European Journal of Engineering and Technology Research
Vol 9 | Issue 3 | June 2024
ISSN 2736-576X

RESEARCH ARTICLE

A Cheap and Basic Solar-Powered Smart Irrigation System Proposal for Medium and Small-Scale Farming

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ABSTRACT

Nowadays, the need for water consumption for agricultural production is increasing. Economical use of water has become mandatory both to increase agricultural product yield and to eliminate the damage caused by excessive irrigation to the soil. Preferred instead of traditional irrigation, Drip irrigation, sprinkler irrigation, and pivot irrigation systems are now being replaced by "Smart Irrigation Systems" that save more water. In this study, a basic solar energy-supported mobile phone-controlled smart irrigation system, recommended for medium and small-scale agricultural enterprises, is proposed. In the study, the basic elements that make up the system, their approximate prices and circuit connection ways are shown. In the study, the cost, water, energy consumption, and payback periods of smart irrigation systems with traditional drip, sprinkler, and pivot irrigation methods were compared. As a result, although the initial investment cost in smart irrigation systems seems relatively high, it offers significant advantages in terms of resource efficiency and environmental sustainability. It is a fact that modern irrigation systems will make important contributions to national economies in the long term by increasing agricultural production and saving energy and water.

Keywords: Agriculture, New technology, Smart irrigation, Solar energy.

Submitted: April 21, 2024
Published: June 10, 2024

10.24018/ejeng.2024.9.3.3174

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1. Introduction

Modern agricultural applications are applications that combine and enhance the computing power of digital technologies with traditional agricultural knowledge to increase agricultural productivity. These technologies require minimum manpower while solving water loss, weed problems, crop loss, pests, diseases and various environmental problems caused by agricultural activities. The main purpose of smart irrigation systems is to reduce production costs and therefore increase benefits.

It achieves this by saving water, energy, fertilizer, and chemicals in agricultural activities. The growth of agricultural crops, maintenance of the landscape, reduction of weeds, as well as watering of soils in dry areas or during seasons with less rainfall depend on irrigation [1].

Nowadays, we hear and will continue to hear many new concepts and terms, such as smart agriculture, digital agriculture, robotic agriculture, agricultural artificial intelligence, and automated agriculture.

Smart Agriculture is a new agricultural term that promises major innovations in food management and production. Smart Agriculture can be thought of as an evolution of the term Precision Agriculture. However, the equivalent of "Smart Agriculture" in the literature is the term "Smart Agriculture" [2].

In parallel with the increasing population in the world, the increasing food needs must be met through agricultural activities, which also means that the amount of water used for agricultural purposes will also increase significantly. This is why we will start to hear more about many new concepts and terms, such as smart agriculture, digital agriculture, robotic agriculture, agricultural artificial intelligence, and automated agriculture, which we mentioned above.

Irrigation water withdrawal from the subsoil is the primary cause of groundwater depletion worldwide. Agriculture currently accounts for 69% of global water withdrawals. This water is used primarily for irrigation but also includes water used for livestock farming and aquaculture. This rate can reach up to 95% in some developing countries [3].

Therefore, to meet the increasing food need and to produce agricultural products in a balanced and continuous manner, it is important to build irrigation facilities as soon as possible to meet the water needs of economically irrigable areas. What is equally important is to increase water efficiency in agriculture and to expand economical irrigation systems for this purpose.

In the world and our country, a large portion of the water used for irrigation for agricultural and landscape purposes evaporates before reaching its purpose or mixes back into the soil due to the inefficiency in the traditional methods and systems used in irrigation.

While in classical irrigation systems, an average of 4 liters of water is given per second to 1 hectare of irrigation area, only 1.2 liters of water is given in modern irrigation methods such as sprinkler and drip irrigation. Thus, 2/3 of water is saved. Increased productivity in agriculture with modern irrigation and diversification of production patterns lead to direct and indirect increases in farmer incomes. On the one hand, this situation serves the purpose of reducing poverty, which is one of the goals of rural development, and on the other hand, it prevents migration because it increases the standard of living [4], [5].

Especially in some parts of the world, modern water-saving systems need to be disseminated in order to reduce unnecessary use of water in agricultural production due to limited water resources [6].

Smart irrigation systems have various advantages over traditional irrigation methods. We can briefly list them as follows:

- *Provides Optimum Plant Growth:* Smart irrigation systems help optimize plant growth by providing sufficient irrigation at the right time, considering the type of plant produced, soil moisture level, and environmental factors. This provides higher yields with healthy, adequately grown plants in agricultural production compared to less precise drip irrigation systems.
- *Low Cost:* Although the initial investment in smart irrigation systems is higher than in traditional drip irrigation systems, they are more cost-effective in the long term, thanks to factors such as potential water savings and product quality improvement. In particular, the remote monitoring and control features of smart irrigation systems provide significant economic savings by reducing labor and maintenance costs over time.
- *Provides Water Savings:* Smart irrigation systems use sensors data analysis, and other technologies to reduce unnecessary water use, making water, one of the most important inputs of agricultural production, more economical. It is seen that it saves a significant amount of water compared to other irrigation methods and drip irrigation systems.
- *Precision Irrigation:* Smart irrigation systems could precisely deliver water to irrigation zones that vary depending on the plant type, thus preventing water waste and providing the optimum humidity level for plant growth. Although drip irrigation systems are also used in precision irrigation, they have a disadvantage compared to smart irrigation systems because they cannot be dynamically adjusted according to real-time environmental conditions.
- *Increases Water Efficiency:* Smart irrigation systems precisely determine when and in what quantity water will be used by using advanced technologies that can detect soil moisture sensors, weather data, and evaporation and transpiration rates. Since this process can be done with both fixed programs and manual adjustments, higher efficiency in water use is achieved compared to drip irrigation.
- *Remote Control and Monitoring:* Smart irrigation systems provide users with convenience, such as control and management of irrigation systems from anywhere by providing access via smartphone or computer. In this respect, smart irrigation systems provide ease of use and flexibility compared to traditional drip irrigation systems that require manual adjustments.

Among the irrigation methods used in agriculture, traditional irrigation, drip irrigation, pivot irrigation, and smart irrigation systems differ in terms of cost and payback periods. However, these costs and payback periods vary depending on many variables, such as the size of the agricultural enterprise, land conditions, access to water resources, product type, energy, and water costs. For this reason, a professional feasibility study service should be obtained when planning smart irrigation system investments, especially for large agricultural enterprises.

Traditional irrigation, drip irrigation, pivot irrigation, and smart irrigation systems are some of the methods used to meet agricultural irrigation needs. The costs, efficiency, and payback periods of these systems vary from each other and depend on various variables.

1) Traditional Irrigation:

Cost: Generally lower cost than drip and smart irrigation systems.

Payback Period: It generally has shorter payback periods than other modern irrigation methods. However, it may be more expensive in the long run due to water and energy costs.

2) Drip Irrigation:

Cost: The investment cost is moderate, especially due to pipes, drip irrigation hoses and other equipment.

Payback Period: Drip irrigation also saves time because it optimizes the use of water and fertilizer. Therefore, the return on investment in the medium term generally meets expectations.

3) Pivot Irrigation:

Cost: Pivot irrigation systems vary depending on the size of the agricultural area, equipment quality and features, energy, and water costs.

Payback Period: Pivot irrigation systems have an effective irrigation capacity for large agricultural areas. High

TABLE I: Cost, Energy and Water Consumption, and Payback Periods of the Systems

Category	Traditional irrigation	Sprinkler irrigation	Drip irrigation	Pivot irrigation	Smart irrigation
Installation cost	Medium	Medium-high	Medium-high	High	High
Operating costs	Medium-high	Medium-high	Low-medium	Medium-high	Low-medium
Energy usage	High	High	Low	High	Low
Water loss	High	Medium	Low	Medium	Low
Payback period	Long	Medium-long	Medium-long	Medium-long	Medium-long

system efficiency and optimum water use can shorten the payback period of the investment in the long term.

4) Smart Irrigation Systems:

Cost: Since these systems require relatively higher technology, they generally have high investment costs.

Payback Period: Smart irrigation systems save water and energy in the long term by optimizing water use thanks to sensors, data analysis, and IoT and Artificial Intelligence applications.

For all irrigation systems, costs and payback periods vary depending on the quality of the equipment used, the size of the irrigation area, water costs, energy costs, and other factors Table I. Therefore, a professional feasibility study will be needed before investing in irrigation systems.

2. Literature Review

Increasing water problems and rising agricultural labor costs direct farmers to new and cheap smart agricultural technologies. In this study, the automation of irrigation systems on farms is proposed. The proposed solution is based on the Internet of Things (IoT), which will be a cheaper and more precise solution to the farm's needs [7]. The fact that water is a scarce resource and the need to minimize excessive waste of such an important resource will also increase the demand for digital, smart agricultural practices. Studies have shown that it is possible to obtain more products by consuming less water with modern agricultural irrigation systems such as sprinkler, drip and smart irrigation systems [6], [8]–[10]. Many scientific studies conducted in recent years have touched upon the advantages of smart irrigation systems and shown how such systems affect crop yield and agricultural costs [11]–[13].

In a study, a smart irrigation system was examined during five-year field trials. The proposed low-cost smart irrigation system and the traditional irrigation system were compared in terms of cost and payback period. The results showed that the average water use efficiency increased from 4.09% (wheat) to 9.8% (sunflower). The payback period of wheat production has been reduced to 82 months under the proposed system [14].

In this study, an automatic irrigation system developed with IoT-based Smart Irrigation System, IoT Technology, and machine learning method using KNN algorithm was examined. The purpose of this system is to provide sufficient water needed by crops, taking into account soil moisture and climatic conditions, thus preventing over-and under-irrigation without the need for human intervention.

The system includes a GSM module, sending the field status to the farmer via SMS and saving the parameters to the cloud [15]. Many studies on IoT-based smart irrigation systems [13], [15]–[17] have yielded positive results in terms of plant savings and product efficiency [3], [6], [18]–[20].

In the study conducted by [21], ambient temperature and humidity consisting of sensing, data processing and actuators, and data received from the soil moisture sensor placed in the root zone were processed. As a result, an improvement of 62.5% and 67.5% was achieved for moisture and soil moisture, respectively.

In another study conducted by [11], a smart irrigation system based on smart sensors that can be used economically by integrating some electronic devices and smart irrigation system elements commonly used in the field of IoT was discussed. It is expected that the irrigation model proposed in the study will contribute to saving water use compared to the traditional irrigation method and to distribute water in a balanced manner without compromising production.

Studies conducted in recent years have shown that Internet of Things (IoT)-based smart irrigation management systems can help ensure optimal water resource utilization in precision farming practices. This study [22] proposes an intelligent system based on open-source technology to predict the irrigation requirements of a field using weather forecast data retrieved from the internet as well as sensing of ground parameters such as soil moisture, soil temperature, and environmental conditions. It has been stated that the information processing results of the three-week data obtained based on the algorithm proposed in the article are quite encouraging.

Recently, in agricultural applications, studies using the Internet of Things and Deep Learning approach have been seen in many areas such as disease detection, plant classification, land cover detection, precision animal husbandry, pest recognition, object recognition, smart irrigation, phenotyping and weed detection [18], [23]–[25]. In the study by [26], a proximal sensing system using a color camera for smart irrigation based on computer vision and deep learning is proposed to determine the water requirements of three soil texture classes under different lighting conditions. An imaging station was created to reduce the workload in obtaining the training images required for training deep convolutional neural network models, and the findings showed that deep learning has great potential in determining the irrigation needs of production areas under changing conditions.

When recommending Smart Irrigation Systems to farmers or medium and large-scale agricultural enterprises, one of the most important parameters to consider is cost [27]–[29].

However, the payback period of the Smart Irrigation System is also important depending on the type of product

HARDWARE COMPONENTS USED IN THE STUDY

Components	Technical Properities	Description
Solar Panel	Capacity	Varies depending on energy requirements; commonly 10 W to 100 W.
	Voltage	Typically 12 V or 24 V.
	Material	Monocrystalline or polycrystalline silicon.
	Efficiency	Around 15% to 20%.
Charge Controller	Current Capacity	Matches the current rating of the solar panels.
	Voltage Regulation	12 V or 24 V, matching the solarpanel voltage.
	Features	Overcharge protection, deep discharge protection, temperature compensation.
Battery	Capacity	Depends on the energy requirements and duration of backup needed.
	Voltage	Usually 12 V or 24 V.
	Type	Sealed lead-acid (SLA) or lithium-ion (Li-ion).
	Cycle Life	Higher cycle life for longevity.
GSM Module	Frequency Bands	Compatible with the region's GSM network.
	SIM Card Slot	Standard SIM or micro SIM.
	Communication Protocol	Typically supports AT commands.
	Power Consumption	Low power consumption for efficient operation.
Microcontroller or Controller Unit	Type	Arduino, Raspberry Pi, or similar microcontroller platform.
	Input/Output Ports	Sufficient ports for sensor connections and GSM module interfacing.
	Processing Power	Adequate for running control algorithms and GSM communication.
	Programming Language	C/C++, Python, or any compatiblelanguage for the microcontroller.
Sensors	Soil Moisture Sensor	Measures soil moisture levels.
	Temperature Sensor	Measures ambient temperature.
	Rain Sensor	Measures ambient humidity.
	Humidity Sensor	Detects rainwater to prevent unnecessary irrigation.
Water Pump	Flow Rate	Matches the irrigation requirements.
	Head	Sufficient to lift water to the desired height.
	Voltage	Typically 12 V or 24 V for compatibility with the system.
Valves and Sprinklers	Type	Solenoid valves for controlling waterflow.
	Coverage	Matches the area to be irrigated.
	Metarial	Durable and weather-resistant materials such as PVC orbrass.

grown, the size of the agricultural land and the irrigation system used.

Studies on cost, optimization, feasibility and payback periods have drawn attention to the importance of this issue and it is recommended that large-scale enterprises, especially large-scale enterprises, have a professional feasibility study done when investing in a Smart Irrigation System [5], [25], [30]–[32].

3. MATERIALS AND METHOD

3.1. *Basic Components of the Smart Irrigation System*

3.1.1. *Hardware Components*

Hardware components used in the study are presented in Table I.

3.1.2. *Software Components*

The following software components were used:

- *Embedded Software:* This includes the firmware that runs on the microcontroller. It manages sensor data, controls the irrigation system based on predefined algorithms, and communicates with the GSM module for remote monitoring and control.
- *Mobile Application or Web Interface:* Allows users to remotely monitor soil moisture levels, temperature, humidity, and manually control the irrigation system via GSM commands.

TABLE II: COMPONENT CONNECTION ORDER OF THE SYSTEM

Component	Connected to
Solar panel	Charge controller
Charge controller	Solar panel, battery
Battery	Charge controller
GSM module	Microcontroller
Microcontroller	GSM module, sensors, water pump
Sensors	Microcontroller
Water pump	Microcontroller

3.1.3. *Experimental Architecture*

The main components and connection relationships of a basic solar energy-supported mobile phone-controlled smart irrigation system are given in Table II.

This smart irrigation system design is one of the most widely used models as an automatic and remote controlled irrigation system depending on environmental conditions and user preferences. The operation of the system is as follows:

1. Solar panel produces electricity from sunlight.
2. The charge controller regulates the voltage and current from the solar panel to charge the battery efficiently.
3. The battery stores the energy produced by the solar panel to power the system at night or in low light conditions.
4. GSM module enables remote communication with the irrigation system via mobile networks.
5. The microcontroller serves as the brain of the system, collects data from sensors, controls the water pump and provides communication with the GSM module.
6. Sensors that detect the moisture and temperature of the soil and sensors such as rain sensors are responsible for providing data to the microcontroller.
7. The water pump draws water from a water source (such as a well, pool, water tank, stream, lake, pond) and distributes it through valves and sprinklers to irrigate the areas where it is needed Fig. 1.

3.2. The Cost Analysis of the System

The cost of a solar-powered GSM-controlled smart irrigation system can vary widely depending on several factors such as the quality of components, system capacity, brand preferences, and geographic location. Here's a rough breakdown of the costs for each component:

1. *Solar Panel:* The cost of solar panels can range from $1 to $3 per watt. For a system with a capacity of around 100 W, the cost would be approximately $100 to $300.
2. *Charge Controller*: A good charge controller might cost between $20 to $50, depending on its features and brand.
3. *Battery*: The cost of a suitable battery depends on its capacity and type. A 12 V sealed lead-acid battery of moderate capacity could cost around $50 to $100.
4. *GSM Module*: GSM modules vary in price depending on the brand and features. A basic GSM module can cost around $20 to $50.
5. *Microcontroller*: Depending on the type and brand, microcontroller boards like Arduino or Raspberry Pi can cost between $10 to $50.
6. *Sensors*: Soil moisture sensors, temperature sensors, humidity sensors, and rain sensors can range from $5 to $20 each, depending on quality and features.
7. *Water Pump*: The cost of a water pump depends on its flow rate and quality. A small water pump suitable for irrigation might cost between $20 to $50.
8. *Valves and Sprinklers*: The cost of valves and sprinklers depends on the size of the area to be irrigated and the quality of the components. This cost can vary significantly but might range from $50 to $200 or more for a basic setup.
9. *Additional Costs Include*:

- Wiring, connectors, and other miscellaneous hardware: $20 to $50.
- Installation and labor costs (if hiring a professional): varies widely depending on the complexity of the installation and local labor rates: $200 to $500.

TABLE III: Approximate Price List of the System Components

Component	Price range (USD)
Solar panel	100–300
Charge controller	20–50
Battery	50–100
GSM module	20–50
Microcontroller (MCU)	10–50
Sensors	5−20 (each)
Water pump	20–50
Valves and sprinklers	50–200
Additional costs	20–50
Installation and labor costs	200–500
Total cost	495–1370

In total, the approximate cost of a solar-powered GSM-controlled smart irrigation system can range from $495 to $1370, depending on the specific requirements and selected components (Table III).

It should also be noted that these are approximate price estimates and actual costs may vary from country to country and region to region.

It is recommended to research and compare prices from different suppliers to get the best deals on components. Additionally, when making purchasing decisions, it will be necessary to consider factors such as warranties, technical support and reliability [14], [27]–[29].

4. Results and Discussion

It is very important to consider the profound impact of smart irrigation systems in agricultural irrigation. These systems not only revolutionize water management but also provide significant advantages in energy efficiency and low cost.

To accurately calculate factors such as cost, productivity, and payback period, a comprehensive overview of aspects such as the size of the agricultural area, land topography, and crop variety will be required. The initial investment cost of smart irrigation systems will include the cost of sensors, controllers, pumps, installation costs, main processor, software and hardware costs, and if it will work with solar energy, the cost of elements such as solar panels, batteries, and converters.

In the study, the basic elements that make up the system, their approximate prices, and circuit connection ways are shown. In the study, the cost, water, and energy consumption, and payback periods of smart irrigation systems with traditional, drip, sprinkler, and pivot irrigation methods were compared.

These systems minimize water waste by precisely using the right amount of water at the right time and ensuring that agricultural products receive the moisture necessary for optimum growth. They also reduce energy consumption by streamlining irrigation processes, thus increasing overall efficiency.

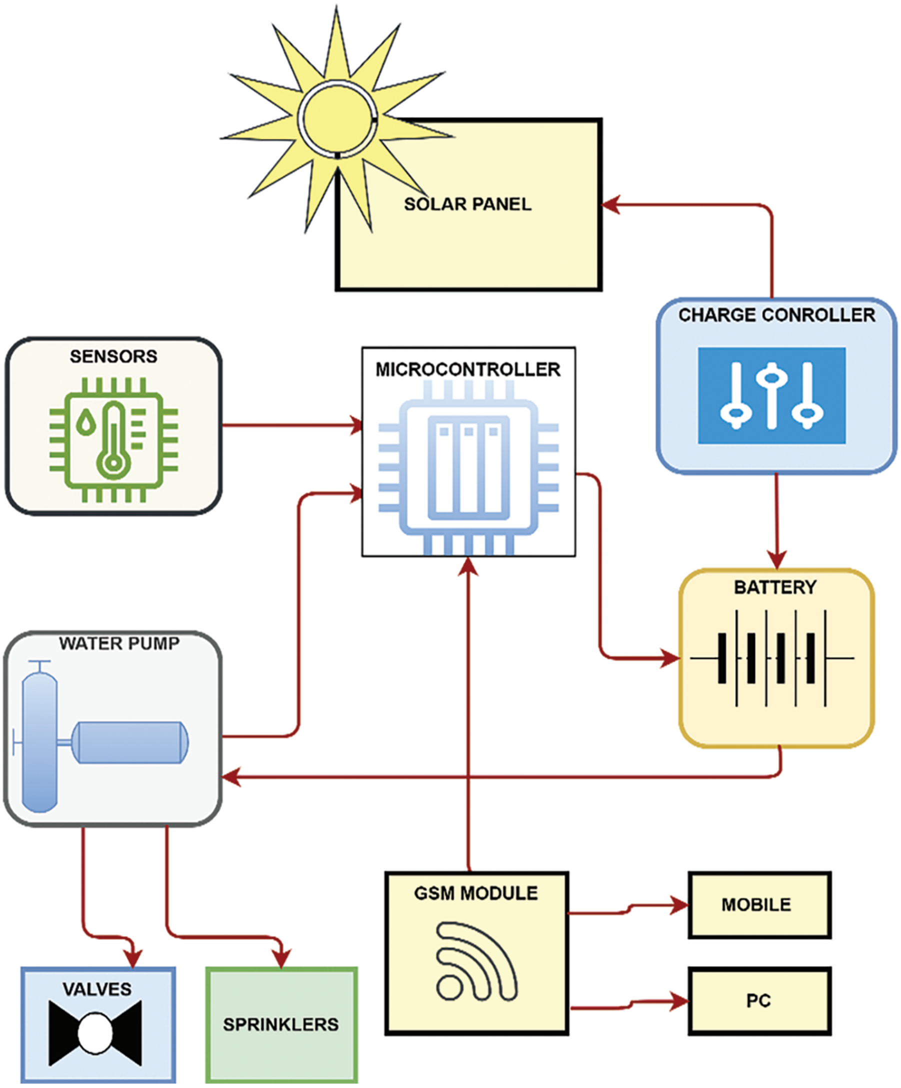

Fig. 1. Solar powered GSM controlled smart irrigation system architecture.

The payback period for investment in smart irrigation systems may vary depending on various factors such as initial investment, energy and water savings, crop yield, and market prices. Typically, farms realize significant savings in water and energy costs over time, contributing to a shorter payback period. Additionally, increased crop yields as a result of improved irrigation practices further accelerate the return on investment.

When evaluating the investment proposal of smart irrigation systems, a comprehensive cost-benefit analysis should be carried out, taking into account the specific requirements of your agricultural operation. As a result, although the initial investment in smart irrigation systems may seem expensive, it provides long-term advantages in terms of cost savings, resource efficiency and environmental sustainability.

The solar energy-supported smart irrigation system and its elements for small and medium-sized agricultural areas, presented as examples in the article, aim to give an idea and guide farmers. It is an indisputable fact that modern irrigation systems will contribute to the individual and public economy in the long term by increasing agricultural production efficiency and saving energy and water.

5. Conclusion

In this study, new technologies are proposed to protect the soil and increase agricultural product productivity by preventing unnecessary water use in agricultural production. The aim is to show farmers the ease of switching to modern irrigation systems, which are not very complex and expensive. Here, an exemplary solar energy-supported, mobile phone-controlled smart irrigation system with low cost and easy installation is proposed. The study aims to provide a projection for small and medium-sized farms by giving the approximate cost of the system, payback period and connection diagram of the elements.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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