Automatic Irrigation System Using Solar Power System

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***Abstract*— This research presents an automatic plant irrigation system that monitors soil moisture levels using an Arduino UNO. The system assesses soil moisture through a soil moisture sensor and activates the motor (water pump) when the moisture level is below a specified threshold. When the moisture level rises above this threshold, the system stops the motor.**

Solar-powered irrigation systems represent a recent innovation in sustainable agriculture and environmental sustainability. They contribute to water conservation and improve irrigation efficiency, enhancing field productivity and reducing natural resource consumption. This article examines the significance of operating solar irrigation systems and how solar energy is utilised in their functioning.

***Keywords*— Irrigation system, Arduino Uno, Solar system, Sensors, Water conservation**

I. Introduction

In the era of advanced technology and electronics, human lifestyles should be smart, simple, and more convenient. Hence, there is a need for automated systems in daily life routines to reduce human activities and workload. One such useful system is an automatic plant watering system, which addresses the common challenge many people face in watering their garden plants, especially when they are away from home [1].

This model utilises sensor technology with a microcontroller to create a smart switching device to aid millions of people.

In its simplest form, the system is programmed to allow the soil moisture sensor to detect moisture levels from the plant at a specific time. If the moisture level in the sensor is below a predefined threshold, the plant receives the required amount of water until the moisture level reaches the set threshold. The system includes a humidity and temperature sensor that keeps track of the atmospheric conditions affecting the irrigation process. A solenoid valve controls the water flow in the system when the Arduino reads values from the moisture sensor, triggering the solenoid valve accordingly [2].

Solar power has several advantages, including the simplicity of its technology and its environmentally friendly nature. The objective is to exploit groundwater and surface water (from rivers and irrigation channels) using solar-powered pumps, storing it in designated tanks, and subsequently redistributing it through modern irrigation systems (such as sprinklers or drip systems).

Solar-powered irrigation systems represent a recent innovation in sustainable agriculture and environmental sustainability. They contribute to water conservation and improve irrigation efficiency, enhancing field productivity and reducing natural resource consumption. This article examines the significance of operating solar irrigation systems and how solar energy is utilised in their functioning [3, 4].

A. *Importance of Solar Irrigation System Operation*

Solar irrigation systems significantly contribute to water conservation. They distribute water in fields based on set schedules or plant needs, reducing wastage and improving water use efficiency. As a result, field productivity is enhanced, and water consumption is greatly reduced [5].

B. *How Solar Irrigation Systems Operate*

The operation of solar irrigation systems depends on solar energy to generate the necessary electricity for system functionality. This is achieved by using solar panels installed on the ground or above fields. These panels convert sunlight into electrical energy, which is stored in special batteries for powering pumps and irrigation control systems.

With smart control systems, specific schedules are set to operate the pumps and distribute water in the fields. These systems are programmed to meet plant needs at various growth stages, which improves irrigation efficiency and reduces wastage. Furthermore, these systems can be connected to weather stations to adjust irrigation schedules based on local weather conditions and forecasts [6].

Environmental and Economic Benefits of Solar Irrigation Systems

Solar irrigation systems provide numerous environmental and economic benefits. Environmentally, they reduce the consumption of natural resources such as water and fuel, thus minimising environmental degradation and air pollution. The use of solar energy also helps decrease greenhouse gas emissions and combat climate change.

Economically, solar irrigation systems are a sustainable and profitable investment in the long term. Although the initial investment cost is high, they offer substantial operational savings over time. They also enhance field productivity and improve crop quality, resulting in higher financial returns for farmers. This system is particularly beneficial in utilising lands across various regions, especially remote areas (such as deserts) where electricity is unavailable. Solar irrigation systems offer practical tools for controlling water flow, as electronic monitoring devices can provide real-time data on water levels in tanks, pump speeds, and well water levels. This can assist in making proactive management decisions to prevent excessive water usage remotely. The system is entirely independent of the power grid, operating all types of pumps directly during the day, and using stored solar energy in batteries at night to power submersible and surface pumps for irrigation [7].

C. Research Objectives

1. Automate plant irrigation using an electronic circuit.
2. Reduce water consumption.
3. Save time.
4. Save effort.
5. Lower costs.
6. Reduce electricity consumption.

D. Research Problem

Farmers face multiple challenges, including frequent power outages, which are essential for sustaining human life. This study, therefore, explores solar energy as an alternative power source. Additionally, farmers are burdened by fuel shortages, the high cost of fuel, and its environmental impact, such as greenhouse gas emissions and toxic byproducts from fuel combustion. Given the high cost and limited availability of fuel, which is subject to depletion, this project proposes a solar-powered irrigation system that requires only sunlight, making it economically viable.

Solar-powered sprinkler irrigation utilises mature solar energy generation technology, offering an environmentally friendly alternative to traditional energy systems that are both polluting and inefficient, thus simplifying the irrigation process.

E. Solar Energy Technologies

Solar energy technologies harness sunlight and heat to provide warmth, light, hot water, electricity, and even cooling for various residential, industrial, and agricultural purposes. Solar cells are semiconductors, sensitive to light, and are encased with a front and back electrical conductor.

Solar cells are made of thin silicon wafers with small impurities, creating a positive charge on one side and a negative charge on the other. The typical power output for a solar cell is around one watt. While solar cells can be manufactured from various materials, some are scarce or toxic to humans and the environment. Silicon, which is abundant, is the most commonly used material, although research continues to explore alternative, environmentally friendly materials. Solar cells are widely used in agriculture, industry, housing, and even in oil extraction.

II. Literature Review

1. A. Mahzabin, C. Alma Taziz, M. H. Amina, M. Gloria, and Md. S. R. Zishan

In this study, the authors analysed to implementation of a fully automatic irrigation system. Based on their analysis, the necessary decisions were made to create a practical system. The designed system showcases multiple features that can be applied in various ways as per user needs, making the system user-friendly.

2. S. Arun Prasath and S. Kannan

Sustainable and efficient agricultural practices have advanced significantly with the development of a solar-powered automatic irrigation system using Arduino Uno. This system integrates solar power, microcontroller-based automation, and advanced sensor technology to optimise irrigation. Through extensive testing and real-world deployment, the system demonstrated significant achievements and outlined a clear path for future enhancements.

3. J. Uddin, S.M. Taslim Reza, Q. Newaz, J. Uddin, T. Islam, and J.-M. Kim (2012)

This paper proposed and successfully implemented an automatic irrigation model using various circuits as illustrated. The system was designed with a focus on cost-effectiveness, reliability, an alternative energy source, and automated control. Given that the model is fully automated, it aids farmers by maintaining adequate water levels and preventing both under- and over-irrigation. Farmers can remotely control the motor on/off through mobile phones. Additionally, the system is password-protected for restricted user access. Solar power provides sufficient energy to operate the system, making it a viable alternative in overcoming electricity constraints and facilitating irrigation for farmers.

4. K. Kumar and B.D. Reddy (2023)

This research presents the design and implementation of a smart solar-powered irrigation system. This automatic irrigation design can be tailored to irrigate fields based on the type of crop being cultivated. The project addresses the pressing social issue of crop damage caused by wild animals and fires, for which there is currently no effective solution. This project holds significant social importance as it aims to protect orchards and fields, helping farmers avoid substantial financial losses and save them from unproductive efforts in field protection.

5. R. K. Megalingam and V. V. Gedela (2017)

This study discussed the feasibility of implementing a smart, solar-powered irrigation system. Tested in a lab, the system was planned to be deployed in a village in Coimbatore, India. The setup includes a solar panel, a moisture sensor, an Arduino microcontroller, and a battery. The energy requirements for the irrigation area are calculated, thus determining the number of solar panels, batteries, microcontrollers, wireless units, and moisture sensors needed.

6. U.K. Okpeki and A.O. Oyubu (2018)

This system was designed and implemented to monitor and automatically manage soil moisture levels in a specified area using a soil moisture sensor. The microcontroller, programmed in C language, reads the sensor values and displays the output on an LCD screen, in addition to controlling the water pump to irrigate the soil when moisture levels drop below the programmed threshold. The system operates autonomously without human intervention. Furthermore, since it is solar-powered, it is suitable for off-grid areas and eliminates the cost of electricity generation.

7. Jitesh Kumar (2019)

This automatic irrigation system activates when the soil moisture sensor detects water requirements. Various crops can be irrigated by simply pressing a button. The irrigation system measures crop moisture levels, which can also generate excess power.

8. J. Wanyama, P. Soddo, P. Nakawuka, P. Tumutegyereize, E. Bwambale, I. Oluk, W. Mutumba, and A.J. Komakech (2023)

This smart irrigation control kit is a low-cost, green technology that enhances irrigation accuracy, freeing users' time for other productive activities. The kit informs farmers of soil moisture conditions, providing real-time insights into farm status without requiring physical presence. The smart system operates a water pump and a microcontroller, all powered by solar energy.

Components of the Solar Irrigation System:

A. Solar Panels

Solar panels, also known as photovoltaic or PV panels, are the primary source of electricity generation by converting incident solar radiation into electric current [7]. A solar cell is a device that converts solar energy directly into electricity through the photovoltaic effect. It consists of a silicon layer with added impurities to provide electrical properties. The top layer facing the sun is doped with phosphorus to allow electron emission upon photon impact (designated as the N-layer), while the bottom layer is doped with boron to absorb electrons (designated as the P-layer). When sunlight photons hit the upper layer, electrons are energised based on the intensity of the sunlight. With an electrical conductor between the two layers, electrons move from the upper layer to the lower layer, generating current and voltage. Solar cells provide clean, renewable energy with an operational life of up to 30 years, although high production costs remain a barrier to widespread use [8].

B. Types of Solar Cells

- Monocrystalline Cells: These cells are cut from a single silicon crystal and have an efficiency ranging from 11 % to 16 %, which means they can convert 110 to 160 watts per square meter under direct sunlight near the equator. Though efficient, they are economically costly.

- Polycrystalline Cells: Made from silicon wafers scraped from cylindrical silicon crystals, they are chemically treated to improve electrical properties. They are less efficient (9–13 %) but more affordable.

- Amorphous Cells: Silicon is deposited in thin layers on glass or plastic surfaces, resulting in simpler manufacturing processes but with lower efficiency (3–6 %) and lower costs, suitable for low-watt applications (40 watts or less).

These cells are protected by an aluminium frame and paired diodes for electrical protection. When a collection of solar panels is arranged into a system, it is known as a photovoltaic array. Each panel typically consists of multiple interconnected cells within a single frame, with standard cell dimensions of 15.6 x 15.6 cm [9].

C. Control Unit

The control unit includes a power regulator and sensors for water level and other components. It serves two main purposes:

- Power Matching: Aligns the power requirements of the pump with the available energy from the panels.

- Pump Protection: Prevents damage by shutting down the electrical output when voltage falls too low or exceeds the pump's operational range, extending pump life and reducing maintenance needs.

D. Solar-Powered Pumps

Solar-powered pumps are categorized based on different variables as follows:

1. Classification by Electric Motor Type:

- AC Motor Pumps: Used in large projects, they are suitable for water treatment and circulation in swimming pools, seawater desalination, and drinking water projects [10].

- DC Motor Pumps: More efficient, with lower maintenance requirements and simpler circuits, these pumps are costlier than AC pumps and less readily available. They are ideal for medium and small projects, such as garden irrigation, livestock drinking water, and small-scale irrigation.

2. Classification by Pump Type

- Positive Displacement Pumps: Known as self-priming pumps, they lift water to higher levels with higher pressure but lower flow rate than dynamic pumps of equal power.

- Dynamic Pumps: These non-self-priming pumps, such as centrifugal pumps, are widely used for domestic water lifting, offering a high flow rate but lower lifting height than positive displacement pumps of the same power [11].

3. Classification by Installation Location

- Surface Pumps: Suitable for depths of up to 7 meters, placed at ground level with an intake pipe extending to the water source, ideal for river and reservoir water lifting.

- Submersible Pumps: Designed for deep-water sources such as wells, with most available models being multi-stage. They come with protective features to prevent damage from dry running and overload.

Practical experiments and economic studies suggest that the payback period for solar pumps compared to diesel pumps ranges from 3 to 5 years. Despite the continued support for conventional fuel in many Arab countries, policies are increasingly shifting towards clean energy as a replacement for polluting traditional energy sources. Solar tracking systems can also be added to improve pump efficiency by at least 30 % [12].

4. Localised Irrigation Networks (e.g., Drip Irrigation)

A localised irrigation network consists of the following components:

- Filtration Equipment: Filters and other devices for purification.

- Fertilizer Injection Equipment: For adding chemical fertilizers.

- Water Distribution Network: Comprising main and secondary pipelines, drip tubing, emitters, and specific fittings.

E. Advantages of Solar-Powered Irrigation Systems

1. Reduces CO_2 emissions: According to the Food and Agriculture Organization (FAO), solar irrigation systems can decrease greenhouse gas emissions per unit of energy used for water pumping by over 95 % compared to diesel-powered or fossil-fuel-based electrical systems.
2. Decreases electricity billing costs.
3. Lowers diesel expenses for electric generators.
4. Reduces maintenance costs for generators.

5. Saves time by eliminating the need for regular generator repairs.
6. Provides a reliable energy source unlike wind, which is inconsistent, making it challenging to depend on for isolated systems without a backup.
7. Supplies water for valleys and homes distant from urban areas and the public power grid.
8. Operates pumps automatically after sunrise or according to a pre-set schedule, reducing operating costs.
9. Simple installation without the need for cables connected to the main power grid.

   Solar energy is clean and does not pollute groundwater or the air, unlike fuel-based pumps [13].

F. *Disadvantages of Solar Pumps*

1. High Initial Cost: The initial setup cost of solar pump systems is relatively high.
2. Reduced Water Flow in Winter: Water flow from solar pumps decreases by approximately 30 % during winter due to lower energy production from the panels. Generally, there is a balance between the increased solar radiation in summer and the higher water demand. However, for drinking water systems, where demand is constant year-round, the system is designed based on winter output, with an unused surplus during summer.
3. Shading Constraints: The solar system site must be free from trees, tall buildings, or obstacles that could cast shadows, reducing panel productivity and leading to suboptimal use of the site area.
4. Complex Maintenance for DC Pumps: DC pumps are challenging to maintain and require specialised expertise, unlike conventional pumps, which have widespread support and readily available spare parts.

Notes and Evaluations from Experts and International Organisations on Using.

III. SOLAR POWER FOR IRRIGATION

- Economic Feasibility Evaluation: A thorough assessment of the economic feasibility of solar-powered irrigation systems should consider various factors, including system size, arrangement, water storage capacity, well depth, geographic distance, and soil type.
- Integration with Modern Irrigation Techniques: Solar irrigation should be integrated with modern irrigation techniques to conserve groundwater and increase irrigation and water productivity.
- Solar Irrigation Risk Mapping: There is a need to evaluate the impact, opportunities, and limitations of solar irrigation systems. Developing a nationwide risk map would help identify high-risk areas where shallow groundwater reserves could be impacted. Regulations should define permissible pumping depths based on actual groundwater levels and renewable water availability within each basin.
- Depth Control for Water Extraction: The depth of water extraction should be controlled according to the number of installed solar panels, indicating the pump's capacity. Satellite imagery and drone technology can be used to monitor the number of installed solar panels.
- Risks of Over-Exploitation of Groundwater: The absence of clear policies and regulations on solar-powered groundwater extraction may lead to groundwater depletion.
- Risk of Overuse Due to Lower Costs: Widespread adoption of solar irrigation could lead to over-exploitation of groundwater, as solar pumping is much cheaper than traditional diesel and electric pumps.

Given the above, water resource authorities in Iraq are encouraged to expand the use of solar-powered irrigation, especially in remote and desert areas with renewable groundwater resources. Since solar energy is available year-round, it is recommended to establish an administrative structure focused on utilising clean, renewable energy (wind and solar) for irrigation purposes [14].

Microcontrollers (Arduino):

Microcontrollers are small programmable computers capable of performing various functions, such as reading temperature, controlling an electric motor, or managing production lines in large factories. This evolution in electronic circuit and system design has shifted from reliance on hardware components to programmable commands that anyone can write and design. In short, a microcontroller is an integrated circuit with a compact size that allows for easy modification and adjustment at any time. For example, if you want to change something in your project, you can simply update the programming code on the microcontroller, test the new commands repeatedly, and achieve the desired objective [15].

Microcontroller Overview

Fig. 1. Arduino system

Microcontrollers contain all the basic components of a computer, including a processor, RAM, ROM, and input/output units. They are prevalent in various electronic devices, such as small toys, and dominate over 50 % of the market for microprocessor applications, with about 20 % being high-complexity digital signal processors. Some cars, for instance, contain more than 50 microcontrollers. Each microcontroller comprises a processor and additional components that perform specific functions. For simple electronic systems, multiple microcontrollers can be used to replace extensive hardware components, making microcontrollers the "executive manager" of electronic circuits and systems.

Programming Environment for Microcontrollers

Initially, microcontrollers were programmed only in assembly language, but now they support high-level programming languages. Their primary functions include:

- Issuing commands to all system elements.
- Receiving and analysing reports from monitoring systems, taking actions based on the analysis.

How Microcontrollers Work

Microcontrollers generally operate based on the Harvard Architecture, where the instruction memory and data memory are physically separate. They receive digital signals (0 or 1) or analogue inputs (in models equipped with an analogue-to-digital converter), outputting in digital form. Microcontrollers analyse the incoming signals—whether digital or analogue—and, based on the analysis, execute predefined commands programmed by the user. The microcontroller then issues these commands to other system elements as digital signals (0 or 1). This allows engineers or hobbyists to use the output to drive various components effectively.

However, microcontrollers alone are insufficient without additional components to create a specific system. For instance, most microcontrollers cannot output more than 5 volts. When controlling a component requiring a higher voltage, additional intermediary elements or circuits, such as transistors, relays, or specific integrated driver circuits, are needed. Moreover, sensors are often used to monitor environmental conditions, relaying information to the microcontroller in an electrical signal. For example, to monitor ambient temperature, a temperature sensor transmits readings to the microcontroller, and similar configurations apply to monitor humidity, fires, gases, and other surrounding conditions [16].

Characteristics of Microcontrollers

1. Compact size compared to traditional control circuits.
2. Easy maintenance in case of errors.
3. Flexibility in modifying operations by updating the programming code without rewiring.
4. Simple system monitoring, enabling fault detection at a glance.
5. Simplified circuit construction due to fewer components.
6. Low energy consumption.

In summary, microcontrollers have become integral to all automated and semi-automated systems and form a foundational part of many applications. They are accessible for use by both professional engineers and hobbyists, making them easy to learn and apply [17].

IV. Soil Moisture Sensor

The soil moisture sensor is typically used to detect moisture levels in soil, making it ideal for designing an automatic irrigation system or monitoring soil moisture levels.

The sensor consists of two main parts:

1. Electronic Board

The sensor includes a variable resistor to adjust the sensitivity of the digital output. It has two indicator LEDs: one for power and the other for digital output. The probe, made up of two prongs, detects the presence of water in the soil.

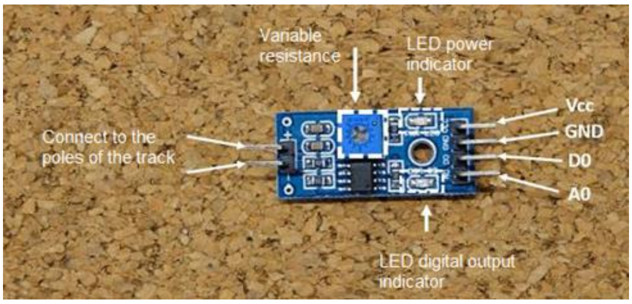

Fig. 2. Electronic Board

How the Sensor Works

The sensor's output voltage varies based on soil moisture levels:

- When the soil is wet, the output voltage decreases.
- When the soil is dry, the output voltage increases.

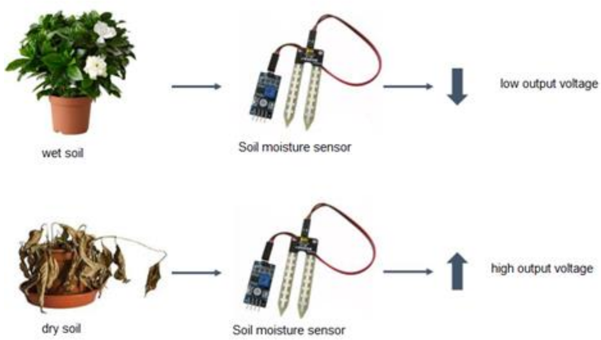

Fig. 3. The output voltage varies

The output can be a digital signal (D0) that reads LOW or HIGH, depending on soil moisture. If the soil moisture level exceeds a preset threshold, the unit provides a LOW output; otherwise, the output is HIGH. The digital threshold can be adjusted using the variable resistor. The output can also be analogue, ranging from 0 to 1023, providing a more granular measurement of soil moisture levels [18].

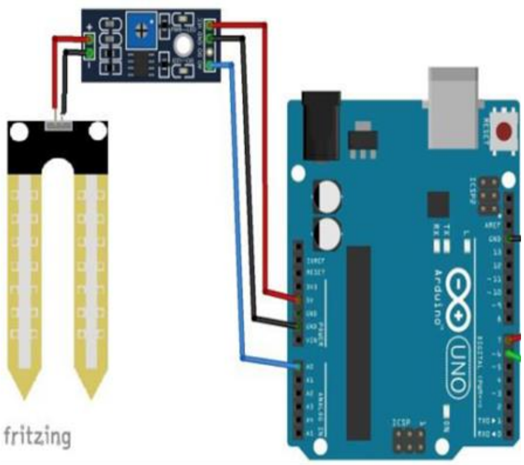

Fig. 4. Output a digital signal

V. Practical Implementation

A project utilising solar energy to power irrigation systems was implemented. Results indicated that this system could enhance irrigation efficiency and reduce water consumption by up to 40 %.

Additionally, new technologies have been developed to improve the performance of solar irrigation systems. For example, a system was developed that simultaneously powers pumps and desalination units using solar energy. This innovative and efficient system is designed to meet environmental sustainability goals and provide water conservation in arid regions.

VI. RESULTS AND CONCLUSIONS

After proper setup and performance monitoring, including water pumping, stopping, and tracking the soil moisture sensor and Arduino function, key benefits of this device were observed. It significantly reduces water consumption by 40 % in irrigation, a critical factor given that agriculture is the largest water consumer. Other advantages include optimising electricity usage, reducing the need for extensive piping, wires, and water pumps (whether fuel- or electric-powered), minimising labour, and reducing the time and effort required for conventional irrigation.

Operating solar-powered irrigation systems is a sustainable and efficient solution to improve irrigation efficiency and conserve water in agriculture. By using solar energy as the power source, reliance on conventional energy sources is minimised, enhancing environmental sustainability. Additionally, solar irrigation systems contribute to increased field productivity and improved crop quality. Leveraging these examples and innovations is essential to expand practical applications and promote environmental and economic sustainability in agriculture.

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