Construction and Performance Analysis of a Solar-Powered Automatic Soil Moisture Control System for Garden Applications

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Of

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Approval

This is to certify that the Project and Thesis work (ME-400) titled "Construction and Performance Analysis of a Solar-Powered Automatic Soil Moisture Control System for Garden Applications" Submitted by Sabbir Ahmad (ID: ME2202027174), Md. Shafiur Rahman (ID: ME2202027173), Al-Amin (ID: ME2202027146), Azmin Hossain (ID: ME2202027056), and Md. Rifatul Islam (ID: ME2202027295), has been duly approved by the examiners. This thesis fulfills a portion of the requirements for the award of the degree of Bachelor of Science in Mechanical Engineering at Sonargaon University, Green Road, Dhaka**.**

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DECLARATION

We, the undersigned, hereby solemnly declare that the work presented in this project has been exclusively carried out by us and has not been previously submitted to any university or organization for the award of any degree or certificate.

We further affirm that the work presented does not violate any existing copyrights.

Moreover, we undertake to indemnify the university against any loss or damage resulting from any breach of the aforementioned obligations.

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ABSTRACT

Efficient water management is a critical requirement in modern agriculture, especially in regions facing water scarcity and unreliable power supply. This project presents a solar-powered automatic soil moisture maintenance system designed to control irrigation for multiple agricultural fields independently. The system utilizes a solar panel with a charge controller and rechargeable battery to ensure continuous and eco-friendly operation without reliance on grid electricity. Three soil moisture sensors are deployed across three separate fields to continuously monitor soil water content. Each field is assigned a predefined moisture threshold of 70% respectively. A microcontroller processes the sensor data and activates the corresponding solenoid valve when the moisture level falls below the specified threshold. Once the required moisture level is achieved, the valve is automatically deactivated, preventing over-irrigation and water wastage. The proposed system operates autonomously, reduces manual labor, optimizes water usage, and supports sustainable agricultural practices. Its modular and scalable design makes it suitable for gardens, greenhouses, and agricultural fields, particularly in remote areas where conventional power sources are unavailable.

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CHAPTER -1

INTRODUCTION

1.1 Overview

Efficient water management is a major concern in gardening and small-scale agriculture. Traditional irrigation methods often waste water and require significant manual effort. To address these issues, this project implements a Solar Based Smart Gardening System that automatically waters plants based on soil moisture levels. The system uses soil moisture sensors to monitor the soil condition and activates a water pump only when irrigation is necessary. A 20W solar panel, solar charge controller, and 12V battery provide a renewable and uninterrupted power supply, making the system environmentally friendly and cost-effective. By automating the watering process, this system reduces human intervention, conserves water, and ensures optimal plant growth. It is suitable for home gardens, nurseries, and small farms, offering a sustainable solution for smart gardening.

For a variety of reasons, sustainable vegetable production prioritizes effective water utilization. The right amount of water application helps to maximize plant yield and quality while reducing the risk that plant nutrients will be washed away from the root zone. This reduces costs for farmers and can lead to high sediment loads that can harm public waterways through eutrophication and groundwater contamination (Brooks et al., 2016)[1]. Additionally, some producers discover that water use efficiency is crucial if water supplies are scarce or if they purchase municipal water (Schattman et al., 2023) [2]. A specific amount of moisture is needed, depending on the plant type. Since plants, among other things, rely on water, this is the case for the survival of others. All living creatures require water to survive. Even though water is relatively basic, its special qualities and capacity to take on various forms make it crucial to the numerous chemical processes that occur on Earth. The primary chemical process for physical life, photosynthesis, is one of these processes. By synthesizing compounds, the soil creates when carbon is present, plants can produce the necessary energy in carbon dioxide, water, and sunlight. This suggests that photosynthesis cannot take place in this process without the presence of these chemicals. As a result, for the plant to continually create energy, the soil around it must be consistently moist. People are frequently found outside of their homes because of their busy schedules. These days, the majority of them are still occupied with their jobs. Many plants and vegetables dry out because they frequently become so concentrated on one thing that they need to remember to do simple things like watering the plants (Bhateja et al., 2023)[3]. According to Rais & Scheoran's (2015) supply chain management study, India produced over 162.187 MT of vegetables and 81.285 MT of fruits in 2015, making up nearly 14.0% of the country's portion of the world's vegetable production [4]. In addition, Rais (2015) stated that it was clear that the supply chain is vital in the delivery of goods and services and the marketing of products, particularly agricultural products like vegetables. If not, enough vegetables are produced in a year, our economy will also be affected. If the supply of vegetables is low and the demand is high, it will cause a lot of damage to our economy. The prices of the products have a high chance of increasing, resulting in us needing help buying them due to their high cost and low supply. Many people in Mindoro are very worried because the general problem in our province is its electricity. Most of the household water supply in Mindoro is connected to electricity, which causes plant and vegetable owners to worry about its high price and sudden, unnoticed brownouts. An automatic plant watering system has benefits that go beyond utility. The technology the researchers created may help save money on electric bills while promoting electric conservation [5].

1.2 Problem Statement

This study aimed to create a solar-powered automatic plant watering system with a moisture sensor using Arduino Uno; it sought to answer the following questions: (1) What is the level of effectiveness of the Solar-Powered Automatic Plant Watering System with Moisture Sensor Using Arduino Uno in terms of convenience and detecting moisture levels of the plant's soil? (2) Is it effective to use the 5V relay, module, solar, and Arduino Uno to water the plant automatically? (3) Is the soil moisture sensor accurate in sensing if the soil is dry or wet? (4) Is there a significant difference between automatic watering systems and manual watering of plants in terms of the time it takes to water them and the height of the plants? Significance of the Study - The study aims to create a solar-powered automatic plant watering system with a moisture sensor using an Arduino Uno. The system seeks to efficiently maintain an optimal moisture level for plants, ensuring consistent growth and maximum productivity. The study's results will benefit the following: This study will also be valuable for the environment. Effectively using this technology to plant many trees and plants will benefit our society because we are promoting water conservation and helping the environment become greener and healthier. For individuals, this study offers valuable assistance in maintaining the health of their plants and ensuring they get watered promptly and effectively. By implementing the findings of this research, they can ensure their plants receive the optimal care they deserve, resulting in a flourishing and vibrant garden. This study helps institutions provide a well-maintained and attractive landscape. The study ensures that the right amount of water is delivered to the plants, promoting healthy growth and reducing the amount of water wasted. Additionally, they save time and effort for maintenance staff, enabling them to allocate their resources efficiently. This study saves time for farmers and other landowners and helps conserve water. It ensures that their crops are hydrated in a timely and efficient manner. Watering your crops efficiently can maximize crop yields while lowering water bills. It can also monitor and regulate practically all aspects of irrigation using an automated irrigation system. For future researchers, to advance this work and provide more information for researchers, both current and future. Researchers may concentrate on making this work more widely known to aid anyone interested in improving the environment. Scope and Delimitation of the Study - This study focuses on the primary goal of developing an automated solar-powered plant watering system that will assist people who plant vegetables and other plants who struggle to water them and need assistance. Because this works with solar, it applies to or is relevant to certain people, reducing their water expenses. An embedded system like this combines hardware and software to assist with a particular activity. The existence of every component can be advantageous to the system by constructing specific Arduino modules, resulting in an irrigation system that people can utilize. The scope of this study covers only the automatic plant watering system with a moisture sensor using Arduino-Uno. An automatic watering system provides more precise irrigation directly to the specific plant that needs to be planted well to reduce water loss due to evaporation or improper watering. It also intends to assist specific audiences, the public, and communities to ease gardening work. This study covers the efficient and effective watering of plants and crops using this Arduino-based watering system. The watering system was tried out using the Munggo plant. This watering system can be used for farming, household gardens, or even simple houseplants. It excludes larger farm territories like ranches and intensive agriculture from the beneficiaries of this system because it can only cover a limited area and a limited water source for it to function. Also, the device has yet to develop an alarm system to detect if the water has run out, so the user must check if the water needs to be refilled manually. This constraint makes it challenging to operate consistently, especially on the aforementioned large farms; it will need hundreds of these before it can cover larger farm territories or a larger garden than usual. This study was conducted during S.Y. 2023-2024.

Conventional gardening and small-scale agricultural irrigation rely heavily on manual watering, which is often inconsistent and inefficient. Overwatering or underwatering can lead to poor plant growth and wastage of water. Moreover, frequent human intervention is required, making it time-consuming and labor-intensive. There is a need for a system that can automatically monitor soil moisture and provide water to plants only, when necessary, while being cost-effective and environmentally friendly.The proposed solution is a Solar Based Smart Gardening System that uses renewable energy and soil moisture sensors to automate irrigation, ensuring plants receive the optimal amount of water without human intervention.

1.3 Objectives

The objectives of this project are:

- To design and develop a solar-powered automatic gardening system for efficient water management.
- To implement soil moisture sensors to monitor soil conditions in real-time.
- To automatically control water supply based on soil moisture readings.
- To utilize renewable solar energy for sustainable and uninterrupted system operation.
- To reduce human effort and water wastage in gardening and small-scale agriculture.
- To create a cost-effective and reliable solution suitable for home gardens, nurseries, and small farms.

1.4 Project Methodology

The methodology of this project describes the systematic approach used to design, develop, and implement a solar-powered automatic soil moisture control system for multiple agricultural fields.

1.4.1 System Planning and Requirement Analysis

- Identify the need for an automated irrigation system using renewable energy.
- Determine system requirements such as power source, number of fields, moisture thresholds, and control mechanism.
- Select appropriate moisture levels (70%) for three different fields based on crop requirements.

1.4.2 Solar Power System Design

- Design a solar power unit consisting of a solar panel, charge controller, and rechargeable battery.
- Calculate power requirements of sensors, microcontroller, and solenoid valves.
- Ensure stable and continuous power supply from the battery to the entire circuit.

1.4.3 Hardware Component Selection

- Choose a suitable Arduino for data processing and control.
- Select three soil moisture sensors for real-time soil condition monitoring.
- Use relay modules to safely interface the microcontroller with solenoid valves.
- Select appropriate DC solenoid valves for controlling water flow to each field.

1.4.4 Circuit Design and Integration

- Design the complete circuit connecting the solar power unit, microcontroller, sensors, and relay-controlled solenoid valves.
- Ensure proper voltage regulation and isolation between control and power sections.
- Assemble and integrate all components on a stable platform.

1.4.5 Software Development

- Develop firmware to:
    - Read analog values from soil moisture sensors
    - Convert sensor data into moisture percentage
    - Compare readings with predefined thresholds
    - Activate or deactivate solenoid valves accordingly
- Implement independent control logic for each field.

1.4.6 System Operation and Control Logic

- Continuously monitor soil moisture levels for all three fields.
- If moisture level falls below the set threshold:
    - Activate the corresponding solenoid valve
- If moisture level exceeds the threshold:
    - Deactivate the valve automatically
- Ensure uninterrupted operation using battery-backed solar power.

1.4.7 Testing and Calibration

- Calibrate soil moisture sensors for accurate percentage readings.
- Test the system under different soil moisture conditions.
- Verify correct activation and deactivation of each solenoid valve.
- Perform power system testing for day and night operation.

1.4.8 Performance Evaluation

- Evaluate water usage efficiency and system responsiveness.
- Analyze reliability of solar power supply and battery backup.
- Assess system stability under continuous operation.

1.5 Quality Preservation

Quality preservation in agriculture is essential to ensure healthy crop growth, optimal yield, and efficient use of resources. The proposed solar-powered automatic soil moisture control system plays a significant role in maintaining soil and crop quality by delivering precise and timely irrigation.

The system continuously monitors soil moisture levels using calibrated sensors and maintains predefined moisture thresholds of 70% for three independent fields. By preventing both under-irrigation and over-irrigation, the system preserves soil structure, nutrient balance, and root health. Excess water, which often leads to nutrient leaching, soil erosion, and root diseases, is effectively avoided through automatic solenoid valve control.

The use of solar energy ensures uninterrupted operation and eliminates fluctuations caused by unreliable power supply, thereby maintaining consistent irrigation quality. Independent field control allows different crops to receive water according to their specific moisture requirements, further enhancing crop quality and uniform growth.

1.6 Optimization Techniques and Scale-Up Considerations

To enhance the performance, efficiency, and reliability of the solar-powered automatic soil moisture control system, several optimization techniques are incorporated:

- Efficient Water Usage Optimization: Precise soil moisture thresholds (70%) ensure that water is supplied only when required, minimizing water wastage and preventing over-irrigation.
- Power Consumption Optimization: The system is designed to operate on low-power components. The microcontroller and sensors consume minimal energy, while solar charging with battery storage ensures optimal energy utilization throughout day and night.
- Independent Field Control: Each field is controlled separately using individual soil moisture sensors and solenoid valves. This localized control optimizes irrigation based on specific crop requirements rather than applying uniform watering.

- Sensor Calibration and Filtering: Calibration of soil moisture sensors improves measurement accuracy. Software filtering reduces noise and prevents unnecessary valve switching, enhancing system stability.
- Duty-Cycle Control of Solenoid Valves: Controlled valve activation intervals reduce mechanical wear, extend valve lifespan, and optimize water flow regulation.
- Efficient Solar Energy Harvesting: The charge controller optimizes battery charging, protecting against overcharging and deep discharge, thereby improving overall system efficiency.
- Modular System Architecture: The system can be expanded by adding more soil moisture sensors and solenoid valves, allowing easy scaling to multiple fields or zones.
- Higher Capacity Solar and Battery System: Scaling up requires larger solar panels and higher-capacity batteries to support increased load from additional sensors and valves.
- Advanced Control Units: More powerful microcontrollers or distributed controllers can be used to handle large-scale sensor networks efficiently.
- IoT Integration: Wireless communication (Wi-Fi / LoRa / GSM) can enable remote monitoring, data logging, and centralized control for large farms.
- Water Distribution Infrastructure: Proper pipeline sizing, pressure regulation, and filtration systems are necessary to ensure uniform water delivery across expanded fields.
- Maintenance and Reliability: Scaled systems require regular sensor calibration, valve inspection, and battery health monitoring to maintain long-term performance.
- Cost and Economic Feasibility: Cost-benefit analysis should be conducted to ensure the scalability remains economically viable for farmers and commercial users.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction

The advancement of smart irrigation and gardening systems has gained significant attention in recent years due to increasing water scarcity and the need for sustainable agricultural practices. Various studies have explored the use of soil moisture sensors, automatic irrigation controllers, and renewable energy sources, such as solar power, to optimize water usage and reduce human effort.

This chapter reviews existing research and technologies related to solar-powered automatic irrigation systems, soil moisture-based watering techniques, and intelligent gardening solutions. The review aims to identify the strengths and limitations of previous works, highlight technological gaps, and provide a foundation for the development of a Solar Based Smart Gardening System that is efficient, reliable, and suitable for home gardens and small farms.

2.2 Literature Review

Solar-powered systems are sustainable and environmentally friendly since they use the energy of the sun, which is a renewable resource. Automatic irrigation systems regulate water consumption by providing plants with the exact amount of water they require. Irrigation systems can use solar power as a decentralized and independent energy source, reducing the dependence on traditional grids, which makes it appropriate for isolated or off-grid agricultural regions. Since solar energy is a sustainable and clean substitute for fossil fuels, solar-powered irrigation systems can help reduce greenhouse gas emissions. Solar-powered automatic irrigation systems can be programmable and monitorable, creating ideal conditions for plant growth and increasing crop yields. Installing solar powered irrigation systems in rural regions can boost agricultural growth and farmers' standards of living. Many studies have proposed the use of sensor technology to track soil moisture content and weather patterns. Sophisticated algorithms and control systems have been proposed to improve water usage and ensure that crops receive the appropriate amount of water at the appropriate time. Researchers have investigated ways to make solar-powered systems more energy-efficient, such as better solar panel designs, energy storage options, and the incorporation of energy-efficient parts [6]. This study aimed at a multimodal approach to automate the agricultural sector. The entire system is solar-powered, ensuring a source of renewable energy. Throughout its useful lifetime, which can last up to 25 years, solar panel systems are extremely robust and require little to no maintenance. Human intervention can be reduced with automated irrigation equipment. This project provides farmers with an automated irrigation system that allows them to effectively irrigate their farmland. The project is divided into three components: a solar panel, an automatic pump control system, and an automatic irrigation system that uses a moisture sensor. The solar panel collects solar energy to convert and produce electricity to operate the automatic pump control system. The microcontroller receives input from the moisture sensor. If the soil moisture content drops below a set threshold, the system automatically activates the pump. When the water level returns to normal, the pump automatically turns off [7]. As solar-powered pumping systems are environmentally friendly, their application in irrigation has increased. In a pressurized irrigation system, a small 1 HP Photovoltaic (PV) pump can be used to irrigate water. According to experimental findings, the pump can effectively run sprinklers and drippers for good irrigation uniformity. In [8], a concise review was presented to understand the current state of automation in agriculture. In [9], a smart agriculture management and monitoring system was proposed, using wireless sensor networks. In [10], the integration of transaction-based systems with IoT in smart grids was explored, highlighting how the combination of connectivity and decentralized energy management can enhance efficiency and decision-making. This study emphasized the role of real-time data exchange in enabling dynamic and automated energy transactions. In [11], a comprehensive literature review on solar water pumping technology was presented, assessing its economic viability and identifying research gaps or obstacles to its wider adoption. Some PV-assisted water pumping systems have an investment payback period of 4-6 years. This review provides a detailed analysis of SPVWPS published between 1975 and 2014. In [12], the general classification of solar-powered water pumping systems was examined, along with the historical context of solar pumping systems, and significant research initiatives on related topics. This review analyzed and summarized studies on the modeling and dependability of PV water Pumping Systems (PVPS), highlighting a numerical approach to size them. The design process, the modeling approach, the control strategy, the availability of data, and site barriers, such as shadow effects, introduce difficulties in PVPS [13]. In [14], the focus was on the techno-economic study of solar-powered irrigation systems. In [15], the design of an Internet of Things (IoT)-based solar irrigation system was presented. The proposed system used a chip controller with built-in WiFi connectivity and a solar cell connection to provide the required operating power. To prevent the pump from overheating, the controller also examined the level of underground water. In [16], numerous problems were highlighted in conventional irrigation systems, including heavy water and electricity usage, along with complicated wiring. The application demonstrated that technology can save water, improve rice quality and output, and enhance the intelligence of irrigation systems. In [17], these points were improved with the help of a PLC-based intelligent irrigation management system and setup software. In [18], an automated irrigation system was developed to optimize water use in agriculture. The technology uses a distributed wireless network of temperature and moisture sensors in the root zone of the plant. In addition, a gateway device was used to provide data to an online application, control actuators, and handle sensor data. An algorithm built into the microcontroller-based gateway controlled the amount of water supplied, using temperature and soil moisture thresholds. In [19], a smart renewable energy irrigation system was developed using an algorithm to analyze soil conditions. A class consisting of several functions was created to allow users and the system to read any sensor and enable any actuator. For example, an instance of this class can monitor environmental variables such as temperature, humidity, and soil moisture. In [20], an automated smart irrigation system was proposed, which was connected to multiple sensors, such as DHT and soil moisture sensors, to monitor soil conditions and make decisions about whether to irrigate the farm. Fuzzy logic was used to automate irrigation, and Arduino served as the fundamental controller for all sensors and solenoid valves. According to this study, as the solar panel's voltage was insufficient to operate the pump and batteries to store solar power were expensive, only the Arduino was powered by a solar panel. In [21], the need for human intervention to open and close gates was reduced by deploying an automated IoTconnected gate through a wireless soil moisture sensor network using GSM . Nine soil irrigation events were used to test the system, which increased irrigation efficiency by up to 86.6%. Solar technology is employed in agriculture at a rapid rate. In [22], a conceptual paradigm for sustainable and inclusive solar irrigation was presented, focusing on ways to reduce costs and increase social access to solar irrigation. The objective is to make this technology environmentally sustainable and equal. This study offers a framework for supporting legislation, policy, and monitoring of solar irrigation initiatives that are economically and environmentally fair, based on examples and observations from various geographic locations. According to [23], government subsidies and decreasing manufacturing costs for PV equipment have popularized the technology and increased farmers' access and interest in it. The most important conclusion of this study is that the implementation of an integrated strategy in practice significantly increases the chance that PV programs will be successful. In [24], the use of PV electricity in an automated irrigation system was described, using a variety of sensors to determine the ideal amount of water for a particular crop and location. The system can irrigate the fields for a predetermined period of time on a specific day or days of the week. If the soil dries below a predetermined threshold, it can automatically water the field. In [25], smart irrigation systems were presented to deliver the right amount of water in the right place, reducing effort and saving time. The main goal of this project was to develop a circuit that uses an Arduino to monitor the water level in an agricultural field and automatically pump the necessary water in. The primary objective was to monitor and detect water levels in agricultural areas, particularly paddy fields. In [26], a solar-powered pumping system with a battery-buffered arrangement was introduced, reducing the total irrigation cost by 63%. The design and implementation process was made simpler by considering all internal and external interactions using the system modeling language. In [27], the tension of soil water was measured using a tensiometer adapted to resemble a manometer. This system enabled irrigation control with the help of a preprogrammed timer and estimated soil water stress. For an extended period, the circuits can be powered by a 12 V DC storage battery. In [28], a solar-powered irrigation system was developed to replace a diesel-powered irrigation system and reduce carbon dioxide emissions from agricultural sources. In addition, farmers who used solar-powered irrigation systems were shown to use fertilizers more efficiently. Solar drip irrigation, as suggested in [29], can simultaneously enhance tomato fruit quality and conserve water. This study used correlation and partial least squares analyses. Accumulated environmental stress impacts tomato fruit quality. Gains in fruit quality under drip irrigation were caused by combined environmental factors, including decreased soil water content, increased air and soil temperature, and the difference between day and night temperatures. In [30], it was shown that solar water pumping systems necessitate evaluating both financial and environmental sustainability and that regulations governing groundwater pumping must be linked to solar pumping subsidies. Solar irrigation plans must take into account groundwater availability and depletion. Data and monitoring are required to improve assessments of impacts on water resources. In [31], a model was developed to estimate the amount of water required for a given field over a given period of time. The model also included field-specific water consumption data that were stored in the cloud. When the soil moisture content fell below a predetermined level, a microcontroller in the soil moisture sensor turned on a pump. The model in [32] determined the amount of water required for irrigation, efficiently regulating water in cultivated fields. This model considered both changes in climate parameters and historical data and also imposed a threshold for data collection to save sensor energy. In [33], a cyber-physical intelligent agent was created for irrigation scheduling, which comprised perception, actuation, reasoning, and control systems. The heuristic was implemented in the reasoning system using crop modeling. The reasoning system forecasted the irrigation schedules with the highest water efficiency. In [34], an intelligent agriculture management system was developed to increase crop productivity and agricultural advantages by utilizing automation and the IoT. This system improved output and energy efficiency, reduced running expenses, and allowed remote control of the equipment.

CHAPTER-3

MATERIALS AND METHODS

3.1 Methodology

The methodology chapter outlines the design, development, and implementation process of the Solar Based Smart Gardening System. It describes the systematic approach used to achieve the objectives of the project, including selection of components, system design, sensor integration, and control mechanisms.

This chapter explains how the system monitors soil moisture levels and automatically operates the water pump using solar energy, ensuring efficient irrigation with minimal human intervention. It also details the experimental setup, hardware configuration, and workflow, providing a clear understanding of the steps involved in developing a functional and sustainable smart gardening solution.

3.1.1 Conceptualization and Design

The conceptualization of this project is based on the need for an automated, energy-efficient, and reliable irrigation system capable of maintaining optimal soil moisture levels for multiple agricultural fields. Traditional irrigation methods often lead to water wastage, uneven watering, and dependency on grid electricity. To address these limitations, a solar-powered, sensor-based irrigation control system has been conceptualized. The system is designed to operate entirely on renewable solar energy, where a solar panel charges a rechargeable battery through a charge controller. The stored energy supplies power to the microcontroller, sensors, and control circuitry, ensuring uninterrupted operation even during nighttime or low sunlight conditions. From a design perspective, the system incorporates three soil moisture sensors, each assigned to a separate field. Predefined moisture thresholds of 70% are selected to meet the specific irrigation requirements of different crops. A microcontroller continuously processes sensor data and compares it with the set thresholds. Based on this comparison, individual solenoid valves are activated or deactivated to regulate water flow independently for each field. Electrical isolation and safety are ensured through the use of relay modules between the low-power control unit and the high-power solenoid valves. The modular design allows easy expansion of the system by adding additional sensor–valve units without significant changes to the core architecture.

3.1.2 Material Selection

Materials were meticulously chosen to ensure optimal performance, durability, and cost-effectiveness. Solar Panel: Monocrystalline or polycrystalline 12V/20–50W solar panel. Reason: Provides renewable energy, efficient power generation, and long service life. Charge Controller: 12V/10A PWM or MPPT charge controller. Reason: Protects the battery from overcharging or deep discharge and ensures stable charging. Battery: 12V, 7–12Ah rechargeable lead-acid or lithium battery. Reason: Stores energy for nighttime or cloudy conditions and provides uninterrupted system operation. Control Unit Microcontroller: Arduino Uno. Reason: Supports multiple analog sensor inputs, easy programming, low power consumption, and sufficient GPIOs for relay control. Relay Module: 5V relay module. Reason: Safely switches high-current solenoid valves using microcontroller logic.Soil Moisture Sensors: Capacitive or resistive soil moisture sensors. Reason: Capacitive sensors preferred for accuracy, durability, and resistance to corrosion; measure soil water content continuously. Quantity: 3 sensors, one per field. Actuators Solenoid Valves: 12V DC solenoid valves (normally closed type) Reason: Provides precise on/off water control; energy-efficient; suitable for low-pressure irrigation. Quantity: 3 valves, one per field.

3.2 Experimental Setup and Equipment

Fig 3.1: Experimental Diagram of proposed System

3.3 Experimental Equipment

- Solar Panel
- Battery
- Charge Controller
- Arduino Uno
- Relay
- Plastic Pipe
- LCD 1602
- Solenoid Valve

3.3.1 Solar Panel

A solar panel is a device designed to convert sunlight into electricity. It achieves this through the photovoltaic effect, utilizing numerous solar cells, typically made of silicon, to absorb solar energy and generate direct current electricity. This DC electricity is then transformed into alternating current by an inverter, making it suitable for powering homes, businesses, and various other electrical systems.

Key aspects of solar panels include:

- **Placement:** They are commonly installed on rooftops or in open areas to maximize exposure to sunlight.
- **Energy Source:** Solar panels provide a clean, renewable energy source, helping to reduce reliance on fossil fuels.
- **Economic Benefit:** Their use can lead to lower electricity bills.

- **Energy Storage:** In some systems, batteries are integrated to store excess energy, ensuring power availability during periods of low sunlight, such as at night or on cloudy days.

Fig 3.2: Solar Panel

Key feature of solar panel :

- **Power Output (Pmax):** 20 Watts
- **Voltage at Max Power (Vmp):** ~18V - 18.2V
- **Current at Max Power (Imp):** ~1.1A - 1.12A
- **Cell Type:** Monocrystalline or Polycrystalline
- Charging 12V batteries (cars, boats, RVs)
- **Efficiency:** Around 22% for high-quality monocrystalline models.

3.3.2 Relay

A relay is essentially an electrically controlled switch. It uses a small electric current to manage much larger currents. When voltage is applied to its coil, small current flows, which then moves the contacts to allow a larger current to pass to an electrical device. Relays act like remote-controlled switches, turning circuits on or off based on outside electrical signals.

The idea behind a relay in electronics is similar to a relay race: a signal is received and then passed on to another part by flipping a switch. For example, when you press a button on a TV remote, it sends an electrical signal that triggers a relay in the TV, turning it on.

Key features of relays:

- **Purpose:** They are vital for safely controlling high-power circuits using low-power signals.
- **How they work:** An electrical signal to a coil creates a magnetic field, which physically moves switch contacts to either close or open a circuit.
- **Flexibility:** Relays come in many types, designed for different amounts of current and for controlling multiple circuits at once.
- **Uses:** They are common in many electrical and electronic systems, from simple electronics to complex industrial controls.

Fig3.3: Relay

3.3.3 Battery

A 12V 7A rechargeable battery is a common power storage unit for backup and solar systems. Its durable plastic casing protects the internal components, which typically include lead plates in an electrolyte solution for lead-acid batteries. More advanced types use gel or fiberglass mats, making them spill-proof and resistant to vibration and temperature changes.

Key features of Battery:

- **Voltage** → 12 Volts (nominal output).
- **Capacity** → 7 Ampere-hours (Ah), supplies 7A for 1 hour or 1A for 7 hours.
- **Type** → Lead-acid (SLA/VRLA), Gel, AGM, or Lithium-ion.
- **Design** → Sealed, spill-proof casing; maintenance-free.
- **Durability** → Resistant to vibration, shocks, and temperature changes.
- **Applications** → Widely used in UPS, solar systems, emergency lights, and backup power.

Figure 3.4: Battey 12V, 7A

3.3.4 Charge Controller

A solar charge controller is essential for solar power systems, regulating the flow of electricity from solar panels to the battery. It safeguards the battery by preventing overcharging and deep discharging, thereby extending its lifespan. This device monitors the battery's voltage and adjusts the power received from the solar panels accordingly. There are two primary types:

- **PWM controllers:** These are generally more affordable and suited for smaller systems. They reduce the power supplied to the battery as it becomes fully charged.

- **MPPT controllers:** These are more efficient and designed for larger systems. They optimize power output by matching the voltage of the solar panels to that of the battery.

  Contemporary charge controllers offer several advanced features:
- **Connectivity:** Options include displays, LEDs, or wireless connectivity (Wi-Fi/Bluetooth) for monitoring and remote control.
- **Load Control:** The ability to switch connected devices on or off based on the battery's charge level or a pre-set schedule.

- **Protection Mechanisms:** Safeguards against issues like short circuits, reverse polarity, overheating, and overcurrent.

Effective power management through a solar charge controller enhances battery longevity, overall system health, and energy efficiency across all types of solar installations.

Figure 3.5: Solar Charge Controller

3.3.5 DC Solenoid Valve

A DC solenoid valve is an electrically operated valve that uses a DC-powered electromagnetic solenoid to control the flow of liquids (in this case, water). When the solenoid is energized, it creates a magnetic field that moves a plunger, opening or closing the valve.

Figure 3.6: DC Solenoid Valve

Working Principle :

1. In the normally closed (NC) type (commonly used in irrigation), the valve remains closed when no power is applied.
2. When DC voltage is applied to the solenoid, the plunger is pulled by the magnetic field.
3. This opens the valve, allowing water to flow through the system.
4. Once power is removed, a spring returns the plunger to its original position, stopping the water flow.

3.3.6 Arduino Uno

The Arduino Uno is a small, versatile microcontroller board using the ATmega328P chip. It's great for projects needing automation, data collection, or control, especially where space is tight. It offers similar functions to the Arduino Uno but in a smaller package.

Key features:

- **Processor:** ATmega328P
- **I/O Pins:** 14 digital, 6 analog
- **Clock Speed:** 16 MHz
- **Connectivity:** USB for programming and power
- **Voltage Regulation:** Onboard regulator

- **Programming:** Uses the Arduino IDE for easy code uploading to control components like sensors, motors, LEDs, and relays.
- **Communication:** Supports I2C and SPI for connecting to various modules.
- **Applications:** Suitable for sensor monitoring, robotics, and IoT projects due to its size, low power use, and adaptability.

- **Accessibility:** Cost-effective with strong community support, good for beginners and experts.

Figure 3.7: Arduino Nano

3.3.7 Soil Moisture Sensor

A soil moisture sensor is an electronic device used to measure the water content of soil. It provides real-time data on whether the soil is dry, optimal, or saturated, which can be used to automate irrigation systems.

Figure 3.8: Soil Moisture Sensor

Types of Soil Moisture Sensors

1. Resistive (Conductive) Sensors
   - Measure the resistance between two probes inserted into the soil.
   - Higher water content → lower resistance; lower water content → higher resistance.
   - Pros: Low cost, simple design
   - Cons: Corrosion over time, less accurate for long-term use
2. Capacitive Sensors
   - Measure the dielectric constant of the soil, which changes with water content.
   - Pros: Longer lifespan, corrosion-resistant, more accurate
   - Cons: Slightly higher cost than resistive sensors

For long-term projects like yours, capacitive sensors are recommended.

3. Working Principle

1. The sensor is inserted into the soil.
2. It reads the soil's water content and converts it into an analog voltage or digital signal.
3. The microcontroller (Arduino / ESP32) reads this signal and converts it to soil moisture percentage.
4. Based on the predefined threshold (e.g., 70%, the system decides whether to activate the solenoid valve or not.

3.4 Circuit Diagram

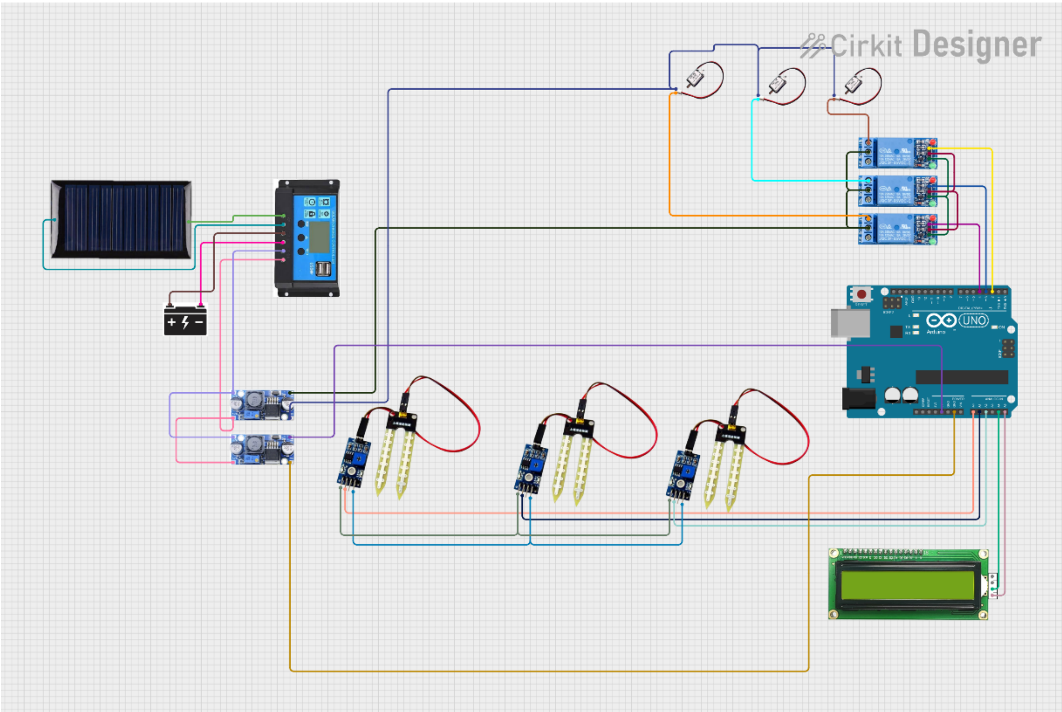

Figure 3.9: Circuit diagram of Proposed System.

In this circuit diagram using Arduino uno, soil moisture sensor, relay module, lm2596, solar panel, solar charge controller, Battery and solenoid valve. Here 3 soil moisture sensors connected with A0, A1, A2 pin of Arduino. LCD 1602 connected with A4 and A5 pin of Arduino. Relay module is connected with D2, D3, D4 Pin of Arduino.

3.5 Block Diagram

Here we included the block diagram of our proposed system and we also discuss about our every single block of this block diagram in bellow:

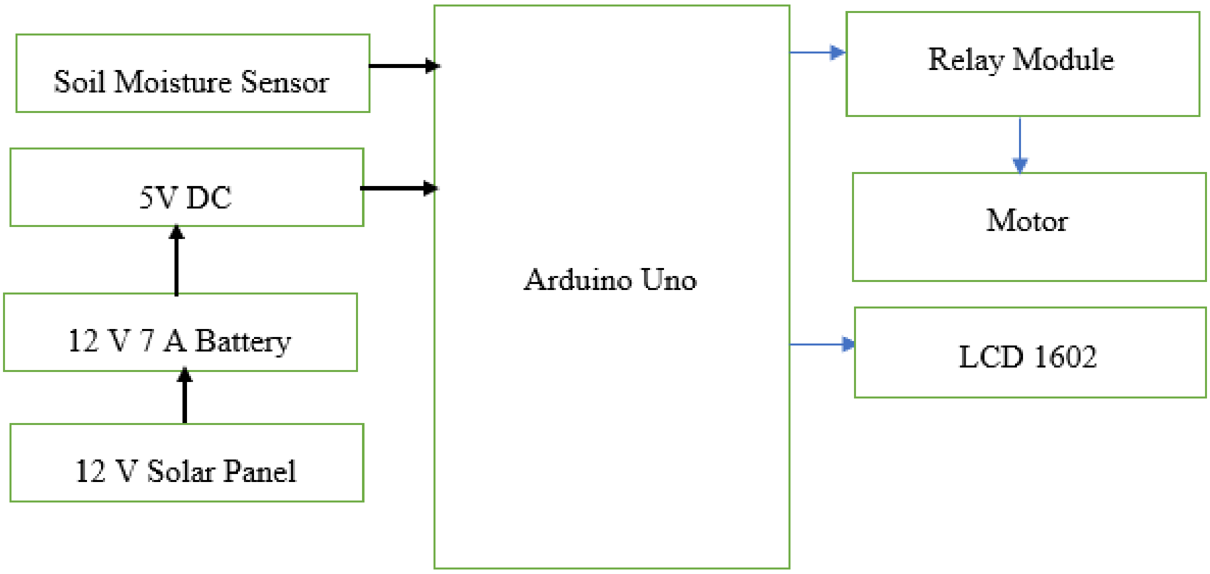

Figure 3.10: Block Diagram of Proposed System

In this block diagram, Soil Moisture sensors are the input of Arduino, Solar panel for power supply. LCD 1602 is the output from Arduino. Relay modules are the output from Arduino and Motor controlled via relay module.

3.6 Full overview

This is the Full overview of our Proposed system.

Figure 3.11: Front view of Project

Figure 3.12: Full Circuit of Proposed System.

Figure 3.13: Back Side of Proposed System.

3.7 Applications

- Home Gardens: Automatic watering ensures optimal plant growth with minimal human effort.
- Nurseries: Efficient irrigation management for a variety of plants and seedlings.
- Small Farms: Conserves water and reduces labor in small-scale agricultural setups.
- Urban Gardening: Suitable for rooftop and balcony gardens in cities.
- Educational Projects: Can be used as a practical example in engineering and environmental studies.
- Sustainable Agriculture: Promotes renewable energy use and smart irrigation practices.

➢ Greenhouses: Helps maintain soil moisture levels consistently for controlled environment farming.

3.8 Cost Analysis

Product Name	Quantity	Price	Total
Solar panel	1	980	980
Arduino Uno	1	850	850
Soil Moisture Sensor	3	100	300
LCD 1602	1	380	380
Relay Module 5V DC	3	100	300
Pipe	-	300	300
Solenoid Valve	3	800	2400
Battery	1	1190	1190
Solar Charge Controller	1	580	580
Buck Converter	2	120	240
Sun Board	1	450	450
Jar	1	350	350
Tub	3	30	90
Connecting Wire	Required	420	420
		Total=	**8830/-**

Table 3.1: Cost Analysis of used components.

CHAPTER - 4

RESULTS & DISCUSSION

4.1 Introduction

The Solar Based Smart Gardening System was tested under real garden conditions to evaluate its performance and efficiency. During experimentation, the soil moisture sensors accurately detected changes in soil moisture levels at different locations, triggering the water pump only when irrigation was required. Observations showed that the system maintained optimal soil moisture consistently, preventing both under-watering and over-watering. The use of a 20W solar panel and 12V battery ensured uninterrupted operation throughout the day, even during periods of variable sunlight, demonstrating the reliability of solar-powered automation. Performance analysis indicated that the system reduced manual watering efforts significantly, saving both time and labor. Water saving efficiency was observed to be substantial, as the pump only operated when necessary, leading to an estimated reduction of 30–40% water usage compared to conventional manual watering. Sensor response was found to be fast and consistent, providing timely activation and deactivation of the irrigation system. Overall, the results confirm that integrating soil moisture sensors with solar energy offers a practical and sustainable solution for smart gardening. The system not only enhances plant growth and health but also promotes water conservation and environmental sustainability. Minor limitations, such as dependency on sunlight and sensor calibration requirements, were noted and can be addressed in future enhancements to further improve performance and scalability.

4.2 Calculation

4.2.1 Solar Panel and Battery Charging Time Analysis

The system uses a 20-watt solar panel to charge a 12 V, 9 Ah rechargeable battery through a charge controller. The charging time of the battery depends on the energy capacity of the battery and the effective power supplied by the solar panel.

4.2.1.1 Battery Energy Capacity

The total energy stored in the battery is calculated as:

$$\text{Energy} = \text{Voltage} \times \text{Capacity}[35]$$
$$= 12\text{V} \times 9\text{Ah} = 108\text{Wh}$$

So, the battery can store 108 watt-hours of energy.

4.2.1.2 Effective Solar Power

Although the panel is rated at 20 W, due to losses in the charge controller, wiring, and environmental conditions, the practical efficiency is about 25%.

$$\text{Effective Power} = 20\text{W} \times 0.25 = 5\text{W}$$

4.2.1.3 Charging Time Calculation

The charging time is calculated as:

Charging Time = Battery Energy/ Effective Panel Power[36]

= 108Wh/5W

= 21.6 hours

Under ideal sunlight conditions, the 12V, 9Ah battery will be fully charged in approximately 21–22 hours.

In real outdoor conditions, where about 8 hours of strong sunlight is available per day, the battery will typically reach 40% charge in one day and become fully charged within 2.5 to 3 days.

Solar Voltage vs Time:

Table 4.1: Solar Voltage vs Time Table

Time	Solar Voltage
10:00	13
11:00	14
12:00	14.4
13:00	15
14:00	16
15:00	16.5
16:00	13
17:00	12

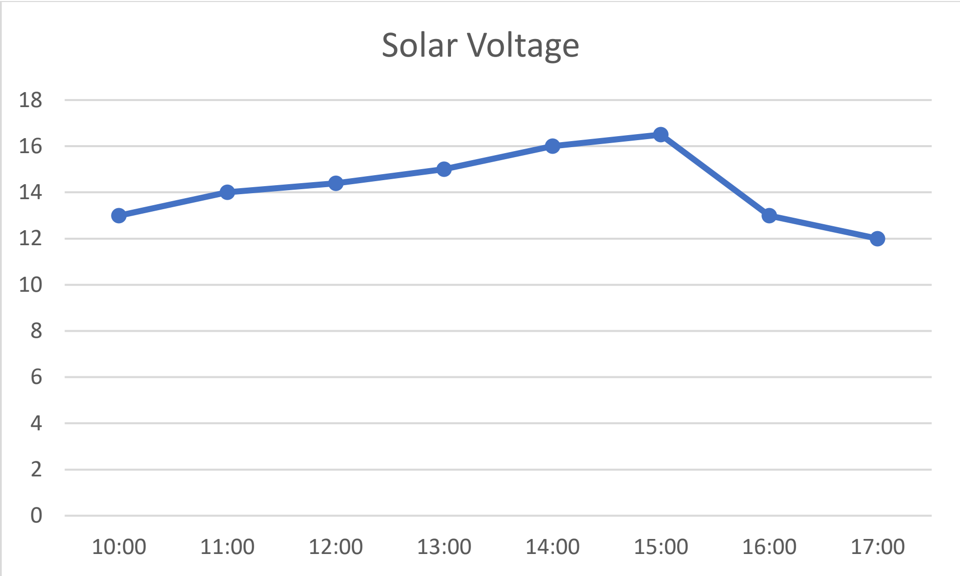

Figure 4.1 : Solar Voltage Vs Time Graph

Battery Backup Time for Solenoid Valves

The irrigation system uses three DC solenoid valves, each rated at 12 V and 0.30 A, and they are powered by a 12 V, 9 Ah battery.

Total Current Consumption :

The current drawn by one solenoid valve is 0.30A. For three valves operating simultaneously,

$$\text{Total Current} = 0.30A \times 3 = 0.90A$$

Battery Backup Time

The backup time of the battery is calculated as:

$$\text{Backup Time} = \frac{\text{Battery Capacity}}{\text{Load Current}}$$

$$= \frac{9\text{Ah}}{0.9\text{A}} = 10 \text{ hours}$$

Practical Operating Time

Considering battery inefficiency, wiring losses, and charge controller losses, approximately 80% of the battery capacity is practically usable.

$$10 \times 0.8 = 8 \text{ hours}$$

The 12 V, 9 Ah battery can supply power to three 12 V, 0.30 A solenoid valves simultaneously for approximately 7–8 hours.

4.2.2 Determining The Amount And Velocity of Water Discharged From The Reserve Tank

We took a beaker and a stopwatch. As soon as the sensor gave the signal of water discharge, we started the stopwatch. We placed the discharge pipe in the beaker. We measured the amount of water that had accumulated in the beaker at regular intervals.

The formula of flow rate is:

$$\text{Flow Rate} = \text{Volume/Time}$$

$$Q = V/T \text{ [37]}$$

Table 4.2 Amount of Water Accumulated vs Time

Volume (ml)	Time (sec)
5	12
10	25
15	38
20	48
25	62
30	73

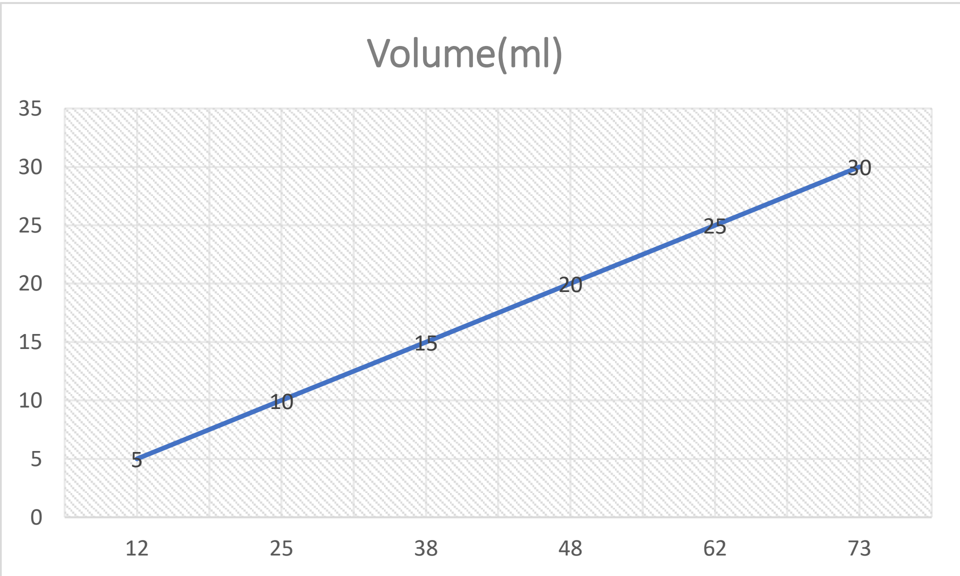

Figure 4.2: Volume vs Time Graph

1st part:

Volume10 ml =0.01 Li

Time 25 sec = 0.4167 min

∴ Flowrate Q_1 = 0.01/0.4167

=0.024 Li/min

2nd part:

Volume 15ml = 0.015 Li

Time 38sec = 0.633 min

∴ Flowrate Q_2 = 0.015/0.633

= 0.0237 Li/min

3rd part:

Volume 5ml = 0.005 Li

Time 12sec = 0.1945 min

∴ Flowrate Q_3 = 0.005/0.1945

= 0.025 Li/min

Average Flowrate = $(Q_1 + Q_2 + Q_3)/3$

= (0.024+0.0237+0.0257)/3

= 0.02423 Li/min

Water flow pipe diameter is 3 milimeter= 0.003 meter

Formula of velocity is:

Velocity = Flowrate/Flow Pipe Area

V = Q/A [38]

Area of Pipe:

Area $A = (\pi d^2) / 4$

$A = (3.1426 \times (0.003)^2) / 4$

$$A = 7.068 \times 10^{-6}\ m^2$$

1st Velocity,

$$V_1 = Q_1 / A$$

$$V_1 = 0.0000004 / (7.068 \times 10^{-6})$$

$$V_1 = 0.0566\ m/s$$

2nd Velocity,

$$V_2 = Q_2 / A$$

$$V_2 = 0.000000395 / (7.068 \times 10^{-6})$$

$$V_2 = 0.056\ m/s$$

3rd Velocity,

$$V_3 = Q_3 / A$$

$$V_3 = 0.000000423 / (7.068 \times 10^{-6})$$

$$V_3 = 0.061\ m/s$$

Average Velocity:

$$Vavg = (V_1 + V_2 + V_3) / 3$$

$$Vavg = (0.0566 + 0.056 + 0.061) / 3$$

$$Vavg = 0.0576\ m/s$$

Since solenoid valves operate only during irrigation cycles and not continuously, the actual daily battery backup will be significantly longer in real application.

4.3 Discussion

The Solar Based Smart Gardening System demonstrates several significant outcomes in terms of efficiency, sustainability, and convenience. By using soil moisture sensors, the system supplies water only, when necessary, effectively reducing water wastage and promoting efficient resource management. The integration of a 20W solar panel with battery storage ensures uninterrupted operation independent of the electrical grid, making the system environmentally friendly and cost-effective. Automation removes the need for manual watering, saving time and effort for gardeners, while the sensors and control mechanisms respond accurately to changes in soil moisture, ensuring optimal plant hydration. Although the system is designed for home gardens and small farms, it can be scaled up for larger areas by adding additional sensors and pumps. However, factors such as sensor placement, sunlight availability, and pump capacity can affect performance, requiring careful calibration. Overall, this project successfully combines renewable energy with smart irrigation technology, providing a practical, reliable, and sustainable solution for modern gardening practices.

CHAPTER – 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The Solar Based Smart Gardening System successfully demonstrates an efficient and sustainable approach to automated irrigation. By using soil moisture sensors, the system monitors soil conditions in real-time and ensures that plants receive water only when necessary, reducing water wastage and minimizing human intervention. The integration of a solar panel, charge controller, and battery allows the system to operate independently of the electrical grid, making it environmentally friendly and cost-effective. This project highlights the potential of combining renewable energy with smart irrigation techniques for home gardens, nurseries, and small farms. Overall, the system provides a practical, reliable, and sustainable solution for modern gardening practices, promoting water conservation and efficient plant care.

5.2 Future Scope

The Solar Based Smart Gardening System can be further improved and extended in the following ways:

- IoT Integration: Enable remote monitoring and control of the garden using smartphones or computers.
- Multiple Sensor Types: Incorporate additional sensors like temperature, humidity, and pH for more precise plant care.
- Water Flow Optimization: Implement a flow meter to monitor and optimize water usage.
- Mobile App Alerts: Provide notifications when water levels are low or maintenance is required.
- Larger Scale Applications: Adapt the system for larger farms and commercial agricultural setups.
- Data Logging & Analysis: Record soil and weather data to improve irrigation strategies over time.

5.3 Advantages:

- Water Conservation: Automatically waters plants only when necessary, reducing water wastage.
- Energy Efficiency: Solar power ensures eco-friendly and cost-effective operation.
- Automation: Reduces human effort by automatically monitoring soil moisture and controlling irrigation.
- Sustainable Gardening: Promotes the use of renewable energy for small-scale agriculture and home gardens.
- Reliability: Ensures consistent soil moisture levels for optimal plant growth.
- Scalable: Can be expanded for larger gardens or multiple zones by adding more sensors and pumps.
- Easy to Use: Simple design makes it user-friendly for gardeners without technical expertise.
- Educational value in demonstrating renewable energy and IoT concepts.

5.4 Disadvantages

The system presents several drawbacks:

- Dependence on Sunlight: The system relies on solar energy, so performance may reduce on cloudy or rainy days.
- Sensor Accuracy: Soil moisture sensors may require regular calibration for precise readings.
- Pump Capacity: Limited pump capacity may restrict the system's use for larger gardens or farms.
- Initial Cost: Solar panels, sensors, and batteries can increase initial setup cost.
- Maintenance: Regular maintenance of sensors, pump, and battery is required for consistent operation.
- Environmental Factors: Extreme weather conditions may affect the performance and durability of components.

5.5 Environmental Impact

- Automatic water supply based on soil moisture levels prevents unnecessary water wastage
- Using solar energy reduces electricity consumption and lowers carbon emissions.
- The absence of fossil fuel use helps reduce air pollution.
- Proper irrigation maintains soil quality and prevents overwatering
- The system supports long-term, eco-friendly, and sustainable garden practices
- Suitable for remote areas: These systems provide a sustainable irrigation solution in remote areas where grid electricity is not available.

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38 A Text Book of Fluid Mechanics And Hydrolic Macheniry by RS Khurmi

APPENDIX

```
#include <LiquidCrystal_I2C.h>


#define F1 A0

#define F2 A1

#define F3 A2


#define R1 3

#define R2 4

#define R3 5


LiquidCrystal_I2C lcd(0x3F, 16, 2);


void setup()

{

  pinMode(F1, INPUT);

  pinMode(F2, INPUT);

  pinMode(F3, INPUT);

  pinMode(R1, OUTPUT);

  pinMode(R2, OUTPUT);

  pinMode(R3, OUTPUT);


  digitalWrite(R1, LOW);
```

```
  digitalWrite(R2, LOW);
  digitalWrite(R3, LOW);

  lcd.init();
  lcd.backlight();
}

void loop()
{
  int F1_V = analogRead(F1);

  int F2_V = analogRead(F2);

  int F3_V = analogRead(F3);

  if (F1_V <= 70) {
    digitalWrite(R1, HIGH);
  }
  else {
    digitalWrite(R1, LOW);
  }

  if (F2_V <= 70) {
    digitalWrite(R2, HIGH);
```

```
}
else {
  digitalWrite(R2, LOW);
}

if (F3_V <= 70) {
  digitalWrite(R3, HIGH);
}
else {
  digitalWrite(R3, LOW);
}

lcd.setCursor(1, 0);
lcd.print("F1");
lcd.setCursor(7, 0);
lcd.print("F2");
lcd.setCursor(13, 0);
lcd.print("F3");
lcd.setCursor(0, 1);
if (F1_V < 10)
  lcd.print(" 0");
lcd.print(F1_V);
lcd.print("%  ");
lcd.setCursor(6, 1);
```

```
  if (F2_V < 10)
    lcd.print(" 0");
  lcd.print(F2_V);
  lcd.print("%  ");
  lcd.setCursor(12, 1);
  if (F3_V < 10)
    lcd.print(" 0");
  lcd.print(F3_V);
  lcd.print("%  ");
}
```