Greenie: The Smart Irrigator

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***Abstract* — The objective of this project is to grow and take care of different kinds of commonly used herbs in a smart manner. A total of ten herbs are supported by the product. The automatic irrigation system is going to protect the user's plant by providing careful maintenance and data that is going to help the respective plant stay healthy. Based on designated programming times that the user can assign through the use of a web application or by voice commands through Alexa, the herb is going to receive the right amount of water that it needs, resulting in water that is not needed to be saved. Watering requirements for the different herbs supported are going to be saved in the database. Smart components such as soil moisture sensors, pH sensors, rain sensors, and humidity and temperature sensors are also connected to the system. Through these, the user can access data regarding their herb at any time. In addition to the advanced capabilities offered by our sensors, Greenie also has access to a weather prediction station through which it can notify users on proper irrigation usage based on weather conditions on a given day.**

***Index Terms* — pH measurement, pumps, sensors, soil moisture, soil properties, water conservation**

I. Introduction

Irrigated agriculture has become one of the most important and lucrative sectors of U.S. agricultural production while still being the largest consumer of consumptive water. In 2012, about half of the total value of crops sold on 28 percent of U.S. harvested cropland was due to irrigated farms [1]. Approximately 7.6 percent of all U.S. cropland was irrigated in the same year, maintaining the decline in irrigated U.S. cropland since 2007. This decline has been linked to the scarcity of water as a supply, causing drought conditions across the farmable regions. Methods of using water smartly have been looked into because of this.

The future of worldwide irrigated agriculture depends, to a large extent, on the implementation of smart irrigation systems in both large scales, such as farms, and smaller scales, such as home gardens. This allows the most efficient use of water, energy, and other resources in such a way as to increase the production levels using fewer, crucial resources. With intelligent irrigation, the profitability of fields is increased, the cost of human efforts is reduced, and the environmental impact of heavy-scale agriculture is minimized by reducing both the use of water and the contribution of polluting elements to the environment [2]. The implementation of smart irrigation systems is essential to ensure the sustainability of irrigated agriculture.

In hopes of aiding this situation, a smart irrigation system using the Internet of Things technology, or IoT, was designed by implementing a network of sensors and APIs to connect and exchange data over the internet. A smart irrigation system could help manage water utilization around the world and increase productivity in fields. This system implements a more local approach, giving individuals the chance to help their communities and the global population by growing herbs from the comfort of their homes.

II. Function of System

Through the use of the hardware, the user can acquire various information regarding the watering levels, soil dampness, and humidity through the use of our designed microcontroller. Data is displayed on the included LCD. The observable information includes soil moisture levels, temperature and humidity levels, and pH levels. To obtain the data, the respective sensors are placed in the planter, which sends real-time data to the microcontroller. Depending on the herb, a humidity range is indicated and whenever the values are outside of the specified range, the microcontroller automatically turns on/off the water pump. Through the use of an integrated weather monitoring application, the system can decide whether the plant requires watering directed by the user on any specific day of the week.

Through the use of the software, the user can water their plant automatically through their mobile device or voice, and also present/read out loud information regarding the plant. On the web application, the user can tap on their screen to either select automatic watering or water their plants manually. The user is also able to ask the system to do either option through the use of their voice thanks to Alexa integration. A Wi-Fi module and relay module are included for this purpose. Additional Alexa commands will also work with an LCD screen, where the user can observe data such as soil moisture levels, whether the plant was watered by rain or not, temperature, humidity, and pH information.

III. System Components

Greenie is best presented in terms of the components that make it up. These components, whether purchased or designed, play an integral part in the entirety of the system. This section serves as an introduction to the hardware components present.

A. Microcontroller

The design of the system is heavily dependent on a microcontroller given that the project requires the use of several hardware components. This component is crucial to the seamless integration of these parts into one system due to their need of interacting with one another and transferring information.

The heart of the system is the Atmel ATmega328P. The ATmega328P is Atmel's high-performance, low-power, and advanced architecture microcontroller from the megaAVR family optimized for C/C++ compilers. The microcontroller has a clock speed of 16 MHz, an operating voltage of 5 V, and 14 digital I/O pins. For this project, two ATmega328P chips are utilized to maximize performance and guarantee the best experience possible for the user. The Atmel microcontroller allows hardware and software components within a system to connect with the use of Wi-Fi modules, being one of the reasons why it was chosen for this system. Another benefit of choosing this microcontroller as the “brain” for this system is the fact that it can be programmed using the popular and easily available Arduino Software IDE. Fig. 1 shows the microcontroller connections that were utilized to connect the hardware required in the system.

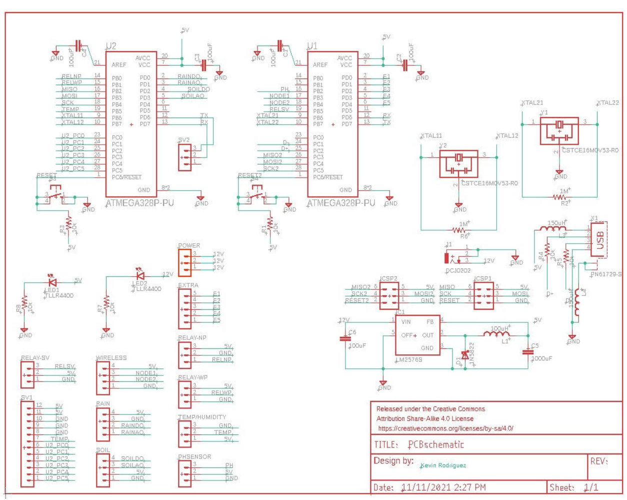


Fig. 1. Microcontroller pinouts.

B. LCD

In the system, the user needs to be able to visualize and/or monitor parameters, and an alphanumeric LCD is the most practical solution. This is due to their low consumption, different sizes available, and how they work with alphanumeric characters. This provides the user with various information about the herb.

For this project, the LCD1602 was selected. The device is lightweight, small, and inexpensive to use. This LCD is made of two lines of sixteen characters to make different kinds of numbers, letters, and symbols. This LCD allows the use of about 160 characters that are produced to be used. The LCD1602 included in the system has a 6-pin interface (standard), an operating voltage of +5 V or +3.3 V (typical), and supports the I2C communication protocol and development board.

C. Soil moisture sensor

To measure the moisture in the planter’s soil, the system contains soil moisture sensors. The data acquired from this sensor is crucial given that this sensor informs the user if the soil has received enough water on any specific day.

The soil moisture sensor selected for the project was the KeeYees LM393. Soil moisture sensors with the LM393 chip are widely used in automatic irrigation systems to detect when it is necessary to activate the water pumping system. The KeeYees LM393 is supplied with a standard measurement board that allows the measurement to be obtained as an analog value or as a digital output, activated when the humidity exceeds a certain threshold. The values obtained from the sensor range from 0 submerged in water, to 1023 in the air. It has an operating voltage range of 3.3 V to 5 V.

D. Rain sensor

The system comes with a rain sensor that allows the software to detect and respond to drops of moisture by either switching the water pump on or off, depending on if the plant has been watered or not by rain.

The rain sensor selected for the project was the Teyleten Robot LM393. Similar to the soil moisture sensor, this rain sensor contains an LM393 chip, making it ideal for irrigation projects. The Teyleten Robot LM393 surface is coated with a nickel plating treatment, giving the rain sensor a higher conductivity and a longer service life. The sensor can be used to monitor different kinds of weather conditions and translate the results into an output signal and analog output. It has an operating voltage range of 3.3 V to 5 V.

E. Humidity and temperature sensor

To measure the humidity and temperature in the air, the system contains a humidity and temperature sensor. Through this sensor, the user receives data regarding the ideal air humidity and temperature needed from the room to optimize their plant's needs.

The humidity and temperature sensor chosen for the system was the DHT-11. This sensor is a simple, low-cost sensor that uses a digital pin to send information. Because it is digital, the sensor is more protected against noise.

F. pH sensor

To maintain the overall health of the user's herb, the system comes with a pH sensor. The correct soil pH is essential to ensure optimal plant growth and crop yield, as it allows nutrients to be freely available for plants to absorb. Each herb has different pH needs, so this information is taken into account by the database. An inappropriate pH range directly affects the capacity of the root system, because if the pH values are extreme, it can lead to precipitation of certain nutrients, making them no longer available. The pH sensor is going to read the pH level of the soil to maintain the health of the user's plant.

The pH sensor chosen was the GAOHOU PH0-14 Sensor Module. The pH electrode probe included in this sensor is accurate and reliable, supplying the user with almost instantaneous readings (less than one minute). This sensor is also versatile, being able to be used for several different purposes, such as aquariums, hydroponics, laboratories, etc.

G. Relay module

The system automatically turns on and off the pumps whenever they are not being utilized. To fully implement the turn-on and turn-off functions of the project, relay modules are included. A relay module is required for this implementation since it must be utilized whenever an application needs to switch from high to low or vice versa within the same circuit.

For the relay module, the HiLetgo 5V Relay Module was chosen. This is a relay module that boasts a stable performance and a strong driving capability. The HiLetgo 5 V relay also contains a "fault-tolerant" design where the relay will not operate if the control line is broken. This makes this relay module ideal for switching power loads. The relay module's contacts are designed to switch between loads with maximum AC and DC levels of 10 A and AC 250 V and DC 30 V respectively. The relay module also includes two LED lights. The green LED is the power indicator and the red LED functions as the relay status indicator. The design for the relay module can be observed in Fig 2. The Atmel ATmega328P microcontroller in the system controls the actions shown in the figure.

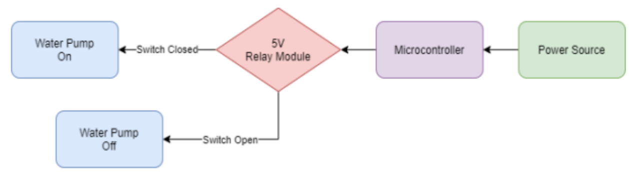


Fig. 2. Relay module connection.

H. Water pump

A distinctive feature of the project is that it irrigates the herbs through the use of a water pump. The water pump is essential for efficient water use and distribution. It moves the water between the container and the planter, becoming especially necessary since the resource needs to be transported from a container located below, which it could not otherwise reach due to the lack of pressure.

The water pump chosen for the project was the LEDGLE Mini Submersible Water Pump. This is an easy-to-install water pump that has both inlet and outlet pumps. Having a water pump with both inlet and outlet pumps gives the user more flexibility, allowing the user to choose if they would like to install the water pump outside or inside the water container. The LEDGLE water pump is low-noise, features anti-explosion and no-spark properties, and is IP68 waterproof. This water pump is also versatile, being able to be used for several different purposes, such as fish tanks, aquariums, fountains, etc.

I. Solenoid valve

A solenoid valve is included in the project to control how much and when water can flow into the herb. A solenoid valve is a combination of two things. First, it is a valve that is electrically controlled to either stay closed or to stay open depending on whether it is a normally closed valve or a normally open valve. For the system, a normally closed solenoid valve was used. This option was chosen because the solenoid gets hot and requires power whenever it is used. Since in a base state it is not desired for water to pass through the system, including a valve that is normally closed allows the system to save power and extend the usage of the components.

In the system, the solenoid valve included is the HFS 12 V DC Electric Solenoid Valve. It is a normally closed valve that is composed of an electromagnetic coil, which is energized to generate a magnetic field that controls the input and output ports. The solenoid valve has a flow aperture of 2.5 mm and a power of 8 W.

J. Nutrient pump

Similar to the water pump, a nutrient pump is also essential for the proper growth and maintenance of the herbs supported by the system. Whether ornamental or horticultural, all plants need to obtain minerals and other elements to grow properly. If they lack nutrition, the health of the plant is at risk. Therefore, it is essential to guarantee an adequate supply of nutrients for the herbs.

To accomplish this task, the system contains a nutrient pump, specifically the Gikfun 12 V DC Dosing Pump. This nutrient pump boasts a "Snap-in" type design through which it is easy to remove the pump head, making it very convenient for pump tube replacement and cleaning. The Dosing Pump has a voltage of 12 V DC, a current of 80 mA, and a flow rate of 0 to 100 milliliters per minute (ml/min). It also has a small pump head size with a diameter of 31.7 mm, making it ideal for precisely pumping small amounts of nutrient solution.

K. Smart speaker

The inclusion of a smart speaker is an important part of the project. Through it, the user can utilize voice commands to activate or deactivate certain actions regarding the product and how it interacts with the user's plant. Through the use of the software created, the user can ask the smart speaker to water their plant manually and also present information regarding the plant on the LCD.

For the smart speaker, the Amazon Echo Dot was chosen to be integrated with the system. It is part of the wide family of speakers made by Amazon whose voice assistance is Alexa. The decision to choose this smart speaker over others in the market was based on three factors: cost, familiarity, and versatility. In terms of cost, the Echo Dot is the most affordable option for a smart speaker since one of the system's designers already owns one. This helps maintain the total budget for the project as low as possible while still accounting for all of the other components integrated into the system. The Echo Dot is the smart speaker that is most familiar to the designers as they have all interacted with one. Given its popularity and wide-range accessibility, it has become a product that is commonly found in homes today. In terms of versatility, the Echo Dot is the best option given that it is compatible with the largest number of technology devices.

The Echo Dot is a crucial component of the project. Through the use of the speaker's smart assistant, Alexa, the user can command different actions to be performed and see its results. Once the user calls Alexa, they can activate the sensors and the water pump. Through the sensors, the user can command Alexa to show the current soil moisture, pH, rain condition, humidity, and temperature levels on the LCD screen. The user can also command Alexa to either turn on or off the water pump.

The commands previously mentioned belong to the system, being three unique commands to Greenie. These commands can be voiced by the user at any point as long as both the system and the smart speaker are connected to the same Wi-Fi network. The three unique commands included are, explicitly, "Alexa, turn on the water pump," Alexa, turn off the water pump," and "Alexa, turn on X display." The "X" in "X sensor" represents any of the four different types of sensors contained in the system.

L. Wi-Fi module

A key piece of ensuring that the irrigation works as intended is an established internet connection. By having an internet connection, the parts needed for the various features are remotely controlled by the user.

The HiLetgo ESP8266 NodeMCU was chosen as the Wi-Fi module for this system. It has an operating voltage of 3.3 V, a clock speed of 80 MHz, and 17 pins.

M. AC/DC power conversion

A design for how to power the system was made when planning the system. The standard in the United States is 120 V and 60 Hz AC electricity [3], therefore, a voltage converter was used since the system requires a 9 to 12 V regulator to provide power to its parts.

The AC/DC power adapter selected was the TMEZON Power Adapter Supply. It has an input voltage of 240 V, an output voltage of 12 V DC, and a current rating of 2 A. This adaptor delivers power to the PCB via a 3-pin, female DC power jack socket that is 5.5 x 2.1 mm in size.

N. DC/DC power conversion

DC/DC power conversion is necessary for this project. Given that the AC/DC power adapter being utilized outputs a voltage of 12 V DC, this value must be converted to different voltages, as different electronic components in the system require different voltage values. The voltage values required for the other parts are around 3 V and 5 V. For this purpose, voltage regulators are utilized.

The LM2576xx family of voltage regulators is being utilized in the system. These regulators are available in the market with fixed output voltages of 3.3 V, 5 V, 12 V, 15 V, and an adjustable output version. This series is simple to use, includes fault protection, and is also commonly utilized today to replace popular three-pin linear voltage regulators such as the L7805. The 3.3 V and 5 V versions used in the system have an output voltage of 12 V and a load current of 0.5 A.

O. Printed Circuit Board

To control the system as intended, a Printed Circuit Board (PCB) was designed. The PCB was designed using EAGLE and was manufactured by JLCPCB. For the design, the engineers wanted to switch to the Atmega2560 due to the larger quantity of pins, however, since this piece has been out of stock, two Atmega328Ps were chosen instead. As seen in Fig. 3, the PCB board layout incorporates support for the LCD, all sensors included in the system, the relay module, the water and nutrient pumps, the Wi-Fi module, and the voltage regulators. The final footprint of the PCB is 67.31 x 69.85 mm. The board is a 12 V input board that has two layers. Fig. 3 shows the PCB layout with the top layer in red and the bottom layer in blue.

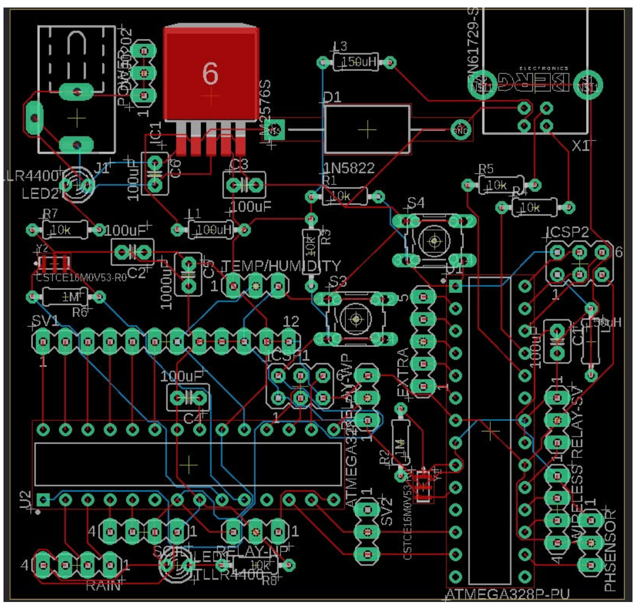


Fig. 3. PCB board layout.

IV. System Software

This section serves as an introduction to the different software technologies present in the project. Just like the hardware components previously discussed, the software components are an integral part of the system.

A. Communication

The microcontroller sends data from the sensors to the server through wireless communication. This allows users to get information about their herb. Through the Wi-Fi module, the transmission of data from the microcontroller to the cloud is direct and the system has to be installed anywhere close to a Wi-Fi access point. Because of the flexibility and the availability of Wi-Fi technologies, the system's users can access the web application anywhere using any device as long as they are connected to the Internet. Fig. 4 demonstrates the interaction between the user and the system. The user interacts with the system through a server. The server receives all the requests from the user and sends them to the system. The server then gathers the response from the system and then sends it to the user.

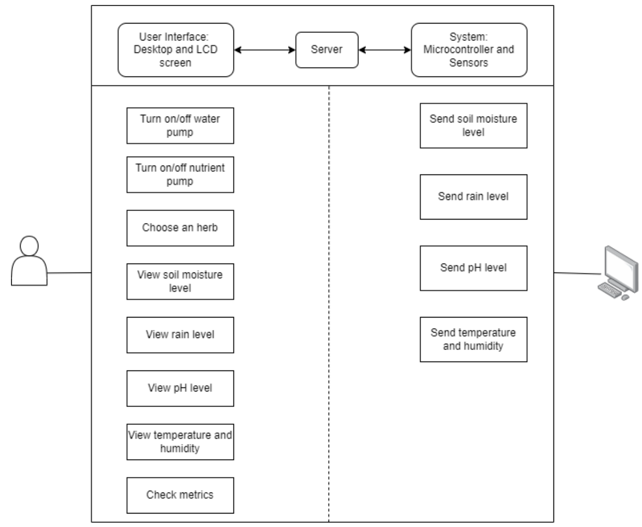


Fig. 4. Communication between the user and the system

B. Database

A database is commonly known as a useful source where a large collection of data is efficiently stored and retrieved. In developing the project, a database was created as a way to better integrate with the web application. By interacting with the user interface, the system can extract the key components needed from each herb and use that to decide how the irrigation system operates.

The database used in this project is Firebase. Firebase is a NoSQL database, making it ideal for large sets of unstructured data and flexible data models. This database is not only compatible with all of the devices in the system, but it also has custom libraries made specifically to make the devices work with it. Firebase also has a real-time database, updating the information instantly.

C. Interface

The user interface allows users to interact with the system. One of its main goals is to provide users with effective and efficient control of the system. This includes the use of a web application. One of the advantages of using a web application is accessibility as it provides users access on any device through a web browser. The user can view the herb's daily statistics through the web application. The herb's statistics include the current soil moisture, the current pH level, the current temperature and humidity, and whether it has been watered or not. The web application contains a list of herbs that the user can choose from, which includes information about the herb to determine how the irrigation system operates. All information is going to be stored in the cloud database. The web application also provides an option for the user to turn on or off the irrigation system. An overview of the web application can be observed in Fig. 5 in an easy-to-follow diagram.

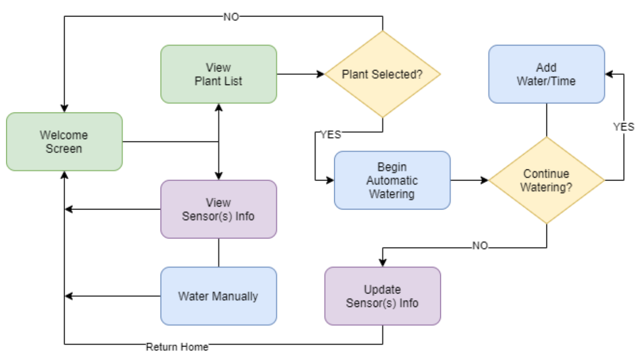


Fig. 5. Web application high-level overview

For the web application designed for this project, pure HTML, CSS, and JavaScript were utilized. Bootstrap was also used as an add-on rather than a framework by adding one extra line of code to the HTML file. Although Bootstrap provides predesigned grid systems, tables, and buttons, additional styling and font links were added to provide users with the best user experience possible.

D. Weather integration

Another feature incorporated into the software of the project is weather integration. Given that the project is a smart irrigation system, the use of water must be optimized, which is a reason why it would not be ideal to use water from the water pump while it is raining outside. To account for this, it was decided to incorporate weather as a useful tool throughout the user experience. On the main page of the web application, the current weather is posted for the user so they can decide whether or not to leave Greenie outside.

To accomplish the task, weather data relative to the user's location is retrieved and sent to the database. The method used to retrieve the data is through a weather API provider, OpenWeatherMap. OpenWeatherMap is a free-to-use weather API that provides minute-by-minute forecasts and historical data through a large number of weather stations around the globe.

E. Repository management

A key piece to ensuring that the web application is set up properly is managing a software repository. With a software repository, all of the code required for the software components can be stored and deployed to a web service. To store the code, the engineers utilized a shared Google Drive folder, which gave them the ability to write code collaboratively. To deploy the code, a cloud service named DriveToWeb was utilized.

F. Web service

As previously stated, for deploying code, a combination of an online cloud service called DriveToWeb and a URL shortening web service called Tinyurl were utilized. To utilize these services, a Gmail account was created specifically for the project and the HTML, CSS, and JavaScript files were placed in a folder on Google Drive. The equivalent of this would be housing code in a GitHub/Gitlab repository. The folder was made public so that the service providers from DriveToWeb could access the code. From there, the service providers utilized their servers to create a link for the web application so that anyone can access it from a web browser. Lastly, Tinyurl was used to create a reference link that was easy to remember for the user so they have a more convenient way of reaching the web application.

G. Arduino Integrated Development Environment

The software utilized to connect the software to the hardware components is the Arduino Integrated Development Environment (Arduino IDE). The Arduino IDE is an open-source programming software that allows users to write code in C or C++ and upload it to any Arduino compatible board. It is compatible with Windows, macOS, and Linux.

The Arduino IDE has several features which led the engineers to choose this program. One of its features is the board module options, which allows users to choose which board they are using for their project. When another board is added or when modifications are made, the port data is automatically updated. Another feature of the Arduino IDE is direct sketching, wherein users can do sketches within the text editor. The text editor provides users with an interactive experience through its additional features. It also lets users decide whether to document their project or not. This feature helped the engineers track their progress and all the modifications that were made. Even if this IDE is specifically intended for Arduino boards, it can support boards from other developers as well with the help of third-party hardware. The Arduino IDE contains hundreds of libraries that can be used by users. The system's microcontroller, sensors (soil moisture, rain, temperature and humidity, and pH), LCD screen, and relay module are programmed using the Arduino IDE.

V. System Design

The product's design is important given that the architecture of the product must be understood to better meet the needs of users. Greenie's design takes into consideration aesthetics as well as small-garden efficiency. Greenie consists of four different sections enclosed in two rectangular containers. These four different sections are the "Herb and Soil" and "Water" encasements, located on the top container, and the "Electronics" and "Nutrients" encasements, located on the bottom container. In Fig. 6, the front view of the system can be observed.

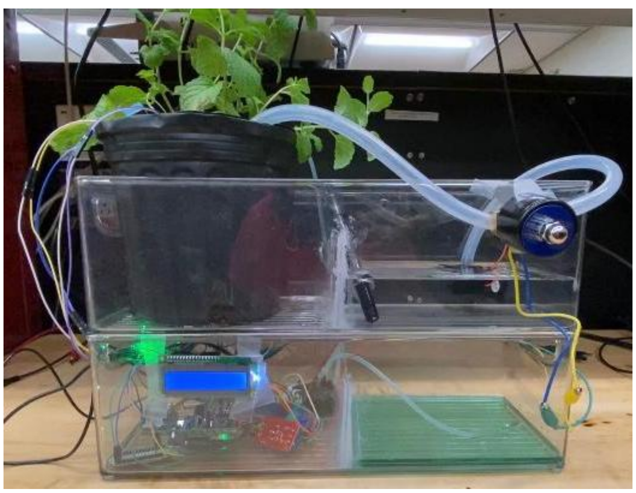


Fig. 6. Front view of the planter

A. *Herb and soil compartment*

The "Herb and Soil" encasement houses the user's selected herb out of the ones supported by the software. The user can fill in the area with their selected soil type, allowing the user to personalize. All of the sensors and the outlet tubing of our water pump are located in this section.

The sensors consist of one soil moisture sensor, one rain sensor, one pH sensor, and a humidity and temperature sensor. The soil moisture sensor is to be inserted into the soil and placed as near the plant as possible, to ensure that the soil around it is fitting for its growth and health. The pH sensor is to be inserted into the soil and located close to the plant and the water tubing to ensure that the pH levels from the soil and water are ideal. The rain sensor is to be placed near the plant as the system must inform the user if their herb was properly watered by the rain if placed outside. Lastly, the humidity and temperature sensor is to be placed in the enclosure as well. Given that this sensor measures the humidity and temperature of the room, it can be placed at a distance from the herb. Space for the outlet water and nutrient tubings was also taken into consideration. The tubings are placed on the side of the "Herb and Soil" compartment since this placement ensures that they can reach from the "Water" and "Nutrient solution" compartments.

B. *Electronics compartment*

In the "Electronics" section, the parts and components required for the project to function are placed. In this compartment, the PCB, LCD, and any other electronic parts needed are going to be located. The smart speaker is located outside, but close to, the encasement so that the user can easily access this part when needed. The sensors are connected using long enough wires that allow them to be planted in the "Herb and Soil" section above.

C. *Water compartment*

In the "Water" encasement, the water required to irrigate the herb is contained. In this compartment, the inlet/outlet water pump is located. The solenoid valve is not submergible so it is placed outside of the compartment but still connected to the water pump tubing.

D. *Nutrient solution compartment*

In the "Nutrients" compartment, the nutrient solution required by the current herb is contained. Here, the nutrient pump and its tubing are placed. The outlet tubing leaves the compartment through open handles to reach the herb supposed to be watered above. The tubing is long enough to ensure that the nutrients reach the herb.

E. *Enclosure*

The selected material for the enclosure was hard plastic. This material was chosen since plastic containers are lightweight and resistant. In terms of price and availability, this material is inexpensive and easily available in stores. The containers selected include built-in, easy-grip side handles that make it easy for the user to transport from indoor or outdoor space. The handles are also being used as access points, making it easier for the components on the bottom to reach the compartments at the top. The bins are clear, making it ideal for the user, as they can constantly observe the water and nutrient levels.

The specified dimensions for the project were set to be less than or equal to 20" x 20" x 20". Each container is 16" x 5.75" x 5", so when stacked, the entire system has dimensions of 16" x 5.75" x 10". These dimensions fit the set project specifications.

VI. Conclusion

This two-semester-long project has been a valuable experience for the engineers behind Greenie. Not only were we able to put into practice theories that we have learned throughout our college career, but we were also able to obtain real-life experience in designing and building projects as Electrical and Computer Engineers. Experience in group working, preparing and conducting professional meetings, and writing technical reports was obtained thanks to these courses.

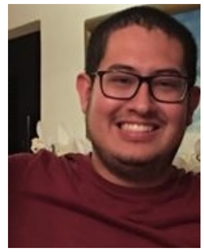
VII. Acknowledgements

As a group, we would like to convey our gratitude towards the professors and mentors that worked with us during this journey. We would like to give special thanks to Dr. Samuel Richie, our Senior Design mentor, as well as our review committee.

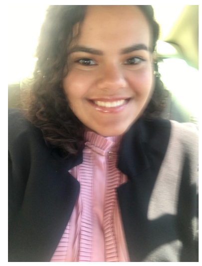
VIII. The Engineers

Elliott Gray is a baccalaureate student in Computer Engineering at the University of Central Florida. He currently does software engineering work at Lockheed Martin. Upon graduating, he plans to continue working with Lockheed Martin full-time as a Software Engineer.

Patricia Luzano is a baccalaureate student in Computer Engineering at the University of Central Florida. Upon graduating, she hopes to find a job as a software engineer, gain industry experience, and eventually pursue graduate school.



Kevin Rodriguez is a baccalaureate student in Electrical Engineering at the University of Central Florida. He is passionate about control systems and circuit design. Upon graduating, he will pursue a career in power distribution.



Angelica Vargas Martinez is a baccalaureate student in Electrical Engineering at the University of Central Florida. She currently holds a Minor in Mathematics from the University of Central Florida. Upon graduating, she hopes to find a job as an electrical engineer.

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