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AUTOMATIC SOLAR-POWERED PLANT WATERING SYSTEM FOR HOME GARDENING

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Abstract

The article covers the development of an automated solar-powered plant watering system that will help home gardeners who struggle with locating sufficient time to irrigate their plants. The system monitors the surrounding plantation and the state of the soil beneath the plants using DHT11 humidity temperature sensors and soil moisture sensors. Utilising the Arduino IDE programme, the Arduino Uno R3 (Atmega 328p) receives the readings from these sensors to determine the state of the plant. In order to determine if the plant is receiving enough water and to regulate the water pump to irrigate it, the Arduino IDE programme computes the sensor values and determines whether the soil condition is above or below the threshold value. For the automated plant watering system to function, a five-volt solar panel and an MPPT charging controller are required. The DHT11 Sensor and Soil Moisture Sensor recommended ranges are clearly stated and documented in the article.

Keywords:

Plant Watering, Watering System, Solar Power, Home Gardening, Embedded System

1. INTRODUCTION

Following the COVID-19 pandemic and the global execution of the Movement Control Order, home gardening and plant cultivation have gained popularity. For those who enjoy home gardening, there are numerous options available, such as soil-based [1], hydroponic [1] [2], aquaponic [3] [4], and aeroponic [5] [6] systems. Because of its low cost and simple layout, the soil-based method is the one that most home gardeners like. To maintain the plants thriving in a wet environment, however, the soil-based method necessitated that gardener's water the plants on a regular basis.

Though professional automated plant watering systems [7] [8] are available on the market, they are expensive and massive, therefore they are best suited for large commercial farms. Furthermore, because these systems run on a 24-hour water and electricity supply, a typical home gardener using them would waste water and electricity. These could make home gardeners' routine jobs and financial burdens more severe. Apart from that, the operation of these systems might need a sizable landscape area. Therefore, the goal of this project is to set up, in the planter's home area, an inexpensive automated system that uses solar power and requires little human intervention.

Prasejo et. al [9] designed a soil moisture sensor-equipped automated plant watering system. The product's benefit is its soil moisture sensor-based autonomous irrigation system. This is because of the farmers or planters not having to manually water the plant. Additionally, it may guarantee that the plant receives the proper amount of water without wasting any. Unfortunately, this product has many drawbacks as well. For example, the AC power source is not environmentally friendly, and there is no manual switch to open or close the system based on certain conditions. As a result, it could not be affordable or user-friendly for unskilled individual gardeners.

A wirelessly controlled robot-based smart irrigation system was developed by the author [10] as a solution to the water waste associated with standard automated irrigation systems. In summary, the planter or farmer may check the plant's status with the help of this robot's numerous sensors. Additionally, the parameters value will display on the application when controlled by mobile applications. Furthermore, it is powered by a solar power system. There are certain drawbacks, too, such as the fact that sprinkler watering is not the most effective technique. Apart from that, several embedded parts are powered by two tiny solar panels, which could not provide enough power to run the robot. Another drawback is that this gadget is pricey due to its many sophisticated parts, which include a high-pixel camera and a motor. Therefore, this product might not be appropriate for home gardeners.

Considering this, it may be concluded from the literature that while some significant elements are required, others are superfluous when designing a plant watering system for home gardeners. Drip irrigation, solar power, an automated plant watering system that adjusts for plant temperature and soil moisture content, and monitoring are among the key features. Superfluous features, such as high-pixel cameras, robots, and sprinkler irrigation can be excluded from the plant watering system for home gardeners. The following is how the paper is structured: Section 2 describes the proposed model for the automated plant water system, together with the suggested solar powered supply system. Section 3 contains some experimental data. Finally, in section 4, some conclusions and envision of future developments will be drawn.

2. PROPOSED MODEL

This section will discuss the proposed model of the automatic solar-powered plant watering system for home gardening, which includes the automated plant watering system, the solar power supply system and the User Interface. The proposed model of automated plant watering system is shown in Fig.1. It consists of sensors, microcontroller, solenoid, relay, OLED display module and water pump, which will be discussed in detail.

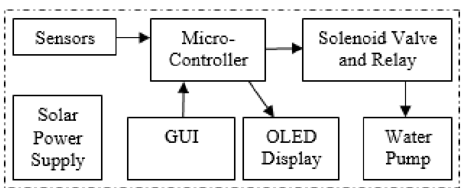


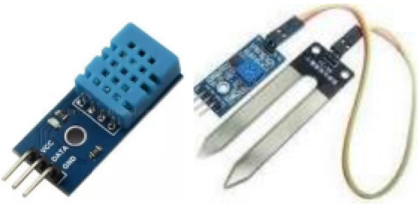
Fig.1. Automated Solar Powered Plant Watering System Model

2.1 AUTOMATED PLANT WATERING SYSTEM MODEL

The automated plant watering system is powered by the solar power system. The temperature and humidity levels surrounding the plant area will be measured using temperature and humidity sensors. The soil moisture content will be determined by moisture level sensors. To regulate the relay and solenoid valve of the water pump and pump water to the appropriate planting area, the microcontroller will gather data from the sensors' measurements and assess the state of the watering. Additionally, the relay will be activated and the solenoid valve for water dispensing will be stopped whenever the soil moisture reading surpasses the threshold valve. The water sources are connected directly to the home water tap to help lessen the requirement for the system to be filled with water on a regular basis. The microcontroller and personal computer are connected via serial communication so that the reading from the plants may be monitored. On the OLED Display, the readings from soil moisture and temperature humidity sensors are shown. The user can manually water the plant thanks to the Graphical User Interface (GUI). Below is an explanation of each capability block's specifics.

2.1.1 Sensors:

DHT11 Temperature and humidity sensors are used to measure the temperature and humidity in the area surrounding the plant, as shown in Fig.2(a). The sensor consists of a thermistor and a humidity sensing capacitor. For temperature sensing, the Negative Temperature coefficient (NTC) thermistor will have lower resistance value when the temperature is increased. To measure humidity, the humidity sensing capacitor has two electrodes with moisture holding substrate applied to the surface. The two electrode resistance changes are proportional to the relative humidity. The higher the humidity, the lower the sensor's resistance. This sensor can determine the range of Relative humidity (RH) from 20 to 90% and the temperature range is as low as 0 to 500°C. The YL-69 soil moisture sensor, also known as a hygrometer, as shown in Fig.2(b) is commonly used to detect soil humidity. The sensor is set up by two pieces which are the electronic board and the probe with two pads that detects the water content. The sensor includes a potentiometer for adjusting the sensitivity of the digital output (D0), as well as a power LED and a digital output LED. Depending on the water content, the output may be a digital signal (D0) LOW or HIGH.



(a) (b)

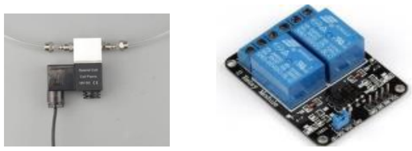
Fig.2.(a) DHT11 sensor (b) YL-69 Soil moisture sensor

2.1.2 Microcontroller:

The Arduino Uno R3 microcontroller was utilized in this prototype. It was selected because of its easy programming, affordable price, and fit size. In order to control the water pump and display messages on the OLED display, the microcontroller is configured to read data from the sensors and GUI, process it, and then send it to relay and solenoid valve circuits.

2.1.3 Solenoid Valve and Relay:

A solenoid valve is an electrically controlled valve which is used to regulate the flow of plant watering, as shown in Fig.3(a). By applying a voltage over the coil, the valve opens, and the water can flow through. The relay module is used to control higher-powered circuits (Pump and solenoid valve) by using a low power signal (from microcontroller), as shown in Fig.3(b).



(a) (b)

Fig.3(a). Solenoid Valve (b) Relay Module

2.1.4 OLED display module

Users can view sensor data, including temperature, humidity, and soil moisture values, using an OLED display module. The 0.96-inch OLED I2C display is in used, as shown in Fig.4. It has a resolution of 128x64 pixels. The display module can be connected to any kind of microcontroller, including the Arduino Uno R3, using SPI/IIC protocols. The reason OLED is preferred over LCD is that it does not require a backlight.

Fig.4. 0.96-inch OLED I2C display

2.1.5 Water Pump:

The selected water pump in the automated plant watering system for home gardening is the DC submersible water pump, as shown in Fig.5. The selected DC water pump is more convenient than the AC water pump because it is portable and has no limitation on working environment. The DC water pump's motor speed control design is likewise more straightforward. Aside from that, the DC water pump has a higher power efficiency because it uses less energy to run than the parallel AC water pump. However, the pumping speed is significantly slower and has a shorter lifespan than the AC water pump due to the low power supply limitation. The intended DC submersible pump's purpose is to move water from below the application's surface level locations, such as the ground. This pump's compact design makes it suitable for use in the majority of challenging work environments. Because the pump body can operate underwater, it also produces less noise. Taking into account the aforementioned benefits, the DC submersible water pump that was chosen is the best water pump for home gardening.

Fig.5. DC Submersible Water Pump

2.2 SOLAR POWER SUPPLY SYSTEM

The automated plant watering system is powered by the solar power system. The block diagram of the solar power supply system is shown in Fig.6. The conceptual design of the proposed solar power supply system is when the sun ray is received by the solar panel, the solar panel will convert it into DC electricity, pass through the charger controller to charge up the rechargeable battery. The charge controller will determine the battery charge up condition and cutoff the current flow to the system when the battery is fully charged. DC to DC converter is a step-up boost voltage converter to supply voltage to loads that require higher voltages (for e.g., water pump). Voltage Booster is also a step-up voltage supplier; however, it is suitable to power up the low power loads (for e.g., microcontroller, sensors etc.).

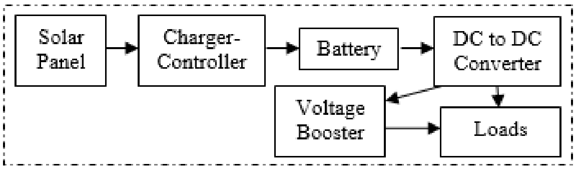


Fig.6. Block Diagram of Solar Power Supply System

2.2.1 *Solar Panel:*

The solar panel is the main medium to convert the sunlight into the DC electricity. The solar panel that is considered in this project is the solar panel rated with 5V and 20A (100W), as shown in Fig.7(a).

(a) (b)

Fig.7(a). 5V Solar Panel (b) MPPT Charger Controller

2.2.2 *Charger Controller:*

The solar charge controller is a voltage and current controller to monitor the charging process of the battery and prevent the possibly of overcharging. It can connect the solar panel voltage and current charge to the battery. The MPPT (Maximum power point tracking) solar charger controller as shown in Fig.7(b) is used to control the device voltage and current. This controller can fully utilize the 12V battery. The controller can control the voltage charge from solar panel to the battery even if the solar panel supplies much higher voltage and it can set the constant voltage supply to the battery. Hence, it can reduce the system maintenance and increase the battery lifetime.

2.2.3 *Battery:*

The automated plant watering system uses a rechargeable lead-acid battery. There are three various voltage options: 6V, 12V, and 24V. The 12V lead-acid battery as shown in Fig.8 is adopted since it is significantly less expensive than parallel lithium varieties, safer for extended periods of operation at higher temperatures, charges more quickly, and does not require self-combination to produce a dedicated 12V output supply.

Fig.8. 12V Rechargeable Lead-Acid battery

2.2.4 *DC-DC Converter:*

DC to DC converter is a step-up boost voltage converter. The function converts the input voltage range of 3 to 32 V to the output voltage range of 5 to 32 V. The XL6009 DC to DC step up module as shown in Fig.9a was chosen for the proposed solar power supply system. Modules come in two varieties: one with an output voltage that is fixed at 3.3 V, 5 V, and 12 V, and another version that is adjustable. The module's potentiometer solder serves as the basis for the adjustment.

(a) (b)

Fig.9(a). XL6009 DC-DC converter (b) USB voltage booster

2.2.5 *Voltage Booster:*

The USB voltage booster, also known as the USB step up Boost Converter, is a device that increases input voltage to a higher voltage, much like the XL6009 DC to DC step up module. The majority of the low power components (microcontroller, sensors etc.) can be supplied power by this module's output because it is a steady 3V to 5V converter.

2.3 USER INTERFACE

The graphical user interface (GUI) layout is shown in Fig.10. This GUI has the ability to automatically or manually control the watering system and keep an eye on the health of the plant. The purpose of this GUI is to serve as a serial communication interface between the firmware and the graphical user interface. The GUI will identify which COM ports are present on the installed PC and display the appropriate COM ports from the user PC. Therefore, the COM Port must be chosen in order for the Python GUI and the PC to communicate. Once the correct COM port has been chosen, serial communication will cause the output result to appear as it does on the right side of the screen. Updates to the output will occur every five seconds. The outputs from the corresponding sensors are the temperature, humidity, and soil moisture content.

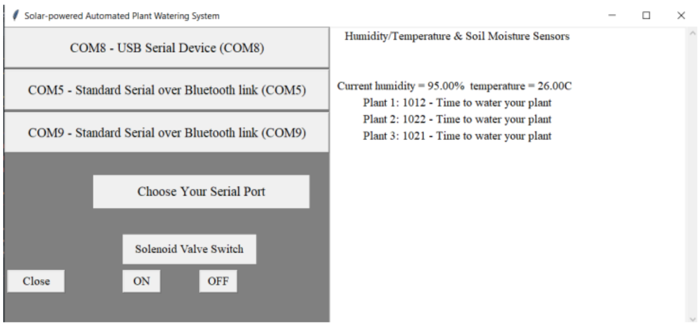


Fig.10. The GUI Application

Another function of the GUI is the watering system control, as illustrated in Fig.11 . By entering a function in the firmware, this function allows the solenoid to be manually controlled. The firmware will operate in "true" mode when the "ON" button is selected. Conversely, the function "false" will be executed when the button labelled "OFF" is clicked.

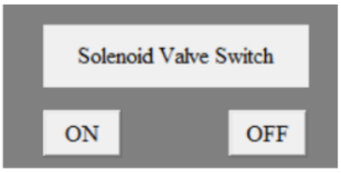


Fig.11. The Switch to control Solenoid Manually

3. EXPERIMENTAL RESULTS

The prototype for the Automatic Solar-Powered Plant Watering System is fabricated, as shown in Fig.12. From this work, it is possible to regulate the soil's moisture content on cultivated land. Depending on the soil's moisture content, the water pumping motor will automatically turn on or off via the relay and solenoid valve. This increases crop output in home gardening even when the owner is gone for a few days or weeks since it conserves water and enables the water level to be reached at a specified position on the plant. The servo motor in the solenoid valve evenly distributes water throughout the plants to ensure the best absorption throughput. Consequently, there is less wastage of water. In addition, the system enables the distribution of water to the plant in response to changes in temperature, soil moisture content, and plant species. The suggested approach reduces the efforts made by significant farming regions.

The plant's requirements can be precisely tailored by modifying numerous aspects of the system using software. A scalable, auxiliary technology is the end product. Soil can be classified as wet or dry by using a moisture sensor. Water pumping will be initiated automatically by the motor if it is dry.

Prior to being installed to the site, the temperature, humidity, and soil moisture sensors utilized in the project are correctly calibrated. The DHT11 temperature and humidity sensor proposed in the project is pre-calibrated by the manufacturer, providing accurate temperature and humidity readings. Each DHT11 sensor features extremely accurate calibration data of humidity calibration chamber. The calibration coefficients stored in the one time programmable(OTP) program memory, as calibration coefficients. Therefore, no additional calibration is typically required for this sensor.

The data and results for one thousand trials points of DHT11 Temperature and Humidity Sensor measured under normal weather conditions, hot weather condition and raining weather condition is shown in Table.1. The data and results for one thousand trials points of YL-69 Soil Moisture Sensors measured under soil dry condition and soil wet condition is shown in Table.2.

Fig.12. Automatic Solar-Powered Plant Watering System Implemented on the Plantation Site

Table.1. Reading of the DHT11 Sensors.

Condition	**Trials**	**Temperature Variation**	**Humidity Variation**
Normal weather (Morning 7:00 am - 12:00 pm)	1,000	30°C to 39°C	50% to 60%
Hot weather (12:00 pm - 6:00 pm)	1,000	40°C to 46°C	61% to 70%
Raining weather	1,000	26°C to 32°C	92% to 100%

Table.2. Reading of the YL-69 Sensors.

		Trial	**Sensor's Reading Range**
Dry Condition		1,000	989 - 1086
Wet Condition	50%	1,000	545 - 601
	100%	1,000	350 - 368

Based on the result obtained in Table.1, it can be observed that the temperature and humidity sensors are able to provide a consistent value under normal condition (measured on the test site soil on morning 07:00 am - 12:00 pm). The recorded temperature reading is from 30°C to 39°C and humidity reading is from 50% to 60%. The hot weather at the test site was recorded from 12:00 pm to 6:00 pm in order to evaluate the reliability of the sensors. Additionally, the sensors consistently provide a temperature between 40°C and 46°C as well as a humidity reading between 61% and 70%. Owing to the rainy season, the sensors were also tested during rainfall. The sensors can also precisely measure temperature between 26°C and 32 °C, as well as humidity between 92% and 100%.

Based on the result obtained in Table.2, after 1,000 trials the optimal range of resistive value of soil was obtained when the soil is in dry and in wet condition. Dry soil reading varies from 989 to 1096. Wet soil reading is captured when the soil is 50% moisturized, the resistive reading varies from 545 to 601. When the soil is 100% moisturized, the resistive reading varies from 350 to 368.

Therefore, the YL-69 moisture sensor's threshold value is set to 800 because that is the best way to determine whether the plant needs watering or not. If the threshold value is set too low (for example 200), then it might take a longer time to indicate that the plant doesn't need watering. The threshold value also should not be set too high (for example 1,800), because it might take a long time to indicate that the plant needs watering. Thus, the threshold value is set to 800 because it is the median of overall YL-69 sensor's performance reading.

An example of OLED's output display is shown in Fig.13 for a case when the humidity is 95% and temperature is 27°C, along with the soil moisture sensors output of plant 1, 2 and 3 indicating all plants are in dry condition and required watering.

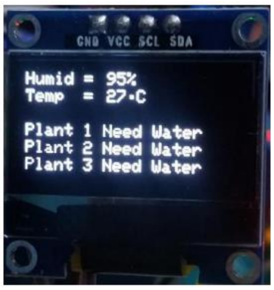


Fig.13. Sample case of OLED's output display

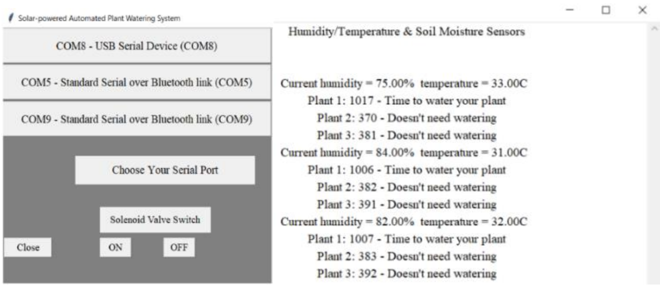


Fig.14. Sample case of OLED's output display GUI output display Plant 2 and Plant 3 below threshold value

When connection between PC and microcontroller is established through serial communication, the respective ports will be displayed in the list of ports available on the GUI. A recorded case of GUI screen display Plant 2 and Plant 3 are below threshold value, which required watering is shown in Fig.14.

For power-saving features to prolong the battery life, a light dependent resistor (LDR) module (Arduino GL55 LDR Photoresistor Light Dependent Resistor Sensor Module, as shown in Fig.15) was added into the system, used to detect the sunlight intensity level to activate the overall system (data measurement, data processing and control system). A sleep and wake modes algorithm for the Arduino microcontroller was also developed to allow the LDR module interrupt the sleep modes and activate wake modes for the system to extend the operational time between battery recharges or replacements.

Fig.15. Arduino GL55 LDR Photoresistor Light Dependent Resistor Sensor Module.

Besides, the lifespan of the battery can be calculated by theoretical equation which is: Power,

$$P = VI. \tag{1}$$

where, the current draw by the water pump can be calculated as Current, $I = P/V = 50W/12V = 4.167A$. Hence, the battery lifespan can be calculated for by:

$$\text{Duration} = 7.2\text{AH} \div 4.167\text{A} = 1.728 \text{ hours}. \tag{2}$$

Since, $0.728 \times 60 \approx 43$min and the battery will drain finish approximately 1 hour and 43min with continuously operation time. Although the lifespan of the battery is short, but the watering system will only require 3 minutes to cover all the watering job. Therefore, the selected Lead-Acid battery capacity is sufficient for this watering system.

The current selected DC submersible water pump has a higher power efficiency because it uses less energy to run than the parallel AC water pump. The DC water pump's motor speed control design is likewise more straightforward. However, the current pump did not have variable speed control to match water delivery rates with plant requirements.

It requires a variable voltage supply to be modified in order to have variable speed control over the current pump in order to match water delivery rates with plant requirements. There are several benefits to incorporating variable speed control for water pumps into a system. By adjusting pump speed to demand, they not only improve energy efficiency but also lessen mechanical stress on the pumping system, extending the equipment's operating life.

Therefore, the first approach is a PWM controlled voltage regulator built to smooth the PWM output and amplify it using LM317 voltage regulator. However, when the pump draws much current, the regulator will dissipate a lot of heat and the water rate is unstable after long use (10- 15 minutes operated continuously).

The second approach utilizes a flyback diode, inductor and capacitor at the output of the logic level power MOSFET (IRF520). The Arduino PWM frequency is tuned to around 31kHz with an inductor of 1mH and 100 micro-Farad capacitor. In effect, this turns the Arduino into a switching regulator and operates smoothly for 3 hours continuous water pumping activities.

4. CONCLUSION

An Automatic Solar-Powered Plant Watering System for Home Gardening was presented in this paper. This irrigation system has the ability to help those who live in residential areas manage their gardening projects. Solar energy powers the entire system. As such, it is friendly to the environment. The usage of the drip plant watering technique can also reduce wasteful use of water. Data on soil moisture, humidity, and temperature are used to regulate the irrigation operation. The section on experimental results justifies and discusses the optimal threshold of sensors' reading. Future iterations of the watering system will incorporate IoT and remote-control capabilities to enhance its current practice of requiring the user to either manually stop the water via a graphical user interface (GUI) or wait for the plantation site's sensors to respond. For the solar charging system to continuously shift the position of the solar panel in order to generate maximum electricity, a sun tracking module is also advised. It is strongly advised to develop a mobile application to replace the conventional GUI in this current project. Mobile Apps will enable the user to adopt smaller gadget like handphone or iPad to perform tasks with a minimum effort, replacing the bulky PC or laptop. Bluetooth, ZigBee or related wireless technology was planned to execute in future to address the unique needs of low-cost, low-power wireless IoT data networks. This may enhance the system with remote monitoring and control capabilities via IoT technology. This would allow users to monitor and adjust the watering system settings from anywhere using a smartphone or web interface, improving convenience and accessibility. Lastly, weather forecast data is very important to predict and monitor water storage for the system to be in long run. Hence, a smart water storage system based on weather forecast data will be developed to support the monitoring and maintenance work for the plant watering system to optimize water supply during periods of rain or dry seasons. The upcoming effort will address each of these concerns.

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