Solar Powered Self Watering Plant System

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Abstract *— 1 out of 8 Americans call apartments home. Most apartments' space is limited. Also, people's time is compromised in many activities. This project aims to create a solar powered self-watering plant system, which enables people with limited time and space to have their own inside compact garden with minor supervision. Plants have a specific optimum soil relative humidity range for growing. For the project, parsley and basil were sowed. Soil moisture sensors were used to monitor the relative humidity range of the plants. When out of it, a water pump would automatically flow water to the plant until the humidity range was met. A Matlab code was developed and used to specify the capacity needed for the solar power system, taking into consideration all power loads. The project developed could supply the water needs to the plants for them to grow healthy and being energized with solar power.*

Key Terms *— Moisture Sensor, Plant System, Self-Watering, Solar Power*

PROBLEM STATEMENT

Several people around the world enjoy growing plants. Some of them do it for fun and others for obtaining some fruit for consumption. Not all people have a house where they can comfortably grow their plants in their garden. Some population lives in apartments, where the space is limited, and the majority do not have a garden area. According to National Apartment Association, 1:8 Americans call apartments home [1]. This research focuses on creating a system that enables people with this space limitation to grow a healthy plant in a confined space. Sowing plants is important for many reasons, including that plants produce oxygen, purify the air, absorb carbon dioxide, etc. Part of the basic parameters for a plant to grow and develop are water and sun light. The proposed system will be able to determine automatically when the plant needs water, having as power source solar power.

Project Description

The specific parameters plants in general need to grow and develop need to be found. This includes the relative humidity (RH) plants need to grow and develop healthy. Also, it needs to be calculated the necessary solar panels and determine the necessary components for the solar system. In addition, several components need to be chosen such as the water pump capacity. An analysis needs to be done to choose all these components and that the solar power system source can provide this demand. This will enable to create an automated system capable of detecting and supplying water to the plant with solar power. This project will enable people with limited space to grow healthy plants. Also, the opportunity for people who travel and/or are regularly busy to still take care of their plants.

Project Objectives

The project objectives are:

- Create a Matlab code that enables to escalate the solar system specifications based on the quantity of the desired plants.
- Design and create a system that can supply correct amount of water automatically to two plants.
- Design and create a system that feeds water to two plants using solar power as its power source.

Project Contributions

This project will provide busy people the opportunity to replicate different types of harvest for consumption. This will lower the consumption of foods that contain several types of pesticides, impacting positively human health. It will enable the consumption of 100% organic food. Also, by eliminating the restriction of having a garden, more people will be able to grow plants helping Earth in several ways such as purifying the air and producing oxygen. In addition, this project will eliminate the dependency to use electric power, rather it will use solar power.

LITERATURE REVIEW

Sun can fulfill the energy needs of all humankind. Energy from the Sun can be converted into electricity using photovoltaic (PV) cells [2]. PV cells transform sunlight into direct current (DC) electricity. The charge controller functions to regulate the power generated by the solar panel, preventing potential damage by redirecting excess power back to the panel. The battery system serves as a storage solution for electric power, utilized during periods without sunlight. This system is linked to an inverter, responsible for converting the direct current into alternating current (AC) [3]. The mentioned solar conversion process and respective elements are represented in Figure 1.

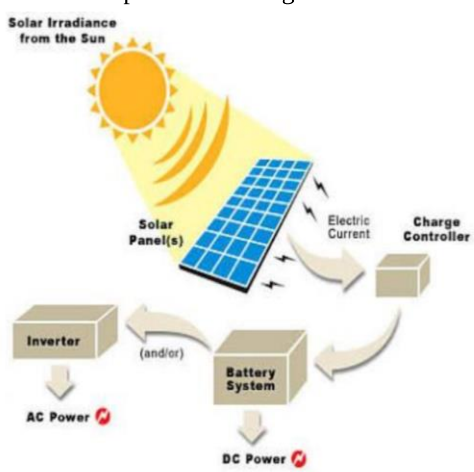

Figure 1
Representation of Solar Energy being Converted into DC and AC Electricity

Solar energy is converted into electricity when solar cells capture photons. This is done by exciting electrons across the bandgap of a semiconductor, which creates electron–hole pairs that are then charge separated, typically by p–n junctions introduced by doping. The space charge at the p–n junction interface (shown in Figure 2) [4] drives electrons in one direction and holes in the other, as shown in Figure 3 [5].

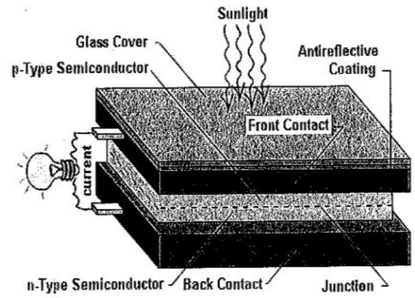

Figure 2
Photovoltaic Cell Components

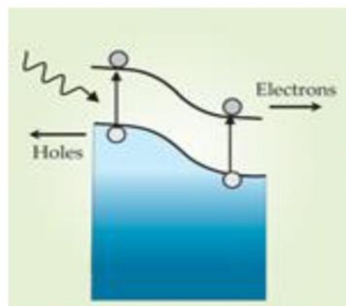

Figure 3
Solar Energy Conversion into Electricity Representation

Previous work on this research topic has been investigated before. It has been developed an automated solar watering system by Amardas and Rahim [6]. They developed a prototype that can irrigate a crop based on the moisture level of soil with minimal human interaction. The electrical components were taken into consideration to calculate the necessary power to be supplied by solar energy. Based on this, they have determined the necessary solar panels/ PV cells [6]. PV cells typically employ semiconductor materials, like silicon. In the production of solar cells, a specialized treatment is applied to a thin semiconductor wafer, creating an electric field with a positive side and a negative side. When the solar cell is exposed to light energy, electrons are dislodged from the semiconductor material's atoms. By connecting electrical conductors to the positive and negative sides, forming a circuit, these electrons can be harnessed as an electric current, ultimately providing a source of electricity. A representation of a basic PV cell is shown in Figure 4 [7].

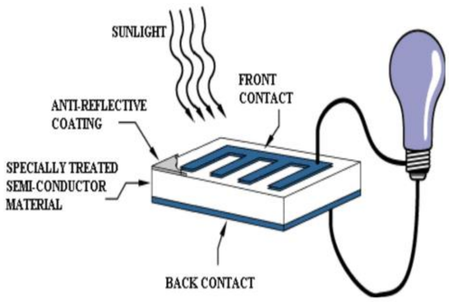

Figure 4
Basic PV Cell

Biswas et al. [8] also worked developing a solar-powered automated crop watering system. As the title states, they did a prototype capable to sense the level of moisture in the soil. When the moisture content of the soil goes below a certain limit, the system is triggered, and the plant is watered. This research was particular because they incorporated the use of switches to select the kind of plant that needs to be sensed and watered. This enables to meet the water needs of a specific plant and prevent over or under watering [8]. As a general guideline, based on the studies conducted by Medici et al. [9], irrigated plants should be grown between 10 and 20 kPa soil water tension (SWT) to achieve a high yield and water use efficiency (WUE) [9]. Soil water tension is the force necessary for plant roots to extract water from the soil [10].

Aghaei et al. explained that designing a PV system incorporates the following steps [11]:

1. Planning and site survey.
2. Assessment of energy requirements.
3. Assessment of solar resource availability.
4. Sizing of the main components of the PV system.
5. Selection of the main components of the PV system.

The initial phase involves planning and conducting a site survey. Following that, the second step includes administering a questionnaire focused on energy consumption. Step three entails assessing climatic conditions and verifying the availability of ample solar resources. After identifying the solar resource potential, the panel generation factor is examined, typically establishing the peak watt rating of the PV plant. This assessment provides insights into the required number of PV panels and the actual peak sunshine available at the installation site.

$$Panel\ generation\ factor = \frac{I_{POA,t} \times Sunshine}{I_0} \quad (1)$$

Upon determining the panel generation factor with (1), the estimation of energy needed from the PV modules can be calculated using data gathered during the load assessment step. The total peak rating of the PV is then estimated based on the energy requirement value, utilizing the specified relation in (2):

$$Total\ Watts\ rating = \frac{Energy\ required}{Panel\ generation\ factor} \quad (2)$$

With the total watts rating calculated, the number of PV modules required to meet the load is estimated as follows with (3):

$$No.\ of\ PV\ modules = \frac{Total\ Watts\ rating}{Panel\ peak\ capacity} \quad (3)$$

After determining the quantity of PV modules, the next step involves sizing the inverter. Typically, the inverter size is selected to be 25–30% higher than the peak rating of the PV array. For instance, if a 100-kW solar PV system is needed, an inverter with a peak rating of 130 kW would be suitable. A straightforward relation for determining the inverter size is expressed as follows in (4):

$$Inverter\ size = Total\ Watt\ rating \times 1.3 \quad (4)$$

Finally, the battery sizing (Bsize) is estimated with the following equation in (5):

$$Bsize = \frac{Total\ Watt \times Hours\ of\ operation \times Days\ of\ autonomy}{Efficiency \times Depth\ of\ discharge \times System\ Voltage} \quad (5)$$

The two plants that will be grown are parsley and basil. According to the Greg app, the relative humidity range to grow parsley and basil is 40-70% for both plants. The Greg app is an application that specifies the correct humidity range for growing a specific plant.

METHODOLOGY

To develop the Solar Powered Self Watering Plant System several steps and procedures need to be done. The procedures have been separated in the sections below.

Necessary Calculations

For the solar system, calculation needs to be done to estimate the power needs. Based on this, the necessary solar panels and battery will be chosen. For this, it is necessary to take into consideration the power consumption for operation of the water pump, soil moisture sensor, etc. Based on this, the necessary number of panels can be calculated. After choosing the necessary solar panels, the battery for saving the charge should be chosen. The capacity of the battery will be determined based on the consumption of the components shown in Table 1.

Table 1
Electrical Components used for the Solar Powered Self Watering System

Electrical Component	Voltage (V)	Current (A)
Water pump	5	0.2
Soil moisture sensor	3.3	0.2

To generate 100% of the electrical consumption with the solar system, first, the charge (Q) of each component needs to be calculated with the equation below (6):

$$Q \# \ of\ plants \times Current \times \frac{Hours}{Day}\ [A-hr] \quad (6)$$

The hours per day are the hours each component is engaged during the whole day. Then, the wattage (W) can be calculated with the equation below (7):

$$Wattage = W = Q \times Voltage\ [W-hr] \quad (7)$$

Then, the sum of wattage for all components will be calculated with (8):

$$\sum W = W_{pump} + W_{moisture\ sensor}\ [W-hr] \quad (8)$$

It is necessary to know and consider the daily average peak sun hours for the area the system is going to be used. In this case we will be designing for Puerto Rico, which is approximately 5.62 hours according to the Department of Energy.

With these hours, the power (P) can be estimated with the equation below (9):

$$P = \frac{\sum W}{peak\ sun\ hours}\ [W] \quad (9)$$

Considering a well-designed solar system with 86% efficiency (e), the corrected power (Pc) is calculated with (10):

$$P_c = \frac{P}{e}\ [W] \quad (10)$$

Then, the number of solar panels can be estimated with the equation below (11), where Pr is the panel rating in Watts:

$$\#\ of\ solar\ panels = \frac{P_c}{P_r} \quad (11)$$

Then, the total Amp-hour demand per day (12) can be calculated with the equation below (where Bv is the battery voltage chosen):

$$Amp-hr\ per\ day = \frac{\sum W}{B_v}\ [Amp-hr] \quad (12)$$

The battery sizing can be calculated after determining the desired days of storage (DDOS) and allowable depth limit (ADT). The desired days of storage are the number of days that a fully charged battery can meet the system loads without any recharge from the solar system. The allowable depth limit is the maximum fraction of capacity that can be withdrawn from the battery. For this project, 1 day and 0.8 were chosen for DDOS and ADT, respectively.

With these numbers, the required battery capacity (Bc) can be estimated with the equation below (13):

$$B_c = \frac{\frac{Amp-hr}{day} \times DDOS}{ADT}\ [Amp-hr] \quad (13)$$

For this project, a submersible water pump that could supply enough water to the plant (using as reference the soil moisture sensor) and consume the minimum power was desirable. Therefore, it was chosen a pump with a maximum lift of 44 inches, rate of 80 L/hr and that only consumes 1W. The maximum lift capacity was chosen based on the water tank used. Assuming the pump will be seating at the end of the tank, the water tank's height is 12 inches. Therefore, a water pump with more than 12 inches of lift capacity needed to be chosen. An independent water pump will be used for each of the desired plants.

System Design Components

Compact water pumps were needed to flow water from the water tank to the plants. These are shown in Figure 5.

Figure 5
Compact Water Pump used in the Design

Also, to save/contain the water for the plant, a water tank/reservoir was needed. The selected reservoir was 12 inches tall.

Soil moisture sensors were needed to monitor the relative humidity of the selected plants. These have an analog output. The moisture sensor used is shown in Figure 6.

Figure 6
Soil Moisture Sensor used in the Design

Water hoses were connected to the water pump to provide water to the plant. The hose diameter matched the diameter of the water pump outlet. PVC hoses were used.

The plants grown were parsley and basil. These were grown right from the seed. Also, a 4-channel relay was used to switch the two loads. It is shown in Figure 7.

Figure 7
4-channel Relay used in the Design

A Waveshare solar power manager was used to safely acquire solar power from the panels and save it into the rechargeable battery. It has the capability of monitoring the battery capacity level and the capacity to monitor when the battery is charging and when battery charging is complete. It is shown in Figure 8.

Figure 8
Waveshare Solar Power Manager used in the Design

A solar panel was used to capture the Sun's energy. It needs to be at a minimum of 6V based on the solar power manager. The panel has a capacity of 1.4W output rating. It is shown in Figure 9.

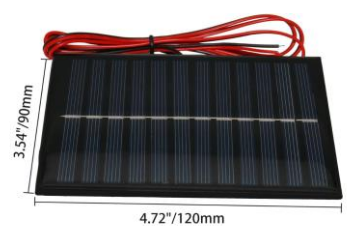

Figure 9
Solar Panel used in the Design

The Arduino hardware includes breadboard for a solderless construction, jumper cables for connecting the interdependent components and Arduino UNO microcontroller for reflecting the written code in the physical system. It is shown in Figure 10.

Figure 10
Arduino UNO Microcontroller used in the Design

Arduino System Code

The code will be developed with the Arduino software. It shall be capable of supplying water when necessary. The code should prompt the water pump to engage and supply water when the soil moisture sensor detects a soil moisture level below the established moisture range (that hydrates the plant) and stopping when the soil moisture sensor detects the necessary humidity in the plant. For this, the logic of the code should be such that it is constantly monitoring the moisture/humidity in the plant and when the necessary humidity parameters of the plant are absent, it is capable of supplying water until the humidity parameters are reached again. It is necessary to know the necessary humidity/moisture in the plant to be considered [12].

System Experimental Setup Steps

In order to assembly the system, the following procedure was followed:

- Set the planted seeds in a flat table.
- Connect the jumper cables in the correct location between the breadboard and the Arduino UNO micro-controller.
- Connect the water hoses between the pump and the plant.
- Connect the positive and negative terminals of the water pump in the breadboard and 4-channel relay.
- Connect the wires of the soil moisture sensor in the correct location of the breadboard and the sensor in the plant's soil.
- Connect the solar system, including the relay and the solar power manager, in the correct breadboard and Arduino UNO micro-controller location.
- Fill the water reservoir with water and submerge the water pump in it.
- Connect the Arduino UNO micro-controller to the solar power system.
- Upload the written code (through the Arduino software) to the micro-controller.
- Test the complete system with the established code logic.
- Notes: No leakages are allowed in the hoses. The water pump should engage and disengage automatically based on the soil moisture sensor reading. The solar system should supply power while the PV panel is acquiring power from the Sun.

Data to be Acquired

After testing the system and validating complete functionality, the following data should be monitored and acquired:

- Moisture level detected for each plant vs. time
- Battery power available (monitored by the solar power manager)
- Plant height vs. time

Note: This recorded data will serve to validate the proposed system objectives.

Project Schedule

To complete the project on time, the following schedule in Table 2 was followed:

Table 2
Research Schedule

Name	Status	Limit Date	Priority
Necessary Calculations	Done	3/15/24	X
System Design Components - Order	Done	3/22/24	
System Design Components - Delivery	Done	4/5/24	
System Coding	Done	4/19/24	
System Setup/Assembly	Done	4/26/24	X
System Test & Debug	Done	5/3/24	
Data Acquisition	Done	5/17/24	

Results and Discussion

Matlab software was used to develop a code that enables to escalate the solar system specifications based on the quantity of the desired plants. This code enables to output the battery specification and number of solar panels needed based on the desired quantity of plants. Please note that values such as panel rating and battery voltage can be adjusted for more demanding configurations. Also, the number of desired days of storage can be increased, but the power demand will be more. However, by using this Matlab code, for two plants, the output is shown in Table 3.

Table 3
Solar System Specifications for Two Plants

Parameters	Output
Number of plants	2 plants
Number of solar panels	1 panel (1.4W output rating)
Number of batteries	1 battery (3.7V/1.8A-hr capacity)
Allowable depth limit	80%
Desired days of storage	1 day

These specifications were used as reference and the solar system was created as shown in Figure 11.

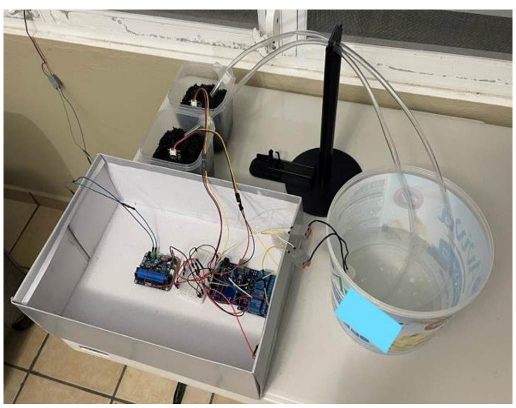

Figure 11
Solar system Assembly

Then, it was time to program with Arduino software the logic for the microcontroller for engaging and disengaging the water pumps. A delay of 10 seconds was implemented to reduce the monitoring time.

After a period of 28 days, plant height vs. time data was acquired for both plants. The plot is shown below in Figure 12.

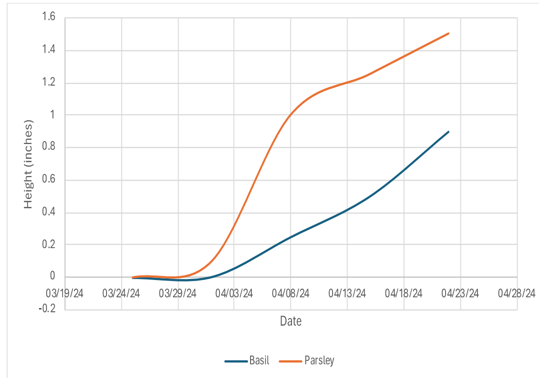

Figure 12
Plant Height vs.Time Plots for Basil and Parsley

It can be noticed that the solar powered self-watering system is providing the correct amount of water, such that both plants are growing. Also, a picture of the plants on 04/15/2024 is shown below in Figure 13. Both plants are exhibiting a healthy color.

Figure 13
Picture of Plants Growth on 04/15/2024

CONCLUSIONS

The developed Matlab code enabled to escalate the solar system capacity to the desired number of plants to be irrigated. For two plants (quantity of desired plants to be irrigated), the solar system needs to have one solar panel of 1.4W output rating. Also, it needs one battery of 3.7V for energy storage, where the allowable depth limit of the battery is 80% and the maximum day of storage is one day. The Matlab code can adjust or escalate based on the desired number of plants to be grown.

The solar system created was based on the output specifications of the Matlab code. After assembling all the necessary components, Arduino software was used to establish the logic to engage and disengage the water pumps for flowing water to the plants. After constantly monitoring the plants' relative humidity, if it was out of the established humidity range (40-70% RH), then it would engage the specific water pump to irrigate the specific dry plant and disengage when the RH range was met again.

This self-watering plant system design was energized using solar power, which enables people with limited space to grow healthy plants with minimum supervision. It was shown that the designed and constructed system worked, after monitoring the plants' height vs. time. Both plants grew at a healthy rate and exhibited a healthy greenish leaf color.

FUTURE WORK

As for future work, this design can be improved in several ways. It can be included a display that indicates that the system is monitoring the RH values and when the system is watering the plants. This is something that although useful, it draws power, therefore it needs to be accounted in the design phase.

Also, a 3D printer can be used to make a stand for placing and positioning the water hoses in the plants.

In addition, a light source can be included in the design for providing artificial photosynthesis to the plants. In the case of this project, the student has placed the plants near a window where these could get exposure to sunlight during the day. The incorporation of the light source greatly impacts the power consumption; therefore, the solar system will need to be more robust. This includes increasing the battery voltage, storage days and panel rating.

Finally, a Wi-Fi device that monitors the water tank's water level could be beneficial. Such that it alerts, through the phone, the user when the water level is low and needs to be replenished.

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