

Design and Development of a Smart Automatic Irrigation System Using Arduino, Soil Moisture Sensor, and Soil Nutrient Sensor for Sustainable Agriculture

Sreevathsa BR¹
School of CS& IT,
JAIN (Deemed to be
University)
Bangalore, India
23bcar0134@jainuniversity.ac.in

Praveen Kumar K²
School of CS& IT,
JAIN (Deemed to be
University)
Bangalore, India
23bcar0117@jainuniversity.ac.in

Hruthik J³
School of CS& IT,
JAIN (Deemed to be
University)
Bangalore, India
23bcar0086@jainuniversity.ac.in

Sushma BS⁴
School of CS& IT,
JAIN (Deemed to be
University)
Bangalore, India
Bs.sushma@jainuniversity.ac.in

Abstract

To ensure crop is healthy, agriculture is largely reliant on effective irrigation and proportionality of nutrients in the land. However, a traditional irrigation system can simply lead to over-utilization of water and soil erosion and soil degradation. The design and development of a smart automatic irrigation network using Arduino Uno microcontroller with soil moisture and soil nutrient sensors are proposed in solving these problems.

The proposed system is a continuous regulation of soil diseases and an automatic turn on irrigation, the reduction in the moisture content of the soil to a certain level that is predetermined. In the meantime, the nutrient sensor would be involved in quantifying the degree of soil fertility that would be employed to correct the nutrient status to an equilibrium. With the help of this integration, one will be able to more accurately irrigate the fields and have greater control over the nutrients without applying the traditional methods.

The system can save approximately 3050 per cent of water and at the same time produce the best soil moisture and non-injurious decrease of nutrients as experiments reveal. The proposed system can be used in small farms, home gardens, and the educational environment due to its low cost, simplicity in designing, and implementation. One can also expect some future improvements as the use of the IoT to monitor, predictive irrigation through data analytics, and solar-powered automation are some other means of making the future more sustainable and efficient.

1. INTRODUCTION

Agriculture is essential in maintaining food security in the world and economic stability of most nations. Aggressive farming activities are necessary in order to satisfy the growing food consumption following the accelerating population growth. Effective management of water resources is one of the biggest difficulties in the agricultural field. The FAO estimates that almost three-quarters of the total freshwater is used in agriculture. Thus, farmers should enhance irrigation performance because it is the key to sustainable agricultural development.

The traditional systems of irrigation tend to be manualized in terms of monitoring and fixed irrigation schedules. Such practices often result in wasteful use of water since it is delivered irrespective of the reality on the ground. This leads to the excess or shortage of water on the crops. Excessive irrigation may cause erosion, loss of nutrients, and wastage of water whereas under-irrigation weakens the growth of plants and crop yields. Effective irrigation management is thus required in order to maintain the optimum soil moisture conditions and enhance crop production.

The recent improvement in embedded systems technology and sensor technologies has been able to promote the creation of smart irrigation systems that have the ability to monitor the soil conditions automatically and adjust irrigation systems. These systems have sensors that measure the real time environmental conditions and microcontrollers that decide, based on predetermined thresholds, whether or not irrigation should be turned on. As an illustration, Singh et al. designed a microcontroller-based irrigation system with soil moisture sensors which greatly helped in reducing the amount of water used as opposed to conventional irrigation system [1]. On the same note, Kumar et al. presented an automated irrigation system, which is based on the Arduino platform, which enhances water management and minimizes human efforts in irrigation processes through sensor-driven control systems [4].

Besides water management, the soil nutrients are also important in agricultural productivity. Nitrogen (N), phosphorus (P), and potassium (K), are some of the basic nutrients needed by plants to grow and develop properly. The imbalances of these nutrients may result in low growth of plants, lower crop production and degradation of the soils. Surveillance of soil nutrients assists farmers in the management of fertilizers and avoiding the over use of fertilizers thus damaging the environment [2]. It is now possible to gauge the level of soil nutrients and other soil characteristics more precisely using modern sensing technologies and thus, farmers can make astute decisions regarding irrigation and fertilization applications [3]. The combination of automation, sensor networks, and microcontroller-based systems is increasingly popular with the advent of smart technology in the world of agriculture.

The IoT-based farm monitoring system offers the ability to collect data in real-time and monitor remotely, which enables the farmer to have more control over the irrigation system and can thus manage it more effectively [7]. Nonetheless, most of the IoT-based applications involve a stable internet connection and increased implementation expenses, which might not apply to small-scale farmers or rural regions.

The current irrigation systems are mainly built to either monitor soil moisture or monitor soil nutrient on a case by case basis. Few systems are capable of integrating both parameters on one solution. The combination of moisture sensors with nutrient sensors could help give more information about the soil conditions, and also increase the efficiency of irrigation. Thus, the design and development of a smart automatic irrigation system based on the Arduino Uno hardware, soil moisture sensors, and soil nutrient sensors will be conducted in this research. The proposed system constantly measures the condition of the soil and automatically regulates the irrigation process in case the level of moisture decreases below a specific set level. The combination of soil moisture monitoring and nutrient analysis hopes to decrease the amount of wasted water, facilitate soil health, and therefore enable sustainable agriculture practices.

2. LITERATURE REVIEW

The recent years have been characterized by a significant amount of attention given to smart irrigation systems as the demand to manage the water within the field of agriculture more efficiently. Other researchers have proposed sensor-based irrigation system whereby, the process of irrigation is automated based on the soil and environmental condition. These systems aim at the effectiveness of water, reduced human input and crop productivity.

Singh et al had developed a smart system of irrigation in the shape of a microcontroller application that made use of soil moisture sensors to automate water supply to the field of agriculture. This paper by them demonstrated that sensor driven irrigation systems can save much water which would otherwise be wasted when the soil moisture in the soil is at a certain level. The system conserved nearly 40 percent of water when compared to the traditional irrigation system [1]. Similarly, Patel and Shah studied the use of soil nutrient monitoring sensors in precision farming. Their researches showed that they should monitor the nutrients available in the soil such as nitrogen, phosphorus and potassium so that the soil can be fertile and at the same time increase crop production. The research article established that accurate monitoring of soil nutrients can help to make better decisions on the fertilization process by the farmers and prevent overuse of fertilizers [2].

Zhang mentioned the application of sensing technologies and automation of the modern agricultural industry. The researchers found out that sensors and automated irrigation systems can be used to improve water management and crop productivity. The other issue that was pointed out in the research is the topicality of the precision agriculture techniques that rely on the real-time observation of the surrounding conditions [3].

Another area that has attracted a lot of attention is the utilization of Arduino based irrigation systems since it is affordable and not difficult to set up. Kumar et al. developed an automated irrigation system using Arduino microcontrollers and a sensor of soil moisture. They activated and deactivated their irrigation pumps through sensor

feedback thereby improving the efficiency of irrigation and reducing the human control [4].

Irrigation systems are also discussed in relation to its efficiency with regard to water usage. Al-Ghobari gauged the method of timing the irrigation process and established that with proper timing of the irrigation process and the effective usage of water, there is a possibility of a substantial increase in the harvests without wasting the water [5].

The automation of greenhouse has been associated with embedded systems in the measurement to control the irrigation process. Rathod developed an automation system of a greenhouse which was an embedded system whereby he installed sensors to detect the soil moisture levels as well as the environmental conditions in order to have control on the irrigation process manually [6].

The development of internet technologies also has contributed to the creation of smart agriculture systems that work on the basis of IoT. Dev and Khan proposed IoT-friendly agricultural monitoring system that will allow farmers to monitor the environmental parameters and the irrigation conditions off-farm. They have also performed a study that has found that the IoT-sensed systems have promoted better monitoring and decision making in agricultural activities [7].

More recent studies too have been committed to improving upon the efficiency of irrigation through integrated sensor systems. One of the suggested smart irrigation systems by Das et al. involves the use of soil moisture sensors and computerized irrigation systems to regulate how water is used and how much resources go to waste with the help of Arduino [9].

Similarly, Di Gennaro et al. have also developed a low cost smart irrigation system that will assist in precision agriculture. They found out that equipment with automated control mechanisms will significantly increase the efficiency of irrigation and that the costs of implementation are low [11].

Other researchers have also conducted studies on integration of renewable energy in irrigation systems. According to Chan et al., the idea of a solar-powered irrigation system operating on the Arduino technology was proposed to enable sustainable agriculture and conserve the use of energy in the irrigation work [12].

The sensor calibration and accuracy has also been analysed to enhance the reliability of irrigation system. Bato examined the calibration of Arduino based soil moisture sensor and pointed out that calibration is vital in the agricultural environment to achieve quality measurements of soil moisture [10].

The irrigation management industry has also been involved in the application of techniques of artificial intelligence and machine learning. Karar et al. created the system of water pumping on the basis of neural networks, which predicts the amount of water required in the environment considering the makeup of the environment, and thereby improves the surveillance of the irrigation program and effectiveness [14]. Recent IoT based plant monitoring has also been proposed so as to be in a position to monitor the soil and environmental conditions in real-time. In order to guarantee the best conditions of the plant growth, Akib and Hasib created an intelligent plant monitoring system basing on sensor networks and automatization of irrigation processes [15].

To the extent that these studies demonstrate remarkable developments in the area of smart irrigation technologies, most of the existing systems in the market today focus on

either soil moisture or nutrient monitoring as a separate system. The researches that integrate soil moisture and nutrient measurement into a single low-cost automated irrigation system are very few. Therefore, the objective of the study is designing a smart irrigation system that will be based on the Arduino technology that will integrate soil moisture sensors and soil nutrient sensors to make the irrigation to be more efficient and able to bring sustainable agriculture.

3. METHODOLOGY

3.1 System Overview

The smart irrigation system suggested would be automated to monitor the irrigation process with the help of real-time monitoring of the soil conditions. The system comprises soil moisture sensors, soil nutrient sensors, an Arduino Uno microcontroller, and the soil parameters are monitored and the system is controlled to respond to the requirements of watering the soil.

The monitors constantly monitor the amount of moisture in soil, as well as the concentration of nutrients. The obtained information is sent to the Arduino microcontroller that processes sensor measurements and compares them to the predefined threshold values. When the moisture content of the soil is lower than the desired content, Arduino will send a signal to a relay module and the water pump will start to irrigate the plants. When the amount of moisture in the soil has surpassed ideal requirement, the pump is automatically shut down by the system.

The system can also measure the level of nutrients in the soil by use of a nutrient sensor besides irrigation control. In case the level of nutrients goes under the recommended level, then the system will alert the user or send an alert on how to use the fertilizer another time. This is a combined method in which both the nutrient and water management is automated on the same system.

3.2 Hardware Components

The suggested irrigation system has a number of hardware parts that are combined to monitor the soil conditions, and automate the irrigation.

a. Arduino Uno

The Arduino Uno is used as the primary controller of the system. The sensory receives the data of the irrigation pump and taps onto the relay module which drives the irrigation pump.



Fig. 1. Arduino

Arduino is widely used in embedded systems due to its low cost, simplicity, and compatibility with multiple sensors.

a. Soil Moisture Sensor



Fig. 2. Soil Moisture Sensor

The volumetric water content in the soil is a measurement of that of the soil moisture sensor. The sensor gives out an analog signal which is an indication of the moisture level.

The sensor value is altered when the soil gets dry and Arduino can sense when irrigation is required.

The smart irrigation system often consists of moisture sensors to ensure the ideal level of soil moisture.

b. Soil Nutrient Sensor (NPK / EC-TDS Sensor)



Fig. 3. Soil Nutrient Sensor

The soil nutrient sensor is an instrument that is utilized to detect some of the important nutrients within the soil including nitrogen (N), phosphorus (P), and potassium (K).

In other cases, the nutrient level in the soil is estimated based on the use of EC or TDS sensors that measure soil conductivity.

Nutrient monitoring assists farmers in preserving soil fertility and also in working out how to use the fertilizer effectively.

c. Relay Module



Fig. 4. Relay Module

The relay module is actually an electronic switch through which an electronic control of the water pump activity is made possible by the Arduino. As the pump needs higher voltage and current than the Arduino output, the relay module will be used to conduct electrical isolation and safe operation of the pump.

d. Water Pump

Water pump is charged with the responsibility of distributing water to the plants in case of irrigation. The relay module will switch on the pump when the soil moisture rises below the set threshold level.

e. Power Supply

The system operates either on a USB power source or an external power adapter that is based on the needs of the pump. Constant power supply will guarantee that the sensors and the Arduino controller are working.

3.3 System Architecture

According to the proposed irrigation system has a layered architecture that comprises three significant components:

1. Sensing Layer - Soil nutrient sensors and soil moisture sensors measure the real time data of the soil.
2. Processing Layer Processing Layer The microcontroller of Arduino crunches sensor data and matches it to a threshold.
3. Action Layer - According to the data that is processed the relay module feeds the water pump to either activate or deactivate irrigation.

Crop health and water use This architecture allows continuous monitoring and automatic irrigation control to enhance the efficiency of water use and health.

3.4 Working Principle

The principle of the proposed system is working according to the real-time monitoring and automatic control. The moisture sensor is installed on the soil to monitor the level of moisture in the soil at all times, whereas the nutrient sensor is used to measure the level of soil fertility.

The sensor readings are sent to the Arduino microcontroller which then compares the sensor readings with a set of predefined threshold values. Should the level of soil moisture drop below the minimum level, the Arduino will transmit a signal to the relay module, which will turn on the water pump that will water the soil. The Arduino also shuts the pump when the soil moisture is deemed to be at the desired level in order to eliminate unnecessary irrigation.

At the same time, the nutrient sensor checks the nutrient level of soil. In case the levels of nutrients are low, the system can inform the user to apply relevant fertilizers. This integrated

monitoring of moisture and nutrients makes it possible to do efficient irrigation and better soil management.

3.5 Algorithm

The proposed smart irrigation system operates based on continuous monitoring of soil conditions and automatic decision-making using predefined threshold values. The algorithm is designed to ensure that irrigation is performed only when necessary, thereby reducing water wastage and maintaining optimal soil moisture levels.

The system starts with the powering-up of all the hardware-based components such as the Arduino microcontroller, soil moisture sensor, soil nutrient sensor, and the relay module. After the process of initiation is over, the sensors begin recording the data on the soil periodically.

The soil moisture sensor measures the content of moisture in the soil and transmits the Analog value to the Arduino microcontroller. At the same time, the soil nutrient sensor is a device that determines the level of nutrient content in the soil and sends the data to the controller.

Data arriving at the Arduino is then processed and sensor readings are compared against preset threshold levels that are stored on the program.

When the measured level of soil moisture is lower than the minimum given value, the system concludes that the soil is dry and it needs irrigation. In this instance the Arduino sends a signal to the relay module, which will switch on the water pump, and the water pump will begin to irrigate the plants. The irrigation process is done until the moisture level attains the desirable optimal level.

After the soil moisture has reached the desired quantity, the water pump is automatically offened by the Arduino to avoid excessive irrigation. This mechanized system is useful in retaining the moisture content in the soil, as well as, reducing water use.

Simultaneously, the system also analyses the value of soil nutrients that was received by the nutrient sensor. When the level of the nutrient is lower than the recommended one, an alert is reported that informs about the need to add fertilizer or nutrient supplementation.

The whole process is carried out in a loop where the system is able to track the soil conditions on real time hence making decisions regarding irrigation dynamically.

I. Step-by-Step Algorithm

1. Start the system
2. Set up the Arduino and sensors and relay module.
3. Read soil moisture sensor value
4. Read soil nutrient sensor value
5. Compare the value of soil moisture with pre-determined value
6. In case moisture value is less than the threshold
 - o Activate relay module
 - o Turn ON water pump
7. In case moisture value is at optimum level.
 - o Deactivate relay module
 - o Turn OFF water pump
8. Check soil nutrient level
9. In case the level of nutrients is lower than it should be
 - o Create warning or notification
10. The process should be repeated in order to monitor in real time

4. RESULTS AND DISCUSSION

The smart irrigation system was also put into test to determine how it could be used to effectively monitor the soil conditions and automatically irrigate the land. The system performance was evaluated along three dimensions, which are the stability in soil moisture, the efficiency in water use, and the ability to monitor nutrients. The experiment has been done under varying soil conditions to determine the behavior of the system under different moisture conditions.

4.1 Soil Moisture Monitoring

In the testing, the soil moisture sensor kept on checking the level of moisture in the soil. The sensor values were relayed to the Arduino microcontroller that was used to interpret the values and compare them with the set threshold level. The Arduino was attached to the water pump and the relay module was switched on by the Arduino when the soil moisture was lower than the threshold value.

The system could keep the soil moisture within a range of 45-60 which is believed to be within the ideal range of moisture in soil and hence conducive to most of the plant varieties. The system also ensured that the soil moisture remained at the desired level to avoid over- and under- irrigation, which provided improved conditions of plant growth.

4.2 Water Usage Efficiency

A major goal of the proposed system will be achieved through the minimization of water wastage by irrigating the plants when need be. In the conventional irrigation techniques, the water is usually provided at a constant rate irrespective of the real conditions of the soil, a fact that prompts inefficiency in the use of water.

The experimental results showed that the automated irrigation system made a great contribution in the reduction of unnecessary watering. The system proved to consume less water by 3050 percent of irrigation using traditional irrigation methods since irrigation was only initiated when soil moisture level is below the preset value.

4.3 Nutrient Monitoring

The proposed system would also have soil nutrient sensor to measure the status of soil fertility in addition to moisture monitoring. The nutrient sensor is used to determine the concentration of significant nutrients like nitrogen, phosphorus and potassium or approximates the nutrient levels of soil based on the level of electrical conductivity.

In the process of testing, the system could identify the changes in the nutrient levels of the soil and give valuable references on the soil fertility. The nutrient analysis assists the farmers in making better choices on the fertilization and prevents the overuse of fertilizers that may result in soil degradation and environmental pollution.

4.4 System Reliability

The system was shown to be stable when it was put through repeated testing cycles. The Arduino microcontroller was able to process sensor inputs and operate on the irrigation pump without much latency. The relay module facilitated smooth junction between ON and OFF of the water pump thus making the operation of the pump safe and efficient.

Since the system connects to an automatic system, which constantly checks the state of the soil, it will minimize the

necessity of the farmer to monitor the work, and the farmer can concentrate on other farming operations.

4.5 Cost Analysis

The proposed irrigation system will be low cost and affordable to the small scale farmers and home gardener. Table I shows the estimated cost of the key components used in the system.

TABLE I

Component	Cost (₹)
Arduino Uno	450
Soil Moisture Sensor	150
Soil Nutrient Sensor	900–2000
Relay Module	80
Water Pump	300
Miscellaneous Components	200
Total Estimated Cost	₹2000 – ₹3500

Total Estimated Cost: ₹2000 – ₹3500

The system is relatively affordable and should, therefore, be used in practical implementation in small farms, greenhouses, and education project implementation.

4.6 Discussion

The outcomes of the obtained experiment show that the combination of soil moisture monitor with automated irrigation control can help tremendously to increase irrigation efficiency. Dynamism in responding to the conditions of the soil is made possible through the use of sensor so that the system does not have fixed schedules to irrigate the soil.

Moreover, the soil nutrient monitoring also gives a couple of extra advantages to the soil fertility and rational utilization of the fertilizers. These moisture sensors coupled with nutrient sensors on a single platform can contribute to the management of water and the health of the soil and hence to the sustainability of agricultural activities.

5. CONCLUSION

The study showed the designed and developed smart automatic irrigation system on the basis of Arduino Uno microcontroller that was integrated with soil moisture sensors and soil nutrient sensors. The main goal that the proposed system aimed at was to increase the efficiency of the current irrigation process through the monitoring of the soil conditions in real time and automation of the current irrigation process with the help of sensor data.

The results of the experiment showed that the system can be successfully used to measure the amount of moisture in the soil and control irrigation automatically in case the soil becomes dry. The system will also ensure that the irrigation pump is used only when it is necessary and will keep the soil in optimal water content and will also avoid unnecessary watering. This is a method of effective water management which minimizes on unnecessary water use.

Besides measuring moisture, soil nutrient sensing, which is integrated into the procedure, yields a high level of information with regard to the level of soil fertility. When the nutrient levels are monitored this enables the farmers to better control the use of fertilizers and also enables proper balancing

of the nutrients in the soil which is paramount to healthy plant growth and better crop yields.

The suggested irrigation system is easy, cheap, and simple to use with common electronic devices available in the market including Arduino, sensors, and relay modules. The system can be applied in small farms, home gardens, greenhouses and educational projects due to the fact that it is cheap and it operates automatically.

In general, sensor-based monitoring and automated irrigation control can be seen as the evidence of how smart farming technologies can be used to optimize water use, cut down on human resources and contribute to the sustainability of agricultural efforts.

6. FUTURE WORK

Even though the proposed system is effective in the context of tracking the state of the soil and regulating irrigation, there are several ways in which the future work can be improved to increase the characteristics of the system.

The next step could be to incorporate the use of the Internet of Things (IoT) technology to provide an opportunity to monitor and control irrigation equipment remotely using mobile apps or cloud services. This would enable farmers to know the conditions of soil and the status of irrigation regardless of the location.

These environmental sensors can also be extended to include additional environmental sensors like the temperature, humidity, and rainfall sensors to offer a more detailed environmental monitoring. These parameters could be used to improve the decision-making process of irrigation, and improve crop management.

The other area of enhancement could be to have solar power systems to offer sustainable and energy saving operation in rural locations where power supply may be low.

Moreover, more sophisticated technologies like machine learning and predictive analytics might be employed to process environmental data and forecast the needs of irrigation depending on the weather conditions and condition of crops. This would also enhance efficiency in the irrigation process and also facilitate the establishment of smart farming systems.

Besides technology advancements, the suggested smart irrigation system can be applied to the fields of contemporary agriculture and environmental control in several ways. The system may be used on small farms and home gardens to automate irrigation and conserve on the wastage of water. It is also applicable in green houses and nurseries where the soil should maintain the best moisture and nutrient level to ensure growth of the plants. The system could be taught and experimented in the educational institutions and research laboratories to showcase applications of smart agriculture and embedded systems.

Besides, the system may be used in urban farming, smart city agriculture initiatives, where efficient water management is a consideration because of scarcity of water. Such systems would aid accuracy farming techniques with additional development and mass usage, enabling farmers to make the best use of irrigation, enhance crop-producing results, and engage in sustainable crop cultivation.

7. REFERENCES

- [1] R. Singh, P. Verma, and A. Kumar, "Control of microcontroller-based smart irrigation system with soil moisture sensor," *Agricultural Engineering International Journal*, 2019.
- [2] H. Patel and M. Shah, "Precision farming with monitoring sensors of soil nutrients," *Master's Thesis in Smart Agriculture*, 2020.
- [3] Q. Zhang, *Sensing and Automation in Agriculture*. Elsevier Publications, 2020.
- [4] S. Kumar, A. Sharma, and R. Joshi, "Smart agriculture automated irrigation system based on Arduino," *International Journal of Embedded Systems*, 2021.
- [5] H. Al-Ghobari, "Irrigation scheduling and water use efficiency," *Agricultural Water Management Review*, 2017.
- [6] P. Rathod, "Embedded systems applied to greenhouse automation," *IEEE Sensors Journal*, 2018.
- [7] M. Dev and F. Khan, "Smart agriculture systems and analysis based on IoT," *International Journal of Internet of Things Research*, 2021.
- [8] K. Singh and D. Sharma, "IoT-based smart irrigation system using soil moisture sensors," *International Journal of Smart Agriculture*, 2022.
- [9] S. Das, S. Saha, and S. Podder, "Arduino-based smart irrigation system for sustainable agriculture," *International Research Journal of Modernization in Engineering Technology and Science*, 2023.
- [10] V. A. Bato, "Calibration and performance evaluation of Arduino-based soil moisture sensors for agricultural applications," *Philippine Agricultural Scientist Journal*, 2023.
- [11] S. F. Di Gennaro et al., "Development of a low-cost smart irrigation system for precision agriculture," *Smart Agricultural Technology Journal*, 2024.
- [12] C. K. Chan et al., "Solar-powered automated irrigation system using Arduino for sustainable farming," *Engineering Technology & Applied Science Research*, 2024.
- [13] Y. Arafa et al., "Smart irrigation management using sensor networks and GIS technologies," *Cogent Engineering*, 2023.
- [14] M. E. Karar et al., "Neural network-based water pumping control system for smart irrigation," *International Journal of Artificial Intelligence in Agriculture*, 2020.
- [15] A. Hasib and A. Akib, "IoT-enabled plant monitoring and automated irrigation system using sensor networks," *Journal of Smart Farming Systems*, 2024.