiple areas along the soil surface area. This ensures that the soil of the plant is watered but not the leaves. For more information about correct watering, see the fluid flow analysis section.

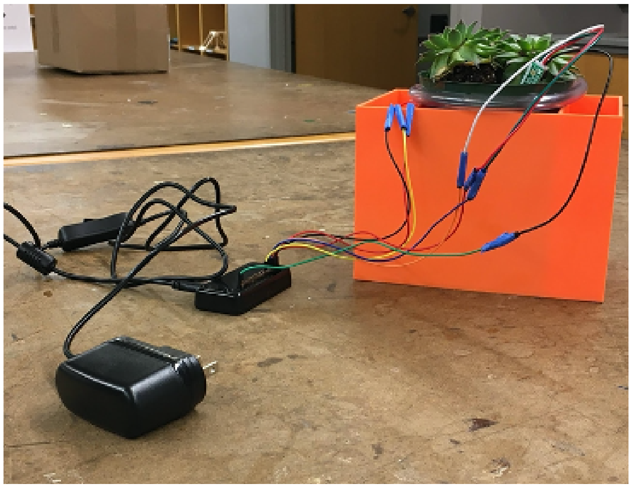


Figure 5.4: Assembled works-like and initial looks-like prototype

Figure 5.5: Closer look at the water reservoir in for the assembled prototype

5.3 User Testing and User Review

For our product, it does not make sense to do user testing. This prototype would essentially need 14 days to be tested to see if the plant can be kept alive, which with the limited time, limited printing and electronics materials, and COVID restrictions, direct user testing could not be accomplished. Nonetheless, we highly value customer feedback and to gauge the potential customer response, we issued an in-person walk-through of our product directly to several Dartmouth students who've owned succulents. The walk-through included a small presentation with pictures and videos of our prototype in action followed by a description of the intended final version of the product. It was concluded with a questions & answers session where our potential customers were able to ask questions regarding the product and share any input they may have. This was a great way to actually provide users with how Oasis works since there is currently no finalized looks-like and works-like prototype.

All surveyed students claimed that they would buy our product if it were on the market. To receive detailed assessments, we asked them to rate how important each feature of the product is to them as a potential user. The scale for such rating was from 1-5, 1 being the least important and 5 the most. The results of this question are shown in *Figure 5.6*. The durability aspect of this pot was rated the highest importance, and this is addressed in the Water Pump and Lifetime section, but in brief, the pot would last more than the college lifetime. In regards to the features of ambient noise and rechargeable, those refer to the noise and lifetime of the water pump in the circuit. More on the lifetime of the water pump later, but the noise level of the water pump when running tests seemed to be low level and would only be on for 20 seconds. Furthermore, two main points of feedback we received were to implement more features including a light system and an app, both of which we'll address in the reflection portion of this paper.

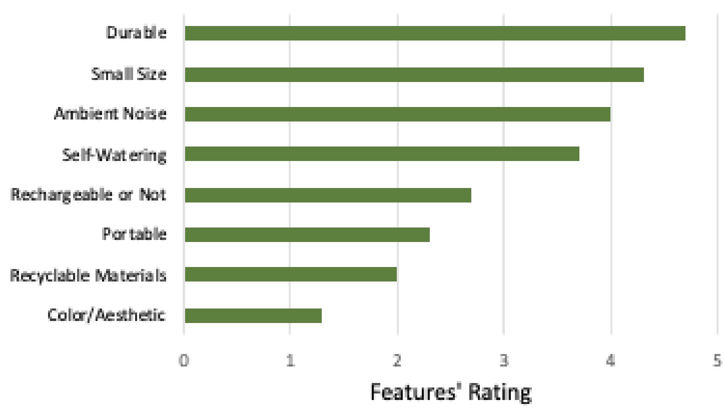


Figure 5.6: Responses from Dartmouth students who have owned succulents

6 Testing and Analysis

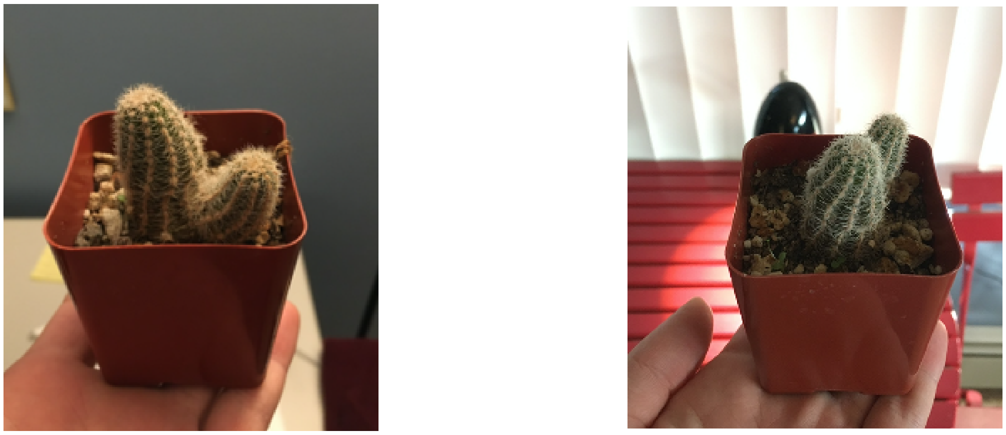
6.1 Benchmark Testing

In the initial prototyping, we were thinking of adding a lighting component that would act as an automated grow light that turns on if the pot detects the succulent has not received enough light. Therefore, we had two variables - light and water - to consider. Since there was no state of art that was specifically geared towards succulents, our benchmark testing evaluated the possible conditions that the succulent would be under if taken care by students in college dorms. Three succulents were used in the benchmark testing, where one operated as the control group. The control succulent received sufficient light and sufficient water, emulating a college student that always remembered when to water their plants and lived in a dorm room that got a lot of light. The second succulent got sufficient water, but not enough light, emulating a college student that remembered to water their plants but did not live in a dorm with enough light exposure. The third succulent got sufficient light, but not enough water, emulating a college student that had good sun exposure but forgot to water their plants.

All three plants were kept under these conditions for 14 days, with visual comparisons to the initial state made at the 7 and 14 day. Pictured in *Figures 6.1-6.3* are the three plants on the first day and seventh day. We had to operate under the limitations of the succulents being sold at the store, so the three succulents are of different species and size, however, all succulent plants need to adhere to the recommended watering and care method to be healthy. Therefore, the only comparison that can be drawn is between the plant and its initial state instead of across all three conditions. Taking this into account, the plant that received sufficient sunlight and water is in the same condition as it started: no spines have fallen on the soil, no discoloration of the body, and no shriveling of the plant. The plant that received sufficient water but inadequate light is also in the same condition as it started: there is no discoloration of the leaves and the plant is not shriveling. However, the plant that received sufficient sunlight but no water is in worse condition than it started: a lot of spines have fallen onto the surface of the soil, the middle of the plant is discolored, the succulent is leaning to one side indicating weak roots, and the cactus near the top of the soil is denting inwards. These conditions only continued to worsen by the 14^{th} day.

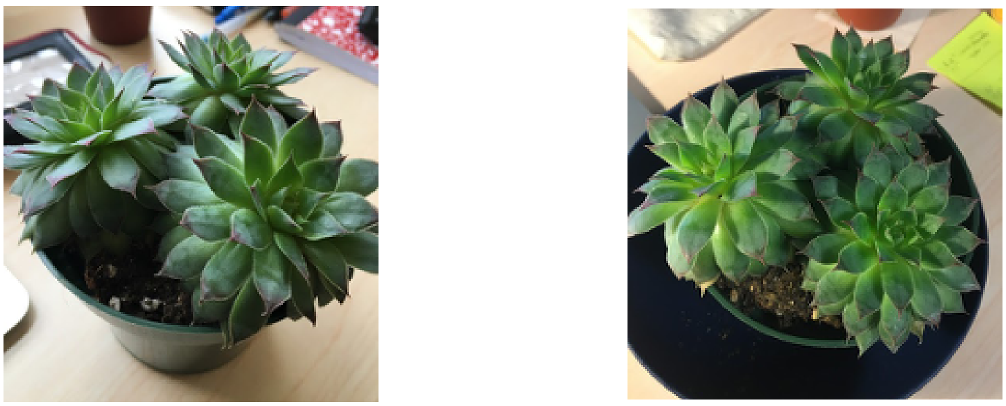
The knowledge that the only succulent that was becoming worse for wear was the one that received no water indicates that the watering system was the most important aspect of the problem. At this point, the implementation of the lighting system was disregarded, but more on this is included in the reflections.

Since the development of this prototype was separated into a works-like and looks-like prototype, and the fact that the works-like prototype has the water pump connected very closely to the rest of the circuit and the wall outlet, we did not want long term exposure of water and electricity next to each other. Therefore, there is no direct comparison of our prototype to the benchmark testing. Given that the plants which were correctly watered survived and that our system follows the same recommended watering cycle, it is safe to assume that any succulent tested in this same manner would also be alive after a 14 day period.



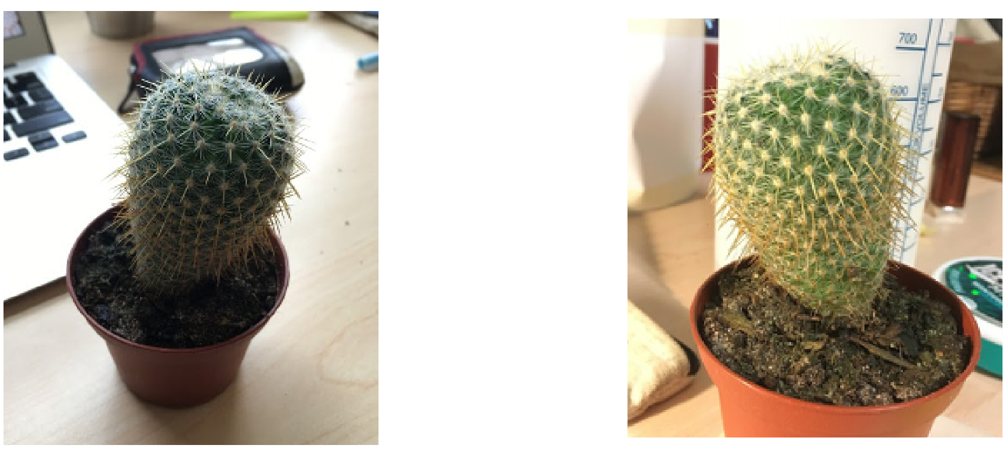
(a) Day 1 (b) Day 7

Figure 6.1: Plant 1: Adequate light and water



(a) Day 1 (b) Day 7

Figure 6.2: Plant 2: Adequate water, inadequate light

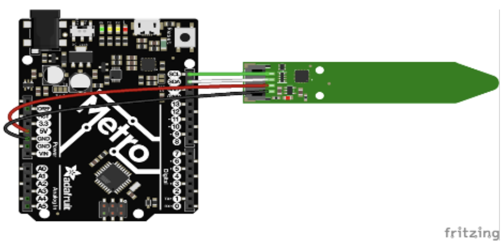


(a) Day 1 (b) Day 7

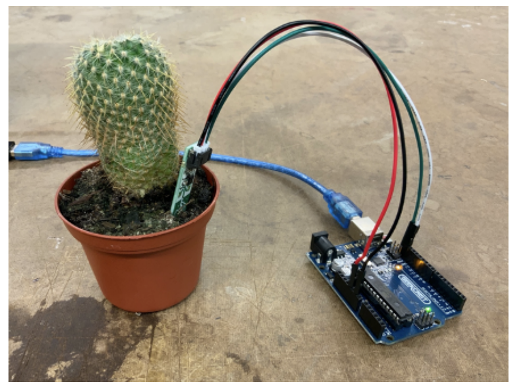
Figure 6.3: Plant 3: Adequate light, inadequate water

6.2 Soil Moisture Sensor

For the initial soil moisture sensor prototype, we connected the Adafruit Soil moisture sensor to an Arduino Uno board since we were still waiting on parts to use the Raspberry Pi Zero W board. The electrical connections [7] *(Figure 6.4a)* and testing code are provided by Adafruit and were used to facilitate this testing. Connecting this assembly to a computer, we uploaded the Adafruit seesaw library on the Arduino IDE software and uploaded the Adafruit Seesaw Soil Sensor Example Sketch on the board, as shown in *Figure 12.4*. This same library was used in the final Python code in order to read the data collected from the moisture sensor. We placed the assembled moisture sensor into a succulent plant pot *(Figure 6.4b)* and two benchmark test readings were taken by opening up the serial console at 115200 baud to read the capacitive measurements. The first benchmark test was for dry soil and the second was for wet soil.



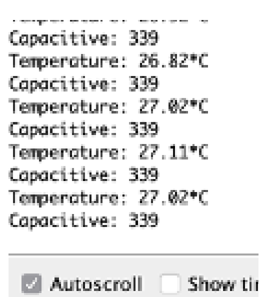
(a) Adafruit moisture sensor connected to Arduino



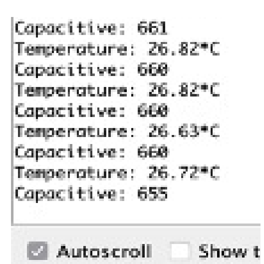
(b) Assembly connected placed in succulent soil

Figure 6.4: Electronic diagram and actual assembly

Notice that when the soil moisture sensor is in dry soil, the serial console capacitive readings when moisture sensor is placed in dry soil are below 400 *(Figure 6.5a)*. On the other hand, when the soil moisture sensor is in wet soil, the serial console capacitive readings are above 400 *(Figure 6.5b)*. These differences in capacitive readings show that the soil moisture sensor is able to differentiate between wet and dry soil (high and low moisture content, respectively). We also noticed that placing the moisture sensor in a vertical position, parallel to the plant pot's side wall, optimizes capacitive readings and makes them more accurate.



(a) Moisture sensor in dry soil



(b) Moisture sensor in wet soil

Figure 6.5: Reading serial console at 115200 baud with the soil moisture sensor in the plant soil

After thorough research, we further determined that these readings are also consistent with those taken when the Adafruit moisture sensor is connected to the Raspberry Pi Zero W board. This similarity paved the way for us to write the code shown in *Appendix* 12.1. Thus, we were able to finally incorporate the moisture sensor to the Raspberry Pi Zero and to Oasis.

6.3 Fluid Flow Analysis

The automatic watering system is a critical component of our product. Unlike many other plants, succulents need to be watered directly on the soil since spraying the water can lead to fragile roots and moldy leaves [8]. In order to ensure that the water pressure coming through the tube is not too strong where the water would splash on the leaves and waters the full surface area of the soil, we decided that the best approach would be to use a tube with a larger diameter that directs the water up from the water pump and then there are a series of holes made along the tube. So, when the tube is wrapped around the perimeter of the succulent, the series of holes would effectively water the whole of the surface area. In order to determine the volume flow of water that leaves from one of these holes in series, we first measured a flow rate of 18 mL/second through the tube. Then we used the formula

$$V = 0.408 \times \frac{F}{D^2}$$

where F is the flow rate and D is the diameter to find the rate in which the water is traveling in distance per unit of time through the tube. Then, The constant water velocity is $V = 0.646\ \mathrm{m\,s^{-1}}$ for a hole with a diameter of $3\ \mathrm{mm}$. The cross sectional area is

$$A = \pi r^2$$

where

$$A = 3.14(0.0015\ \ \mathrm{m})^2 = 7.1 \times 10^{-6}\ \ \mathrm{m}^2$$

Then, the fluid volume flow Q is

$$Q = A \times V$$

where

$$Q = (7.1 \times 10^{-6}\ \ \mathrm{m}^2)(0.646\ \ \mathrm{m\,s^{-1}}) = 4.56 \times 10^{-6}\ \ \mathrm{m^3\,s^{-1}} = 4.56\ \ \mathrm{cm^3\,s^{-1}}$$

In discussions with Raina White, we learned that a series of holes in a tube acts as a parallel circuit. That is, the flow rate from each hole in the series would be identical to all the others. This eliminates the need to determine the flow rate through each individual hole and only focus on adjusting to the specifications of the succulent. Although there is no change in the fluid volume flow rate caused by the series of holes, the size of the hole does change the fluid volume flow rate. In order to determine what size of holes to use, the same calculation discussed above was carried out for different diameters. Plotting these differences results in *Figure 6.6*, where the fluid volume flow rate increased exponentially as the diameter increased. In doing experimental testing, it was determined that the flow rate that caused the minimal amount of splashing on the leaves of the succulent but also provided enough power for the water to be pumped up and over the whole surface area of the soil was a diameter of 3 mm.

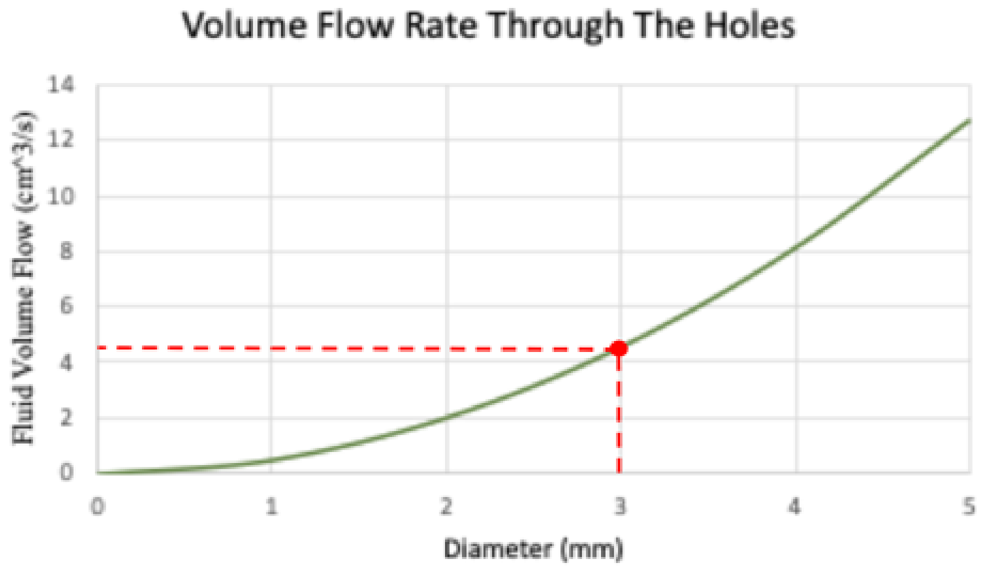


Figure 6.6: Calculating the Fluid Volume Flow ($\frac{cm^3}{s}$) in relation to the Diameter (mm) of the holes

Another aspect that had to be taken into consideration was the placement of the holes on the surface of the tube. This placement affects the trajectory of the water out of the tube, as shown in *Figure 6.7*. For example, a hole that is placed in the upper half of the tube will travel farther and with a greater arc than that of a hole of the same diameter that is placed in the lower half of the tube. Since the former produces a higher arc than the latter, and we want to minimize the amount of water that gets on the succulent leaves, the placement of the hole was chosen in this lower position.

Figure 6.7: Still of the arcs of the water as it flow through the holes in the tube

6.4 Water Pump and Lifetime

Oasis is geared toward Dartmouth students in the Hanover area. Therefore, the plants that were used were bought from Robert's Flowers of Hanover. The shop is known to give free plants to first year students at the start of every academic year but was unable to do so this term due to the COVID-19 pandemic. We were still able to purchase succulents from the store, and the succulents offered were small or medium sized. The medium sized succulents were more abundant in the store, and basing a prototype off this medium size is reasonable because any plant smaller than the largest one offered can be planted in the same volume of soil.

The pot that the medium sized succulent came in was plastic and meant to be repotted into another pot of the same or similar size. The pot was the traditionally tapered shape, where the circumference at the bottom of the pot was 10", the circumference at the top of the pot was 13.5", and the height was $3\frac{3}{4}$". There were no individual pots available, so the succulent could not be removed from the pot and since only the outer dimensions of the pot were known, the volume of soil in the pot had to be calculated. The pot was modeled as a straight line of $y = 6.25(x - 1.6)$ that revolved around the y-axis, where the units are assumed to be in inches. This allows the use of the equation for the volume of revolution to be used as

$$\begin{aligned} Volume &= \int_0^{3.75} \pi (f(y))^2 dy \\ &= \int_0^{3.75} \pi (0.16y + 1.6)^2 dy \\ &= 42.9 \ \text{in}^3 = 703 \ \text{mL} \end{aligned}$$

The volume of the pot was then determined to be $42.9 \ \text{in}^3$ or 703 mL. Since the recommended water volume for succulents is half that of the volume of soil it is in, the volume of water that the water pump needs to deliver in each watering cycle is 352 mL. As determined in the previous section, the overall initial flow rate of the water out of the tube from the water pump was 18 mL/s. So for the water pump to expel 352 mL of water it needs to be on for

$$352 \ \text{mL} * \frac{1\text{s}}{18\text{mL}} = 19.56 \ \text{seconds}$$

which we can say is 20 seconds to account for the transient on and off phase of the water pump.

An important specification that we wanted to keep in mind while designing this prototype is that it lasts four years, the length of time typically spent at Dartmouth. The material of this prototype is orange PLA, making it very durable. Therefore, the only real concern about the lifetime of this product would be the motor in the water pump. The water pump only needs to be on every ten days (at most) or every 14 days (at least) for only 20 seconds. That means that in 4 years the water pump only needs to be on for at most

$$4 \ \text{yrs} * \frac{365 \ \text{days}}{1\text{yr}} * \frac{1}{10 \ \text{days}} * 20 \ \text{seconds} = 2920 \ \text{seconds} = 48.6 \ \text{minutes}$$

The water pump was left connected to a 3V power supply and let run for more than 1.5 hours. During this time, the water pump did not die or lose power in the initial flow rate of water leaving the tube. It was not feasible to determine the time that the motor would die, but since 48.6 minutes is only 54% of the 1.5 hours that the water pump was run for, it is safe to say that the motor of the water pump would last the lifetime of a college student's career at Dartmouth.

6.5 Power Analysis

Oasis is reliant on power from a wall outlet and Myles Duncanson helped us build a safe circuit, involving the Raspberry Pi, a relay, soil moisture sensor, a 9V battery, and the water pump. In the future, we plan to eliminate the battery, and further details are presented in the reflections section. The Raspberry Pi and soil moisture sensor draw negligible power from the wall outlet; however, the water pump does draw power and is also why it needs to be controlled by the relay that allows more current to be deployed. This was calculated using the equation

$$P = IV$$

where P is the power, I is the current, and V is the voltage, where

$$P = (0.18A)(3V) = 5.4W$$

So, the water pump draws 5.4 Watts of power, and this amount is easily satisfied by the wall outlet, which supplies 120 V or 1800 Watts of power.

7 Ethics and Sustainability

7.1 Ethics

To be deemed a viable solution, our product first needed to be safe, legal, and ethical. While Oasis does meet those requirements, several issues arise that must be addressed in the future. Safety, price, materials and the manufacturing process must be taken into account for our product to succeed. While none of these issues significantly detract from our prototype or prevent the prototype from being sold to producers, they are flaws that need to be solved to improve our product.

The first ethical concern is safety. Any time water and electricity are a part of the same device spells certain complications. The main concern is water from the reservoir coming into contact with electronic components. There is a present danger of possible electrocution and we need to ensure the safety of users. To do this, the water reservoir and electronics must be kept completely separate, and the holes between caulked, preventing any flow between compartments. Although the works-like prototype is completely safe, the goal is to ensure that the product keeps water from interfering with the electronics, and that the user will never come into contact with a potentially dangerous product.

Secondly, the product is subject to price issues. To produce the Oasis prototype, it cost approximately $\$65$ between buying the components and 3D-printing the pot. Essentially, Oasis will never be as cheap as a normal terracotta pot one gets from a florist or other plant retailer. This means that the product is an added cost to a plant that some users will be unwilling or unable to pay. Accordingly, Oasis does exclude certain groups because of that added cost. However, with cheaper manufacturing techniques, and using other electronics that we manufacture specifically rather than a Raspberry Pi, the price of Oasis will decrease, making the device more accessible to users and excluding fewer people from the product in the process.

The final ethical concern with our product involves manufacturing and the materials used to build the prototype. At the moment, our product is not recyclable in terms of our electronics and wires. Moreover, 3D-printing is not a sustainable way to produce our product. These concerns will be more actively addressed in the sustainability section, but Oasis, which is intended to promote sustainability and plant growth, should be produced sustainably. The ethical concerns associated with Oasis are not major, but are necessary improvements down the road to better our product.

7.2 Sustainability

Moving forward, we would like to improve the sustainability of our product. To produce the initial prototype *(Figure 5.1)*, we used 3D printing. However, 3D printing has an Okala impact factor (OIF) of 62/lb [9]. In comparison, thermoforming has an OIF of 1.4/lb and injection molding is 0.72/lb. We hope to initially use 3D printing to create a mold and then use either thermoforming or injection molding to reduce the environmental impact of our production processes. Another sustainability improvement we hope to make moving forward is utilizing a recycled plastic when creating our product as this will help further minimize our impact. Virgin acrylonitrile butadiene styrene (ABS) plastic, a material commonly used in 3D printers, thermoforming, and injection molding, has an OIF of 2.4/lb. However, when using recycled ABS plastic, it is reduced to 1.3/lb. The significance of this seemingly small drop becomes clearer when a substantial number of products are manufactured.

Ultimately, plastics are far from the most sustainable option. One step closer to a sustainable product would be to move away from plastics altogether and replace it with a material such as light clay brick, which has an OIF of 0.093/lb, a value much lower than either virgin or recycled ABS plastics. This transition would be a major stride toward achieving a more sustainable product.

While the manufacturing of the product still has a long way to go, Oasis does promote sustainability in other ways. This is a product that encourages more plants to be purchased while ensuring their survival. Additionally, since Oasis is being targeted to Dartmouth students, it promotes a culture of sustainability and thoughtfulness regarding the ease of taking care of plants to this group of people that could one day influence many more.

8 Economics and Business Plan

Oasis' business model *(Figure 8.1)* highlights several factors we considered as an operating business. We acknowledge that understanding these factors will help us optimize supply chains, the cost of labor and production, distribution and marketing networks for our product to potential customers, and development of effective customer support platforms, thereby enhancing customer satisfaction and experience from purchasing to using the product.

We believe customer experience with the Oasis and the consequent satisfaction from using the product relies not only on a "good" product but also on the relationship between the user and the manufacturers. To foster this relationship, we plan to develop an app that will facilitate the formation of an in-app community. This in-app community is essentially an initiative that will allow multiple users to connect to each other and share their experiences with using Oasis. The in-app community will also allow us to connect with customers, thereby allowing us to deploy customer service efficiently.

While Oasis is currently only being targeted to Dartmouth students, it has an ability to be marketed to a broader audience that is interested in easier ways to grow and own a succulent. This larger demographic can be attained by marketing methods, influence from the aforementioned in-app community, and a website that can be built as well. More potential users can also come in after some improvements are made. As discussed more in the reflection section, a development of code that would allow users to specify the type of plant in the pot can turn Oasis from a narrow succulent watering system into a more broad smart pot system.

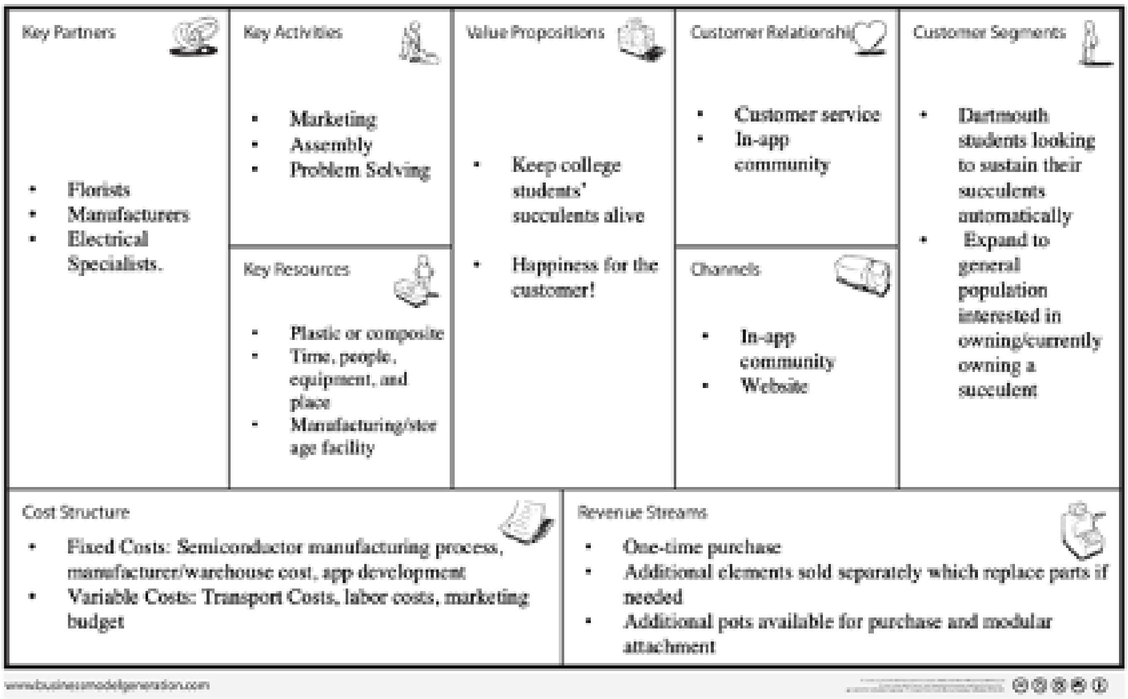


Figure 8.1: Overview of Oasis' Business Model Canvas

9 Reflections

There are a range of improvements that our device needs moving forward. First, the placement of the water reservoir in the SolidWorks prototypes is not conducive to preventing water and electronics from coming into contact. Although our current prototype is safe and prevents water and electricity from mixing, in future iterations of Oasis, rather than placing the reservoir next to the electronics, we will place the electronics above the water reservoir, and seal the two sections off, further increasing the safety of our product. Secondly, the current circuit features a 9V battery, although there is power from the wall outlet. In the interest of making Oasis easy to use, the battery will be removed in future prototypes, so all the user needs to do is plug in Oasis, plant the succulent, and occasionally fill the water reservoir, whilst not needing to worry about replacing a battery. As mentioned previously in the business model, by manufacturing our own electronics board we can create a circuit that has two optically isolated power sources that serve the same function as the battery and wall power. Finally, Oasis will be displayed in dorm rooms at Dartmouth, and aesthetics need to be kept in mind. Future prototypes will not have exposed wires or tubing, but instead be embedded into the pot. In addition, covers will be placed on top of the water reservoir and electronics chamber to make the product more aesthetically pleasing. An example of this future design can be seen in *Figure 12.5*, a SolidWorks design focused on aesthetics.

This project was a rewarding learning experience in itself. We learned how to code both Arduino and Raspberry Pi microcontrollers, creating many programs for the class, but also Oasis. Our entire group feels more confident about integrating sensors with these units to accomplish a task. In addition, we learned about SolidWorks and computer aided design as a whole. Building the structure for Oasis on SolidWorks was certainly challenging, but after that ordeal, we are ready to build new designs and prototypes using this program. Furthermore, we know more about succulents and taking care of plants from taking on this project. Gaining experience from research on patents and plants alike, we learned how to research for an engineering project, delving into the intricacies of patents and figuring out how they work, and what their drawbacks are. Most importantly, we learned how to work together, during challenging times, through the design process and build a prototype. Working over zoom, while trying to integrate all of our individual ideas was especially difficult. However, building a device, working through the iterative design process, and presenting our project remotely all helped us better understand what making a prototype entails.

Moving forward, if we continue with this project we will work on fine tuning the watering system and ensuring it works as efficiently as we want it to. We want to focus on making our product sustainable and recyclable. This includes reducing water waste, using recyclable materials in our product, and using the most sustainable manufacturing methods whenever possible. Another future goal is to add an automated lighting system. Succulents in Dartmouth dormitories may not receive sufficient light during winter months, especially if the window in the room is not facing south. Accordingly, adding a light component will increase the survival of succulents at Dartmouth. This is made easier by already having Oasis get its power from the wall. If this grow light was incorporated, we can be confident that the base power is already there for future implementation. Finally, we want to make Oasis more customizable with an interface or app. This interface will allow the user to choose watering and lighting cycles, turn off the cycles if manual watering is desired, notify the user when the water level is low in the water reservoir, and allow the user to monitor the soil moisture level in the succulent's soil.

Owning plants has shown to have a positive impact on students' mental health and well-being [1]. This positive impact has driven our desire to make this product thus far and will only continue to push us to make it as impactful as possible for all students. We hope our project has a meaningful impact and is able to foster a positive environment for students throughout the Dartmouth community now and into the future.

10 Acknowledgements

We would like to thank Professor Vicki May, Myles Duncanson, Raina White, Gary Hutchins, and Shayne Miller for their consistent support throughout the term. We would also like to thank the TAs for all their help in fine tuning our presentations.

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12 Appendix

12.1 Code

```
import time
import RPi.GPIO as GPIO
from board import SCL, SDA
import busio
from adafruit_seesaw.seesaw import Seesaw

def reading():
    # Soil Moisture Sensor Readings
    i2c_bus = busio.I2C(SCL, SDA)
    ss = Seesaw(i2c_bus, addr=0x36)
    # Read moisture level through capacitive touch pad
    touch = ss.moisture_read()
    return touch

def pumpOn():
    GPIO.setmode(GPIO.BCM)
    GPIO.setup(17, GPIO.OUT)
    GPIO.output(17, GPIO.HIGH)
    print("on")
    time.sleep(20)                              # Pump water for 20 seconds
    GPIO.output(17, GPIO.LOW)
    GPIO.cleanup()

# Set GPIO pin as output and set low before starting
GPIO.setmode(GPIO.BCM)
GPIO.setup(17, GPIO.OUT)
GPIO.output(17, GPIO.LOW)

# Moisture readings twice every day for 14 days
moisture = [[0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0], [0,0]]
try:
    while True:
        # Get moisture readings two times for first 10 days
        for x in range(10):
            for y in range(2):
                moisture[x][0] = reading()
                time.sleep(2)                   # Simulate 12 hour wait between measurements
                moisture[x][1] = reading()
                time.sleep(2)                   # Simulate 12 hour wait between measurements
            print(moisture)

        # If the soil is dry on the 10th day, water it
```

```
        if moisture[9][1] ¡ 400:
            pumpOn()

        # If the soil is still wet/damp, continue for 4 days
        else:
            for x in range(10, 14):
                for y in range(2):
                    moisture[x][0] = reading()
                    time.sleep(2)          # Simulate 12 hour wait between measurements
                    moisture[x][1] = reading()
                    time.sleep(2)          # Simulate 12 hour wait between measurements
                print(moisture)
            pumpOn()

        time.sleep(2)                      # Simulate 12 hour wait between measurements

except (KeyboardInterrupt, SystemExit):
    raise
```

12.2 Figures

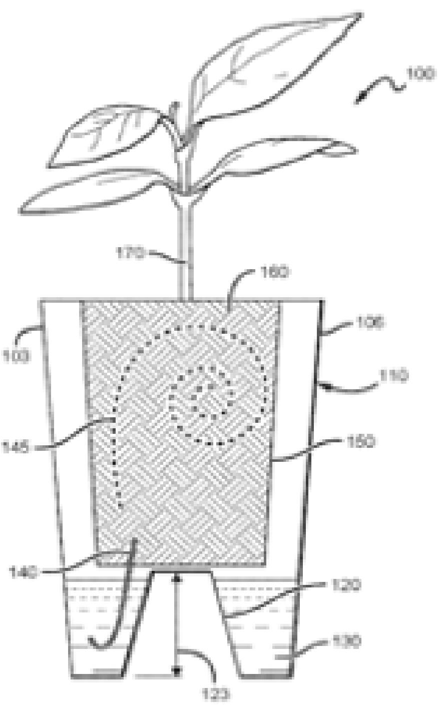

Figure 12.1: Watering System Through Capillary Action Patent No. US 2017/0265407 A1

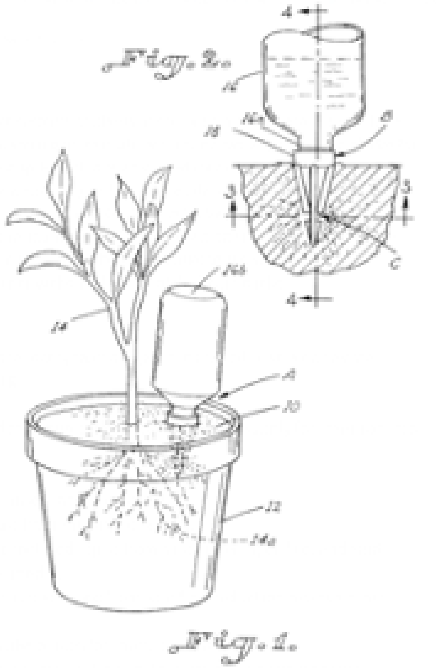

Figure 12.2: Watering Spike Patent No. US 6112456 A

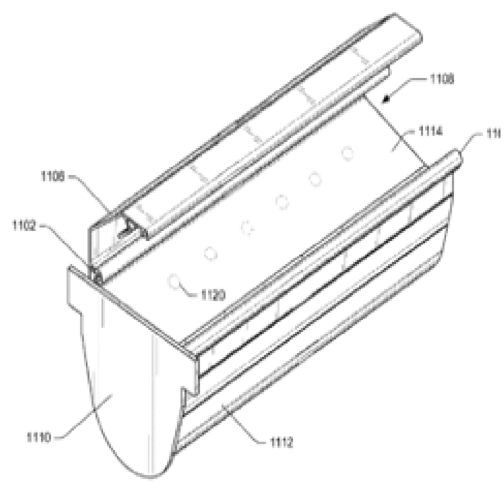

Figure 12.3: Hydroponic Watering System US 10201134 B1

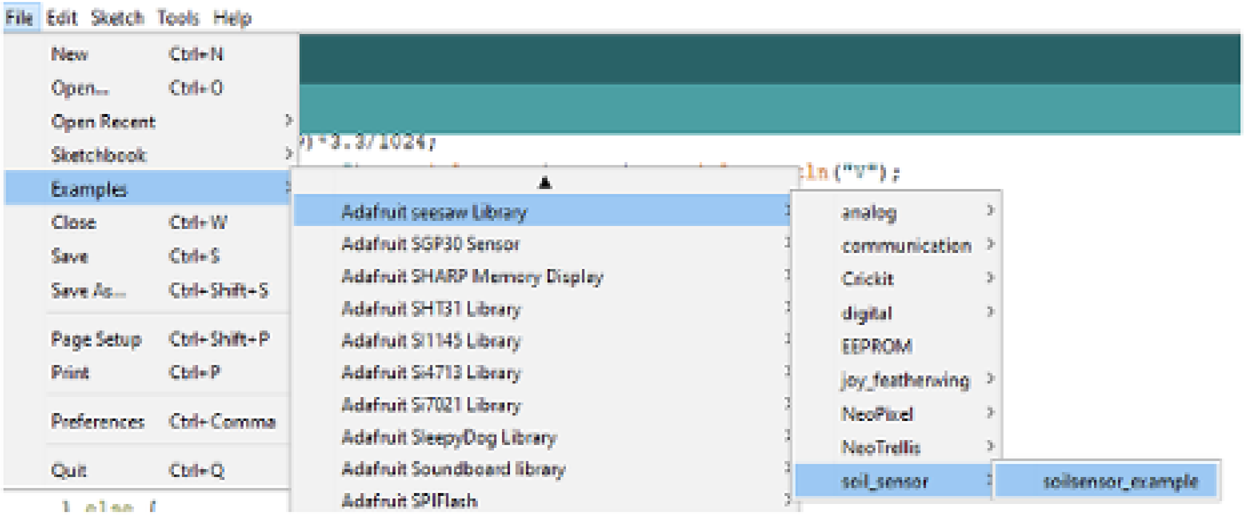

Figure 12.4: Opening up the Adafruit seesaw Soil Sensor Example sketch

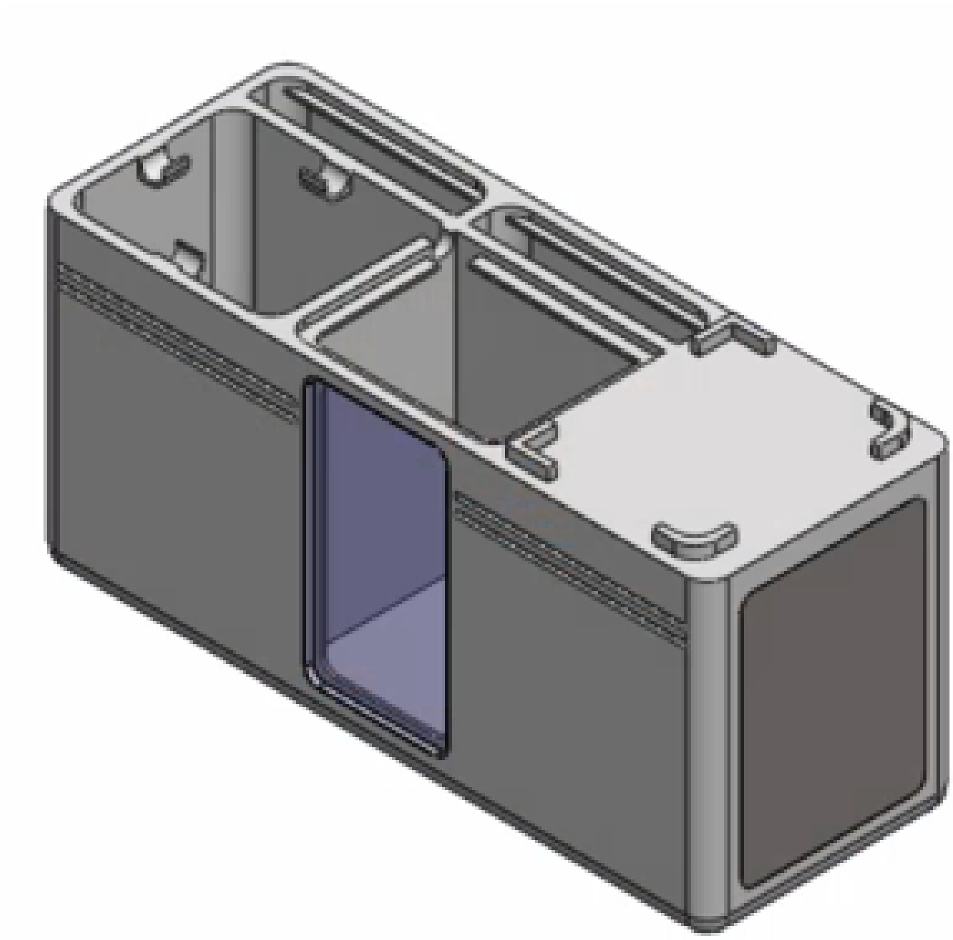

Figure 12.5: Aesthetic Prototype