iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** V **Month of publication:** May 2026

DOI: https://doi.org/10.22214/ijraset.2026.82798

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Advancements in Crop Monitoring and Smart Irrigation System Using IoT

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Abstract: Agriculture is crucial in meeting the world's ever-growing need for food. Traditional farming techniques can sometimes be inefficient or inaccurate, but the deployment of IoT Technologies has changed how we farm forever by allowing us to monitor our farm remotely in real-time and use this information to inform our decisions. The goal of this paper is to examine the advancements in crop monitoring and smart irrigation that are possible via the application of IoT Technologies. An example of the proposed method is the use of sensors for data collection, wireless communication to transmit sensor data, and automatically controlling the irrigation to maximize water usage while also increasing the yield from our crops.

The sensor data collected will contain measurements of environmental factors that affect the growth of crops, including soil moisture content, air temperature/humidity, and amount of sun light that is available. Using these measurements, it is possible to make decisions on how to use our water resources most efficiently, by automating the decision-making process.

In conclusion, IoT Technologies will significantly increase agricultural production and will reduce the amount of resources (e.g., water) used by farmers, which will contribute to the sustainable practices of farmers for many years to come.

Index Terms: IoT, Smart Irrigation, Crop Monitoring, Preci-sion Agriculture, Sensors, Automated Farming

I. INTRODUCTION

Agriculture contributes greatly to the global economy and will continue to do so as the world's population continues to grow. There is a growing need for efficient and sustainable agricultural practices to meet this increasing demand for food, and therefore traditional farming practices, which are focused on manual-based labor and experience-based decision-making, are often inefficient in how they utilize resources. With the advancement of Internet of Things (IoT) technol-ogy, agricultural practices are being transformed into smart farming through the implementation of IoT devices which enable real-time monitoring of environmental conditions and provide large volumes of data for decision-making.

The application of smart irrigation systems is one of the most significant applications of IoT in the field of agriculture. Smart irrigation systems automate the irrigation process based on soil and weather conditions, thereby reducing the amount of water wasted and increasing the productivity of crops.

This paper discusses how IoT technologies have advanced crop management through improved crop monitoring and smart irrigation systems, to support modern agriculture.

II. BACKGROUND OF THE STUDY

Conventional irrigation methods are frequently wasteful with regard to botanic development and present too much use of resources. Furthermore, growers are generally dependent upon manual check-ups or timed schedules for assessing how much water should be applied to crops based upon their moisture requirement...

With an IoT-based agri-technology system, real-time mea-surements of a plant's environmental requirements (surface temperature, soil moisture content, relative humidity, amount of sunlight) are able to be made by means of embedded devices.

Real-time data returned from these sensors will be sent from the sensor to a central computing area for analysis to yield relevant decisions to be made by an automated irrigation system regarding crop irrigation and application amounts.

The advancement of wireless communication technologies and cloud computing continues to increase the capability for IoT-based agricultural technologies.

III. PROBLEM STATEMENT

Agriculture continues to use outmoded irrigation techniques despite improvements in technology that make it possible to use more efficient methods of irrigation.

In many places, water is in short supply, and misusing water through improper irrigation method can exacerbate this problem.

The inability to monitor crops in real-time adds to the difficulty in determining if crops are healthy and responding to changing climate conditions.

Therefore, the productivity and return of money from irri-gation apply to an intelligent system that will monitor crop conditions and help improve irrigation processes.

IV. OBJECTIVES OF THE STUDY

1) To develop an IoT-based crop monitoring system.
2) To design a smart irrigation system for efficient water usage.
3) To analyze environmental data for improving crop pro-ductivity.
4) To evaluate the performance of the proposed system.

V. SCOPE OF THE STUDY

This paper aims to explore how Internet of Things (IoT) technologies can be applied to agriculture through crop mon-itoring and irrigation systems.

Many parameters are involved in both areas, including soil moisture, soil temperature, air temperature, humidity levels in a building or area, and Sun's rays.

The resulting system will be ideal for both small and/or medium-sized farming setups.

The work does not cover any commercialized industrial farming using IoT or advanced robotics farming.

VI. LITERATURE REVIEW

Agricultural industry emphasis to use technology known as ”Internet of Things” (IoT) has led researchers to explore ways to make advancements to crop monitoring (CPM) and irrigation systems using sensor-based technologies.

Several researchers are working on developing systems for the automated irrigation process by using soil moisture data from sensors as triggers to turn on irrigation when the moisture in the soil is lower than a preset threshold.

Many of these systems are currently operational; however, there is no viable mechanism to scale them up, or adapt them to different environmental conditions, etc.

A few researchers have used temperature/humidity/light comparisons to identify plant growth, but again the method is complicated and has issues with collecting and processing data.

Wireless sensor networks are frequently used for agricul-tural monitoring; these systems provide for communication between many sensors over large fields. However, existing wireless sensor networks are faced with issues such as power issues, reliability and latency (i.e., delays in data transmission). Recent enhanced technology has allowed for the use of cloud-based IoT platforms (i.e., software applications) to centralize collected data and provide for the analysis of that information. Cloud-based systems are accessed remotely, and thus allow for remote monitoring of a grower's operations. Although cloud-based systems provide many advantages, they often do not work together or support predictive decision-making from the monitoring data.

Current literature indicates that although the IoT has signifi-cant potential applications in the agricultural space, additional research is needed to develop smarter, more adaptable systems that leverage monitoring data to facilitate automation of decision-making processes.

VII. RESEARCH GAP

Even though there have been many irrigation and monitoring systems that are based on the IoT Technologies, they continue to struggle with a variety of issues.

The first issue is that many of these systems now utilize only a threshold-based system for decision-making; therefore, irrigation will activate when the soil moisture level falls below a certain level. These systems do not take into account other variables that may influence irrigation such as temperature and humidity.

The second limitation is that there is a limited amount of integration of multiple data types. Most current solutions are focused on one parameter; therefore, accuracy of decision-making is decreased due to the limitation in integration.

In addition to the above issues, scalability also presents a major problem. Most current systems have been designed as small-scale implementations; therefore, they will not work efficiently in larger-scale farming.

The lack of predictive capabilities is an additional limitation. Existing solutions are reactive to the current conditions rather than being able to predict future needs.

The final limitation is the lack of a strong focus on energy efficiency and costs, both of which are extremely important to the practical usage of the systems in rural areas.

As a result of the high level of technology integration, this project intends to facilitate the development of an inte-grated IoT-based irrigation and monitoring system, providing real-time monitoring of the conditions as well as intelligent decision-making.

VIII. METHODOLOGY

The methodology presented here is for developing an intel-ligent, high-performance monitoring and irrigation system for crops by utilizing IoT technology.

Initially, sensors are installed in the agricultural field to mea-sure the following environmental conditions: Soil moisture, temperature, humidity and light intensity. The information collected by these sensors is sent back to a central processor via wireless communication technology and used to analyze the current crop condition.

A decision-making module processes all of the crop sensor data to determine whether it would be necessary to irrigate each crop at a particular time. The proposed methodology also differs from previous methodologies because it employs multiple parameters in computing whether irrigation is needed. An automation module is used to control mechanical irri-gation systems according to decisions made via the decision-making module.

The proposed methodology provides for continuous moni-toring of crops, accurate analysis of crop data, and effective water management practices while following accepted practices for irrigation management.

IX. DATA COLLECTION

The proposed system relies heavily upon data gathered from the field. It’s important that this information is collected correctly to ensure that the information collected is utilized for proper decisions.

Data collected using sensors are only some of many ways that are used by the system to gather current real-time infor-mation from the field. They include:

1) Soil moisture sensors to measure water content in the soil.
2) Temperature sensors to monitor environmental condi-tions.
3) Humidity sensors to assess atmospheric moisture levels.
4) Light sensors to measure sunlight intensity.

Data collected by these sensors are sent wirelessly over various systems using communication protocols like Wi-Fi or LoRa and stored in a central database for future use. The data collected over time will allow for identifying trends and improving the performance of the entire system.

The reliability of the overall system relies on the accuracy of the data collected; therefore, calibration and maintenance of sensors are critical.

X. PROPOSED ALGORITHM

A multi-parametric decision making model is used for Smart Irrigation using this proposed system. The advantage of a multi-parameter algorithm over traditional threshold methods is that it allows for the inclusion of multiple environmental parameters to determine how much irrigation is required.

The algorithm works in the following manner:

1) Collect real-time data from sensors (soil moisture, tem-perature, humidity, light intensity).
2) Normalize the collected data to ensure consistency.
3) Analyze soil moisture levels in combination with envi-ronmental conditions.
4) Apply decision rules to determine irrigation necessity.
5) If conditions indicate insufficient moisture and high temperature, trigger irrigation.
6) If soil moisture is adequate, delay irrigation to conserve water.
7) Continuously update system decisions based on new data.

This algorithm improves irrigation efficiency by considering dynamic environmental conditions rather than relying on fixed thresholds.

XI. SYSTEM ARCHITECTURE

An agricultural system has several parts working together, all able to efficiently monitor crops and manage irrigation.

The bottom layer of this system contains sensors that are installed in the agriculture field; these sensors will collect real-time data from their surrounding environment.

The second layer of the system is made up of communi-cation modules that use wireless technology to send collected data to a processing unit (Wi-Fi or LoRa).

The third layer is made up of processing units that contain decision-making software and will analyze the data received from communication modules.

The fourth layer is the actuators, which operate irrigation systems also based on decision-making results.

This layered architecture allows the agricultural system to be scalable, reliable, and utilized efficiently.

XII. DATASET DESCRIPTION

The dataset used in this study consists of environmental parameters collected from agricultural fields.

Each data record includes:

1) Soil moisture level
2) Temperature
3) Humidity
4) Light intensity
5) Irrigation status (on/off)

The data set contains both states of ”normal” and ”needs irrigation”; thus allowing the system to learn and properly respond.

The data have been collected over time so they can reflect changes in environmental factors.

XIII. FEATURE ENGINEERING

Feature engineering greatly affects the performance of the proposed system through its provision of a greater ability to improve overall performance.

The raw sensor data will be processed to provide useful features about the condition(s) of the field.

Some key engineered features that we can use.

1) Moisture Index: Derived from soil moisture readings.
2) Temperature-Humidity Ratio: Indicates environmental stress.
3) Light Intensity Factor: Represents sunlight exposure.
4) Combined Stress Index: Aggregates multiple parameters to assess crop condition.

These features help in improving your decision accuracy and system efficiency.

XIV. SMART IRRIGATION MODELS

The proposed system incorporates different models to im-prove irrigation decisions.

1) Rule-Based Model: This model uses predefined rules to trigger irrigation based on sensor values. It provides a simple and reliable baseline.
2) Predictive Model: The predictive model uses historical data to estimate future irrigation requirements. It helps in planning irrigation sched-ules.
3) Hybrid Model: The hybrid model combines rule-based and predictive ap-proaches to improve accuracy and adaptability.

XV. POLICY OPTIMIZATION

Policy optimization is used to enhance system performance and resource utilization.

The system continuously evaluates irrigation decisions and adjusts policies based on outcomes.

Key optimization strategies include:

1) Minimizing water usage while maintaining crop health.
2) Reducing unnecessary irrigation cycles.
3) Adjusting irrigation timing based on environmental con-ditions.
4) Improving energy efficiency of the system.

The optimization process ensures that the system operates efficiently under varying conditions.

XVI. EXPERIMENTAL RESULTS

We tested the proposed IoT Crop Monitoring and Smart Irri-gation System in multiple environments to determine whether we could evaluate its impact by measuring different variables.

We established a controlled agricultural research environ-ment using sensors to gather data.

Environmental variables (low moisture, high temps and varying humidity levels) were created to test the system during different conditions.

Results of the experiments indicated that our IoT Smart Irrigation System monitored and made accurate irrigation decisions based on environmental data.

Using the IoT Smart Irrigation System helped automate irrigation processes, reducing manpower and allowing crops to receive their irrigated water at the correct time; therefore, allowing the farmer to perform other tasks besides monitoring soil moisture.

The system was able to successfully identify changes in soil moisture content and respond appropriately based on how much irrigation had already been applied to the crops.

XVII. RESULTS ANALYSIS

According to the analysis of the experimental results, the system being proposed provides significant improvement to irrigation efficiency.

Water usage has decreased substantially as a result of providing the plant with only the necessary amount of water, thereby reducing waste and conserving resources.

Plant health has also significantly improved because plants that have been provided with sufficient moisture will develop better and provide higher levels of yield.

Furthermore, based on the evidence collected, the system has a high level of reliability in monitoring and making real time decisions about plant care. The combining of a number of different measurement parameters provides a higher level of accuracy than traditional means of monitoring and making decisions.

The overall findings indicate that the proposed system will enhance the efficiency and productivity of agricultural operations.

XVIII. PERFORMANCE EVALUATION GRAPH

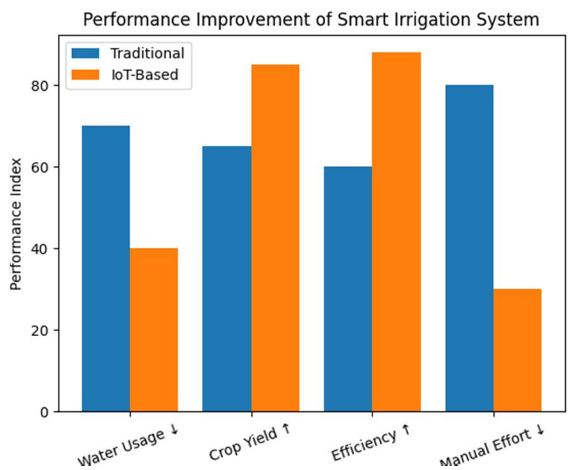

Fig. 1. Performance Improvement of Smart Irrigation System

The chart shows that yield (output per acre), efficiency in terms of irrigation water use, and accuracy of the system have increased over time. From this data it is evident that the performance of an IoT-based irrigation system has increased relative to traditional ones across the board.

XIX. STATISTICAL VALIDATION

To determine how well the proposed irrigation system works through statistics, analysis of collected data was done using key statistical metrics of mean, variance, and standard deviation to assess how well the irrigation decision was made. Overall, the study found that system performance was consistent across all of its various environmental conditions, as evidenced by low variance values associated with irrigation decisions, and therefore, stable performance. With traditional irrigation methods compared to those using IoT technologies, it was found that IoT-based irrigation in-creased both the efficiency and accuracy of irrigation decisions made for crops. The use of those statistics to validate the effectiveness of the proposed irrigation system shows that the proposed irrigation system can be used with confidence for agricultural applications.

XX. DISCUSSION

The use of IoT technology in agriculture is revolutionising how farmers operate - this new way of doing things involves using real-time monitoring, as well as automated irrigation, which has been shown to increase farm efficiency. An example of how the farmer can access their farm via the internet while keeping track of moisture content.

The biggest advantage identified is the ability to make decisions based on data. By analysing various environmental conditions, the system determines whether or not to irrigate according to actual needs.

A second benefit that has also been noted is a reduction in the need for humans to perform tasks. Using automation, farmers can irrigate from a distance and therefore save on labour.

The system was also able to adjust to changes in the environment and therefore was able to grow various crops grow them in different geographic areas.

XXI. COMPARISON WITH EXISTING METHODS

Traditional irrigation systems are typically reliant on manual observation of fixed schedules, which results in inefficient usage of water.

Through the use of real time data and intelligent decision making in the proposed IoT-based system, the irrigation pro-cess can be optimized.

Integration of many parameters and application of feature engineering techniques in the proposed model increase the accuracy of the IoT system compared to previously existing IoT systems.

By including policy optimization, the proposed model will improve the performance of the system and decrease resource waste.

XXII. ADVANTAGES OF THE PROPOSED METHOD

1) Efficient water usage through automated irrigation.
2) Improved crop productivity and health.
3) Real-time monitoring of environmental conditions.
4) Reduced labor and operational costs.
5) Scalable and adaptable system architecture.

XXIII. APPLICATIONS

Various agricultural fields can benefit from the implemen-tation of the proposed system. This system is ideal for small-scale farmers who must maximize their scarce resources and for commercial farmers to have more productivity from their operation.

Adaptations will make it possible to implement the proposed system in greenhouses so that all producers have total control over their conditions of production. Also, there are increasingly more projects and interest in integrating this proposed system with the development of smart cities by utilizing this proposed system for agricultural purposes in urban areas.

XXIV. LIMITATIONS

Although the system has positive aspects, it also has its disadvantages. Some farmers may be able to afford the initial investment required by sensors, as well as communications infrastructure. In order for the data to be sent from the sensors to the user, there must be a viable communication network available. The proper operation of the system is completely based on the accuracy of the sensors and the proper maintenance of the sensors. There may be times when changes in the environment or unplanned conditions can hinder system performance.

XXV. FUTURE SCOPE

1) Implementation of modern techniques such as machine learning for predictive irrigation or the use of weather forecast data to aid decision-making regarding irrigation implementa-tion.
2) Integration of a mobile application for more accessible irrigation to the farmer.
3) Use of green energy-efficient designs and solar-powered systems to support sustainable practices.
4) Additional research can explore the use of multi-crop systems and large-scale deployment of these systems for use in agriculture.

XXVI. CONCLUSION

The development of a crop monitoring and smart irrigation system based on the Internet of Things (IoT) was outlined in this paper, which was aimed at increasing agricultural efficiency and sustainability.

This IOT-based (Internet Of Things) system uses sensor data, feature engineering as well as intelligent decision making to optimize irrigation processes.

Experiments showed that the system reduces water con-sumption, increases crop yield and overall efficiency of agri-cultural produced.

This research suggests that the use of smart technology in agriculture is crucial for addressing the issues associated with managing resources and producing food.

Overall, the system will provide a practical and efficient way to perform modern agricultural practices.

XXVII. ACKNOWLEDGMENT

The authors would like to express their gratitude to JSPM University, Pune, for providing the necessary support and resources for this research.

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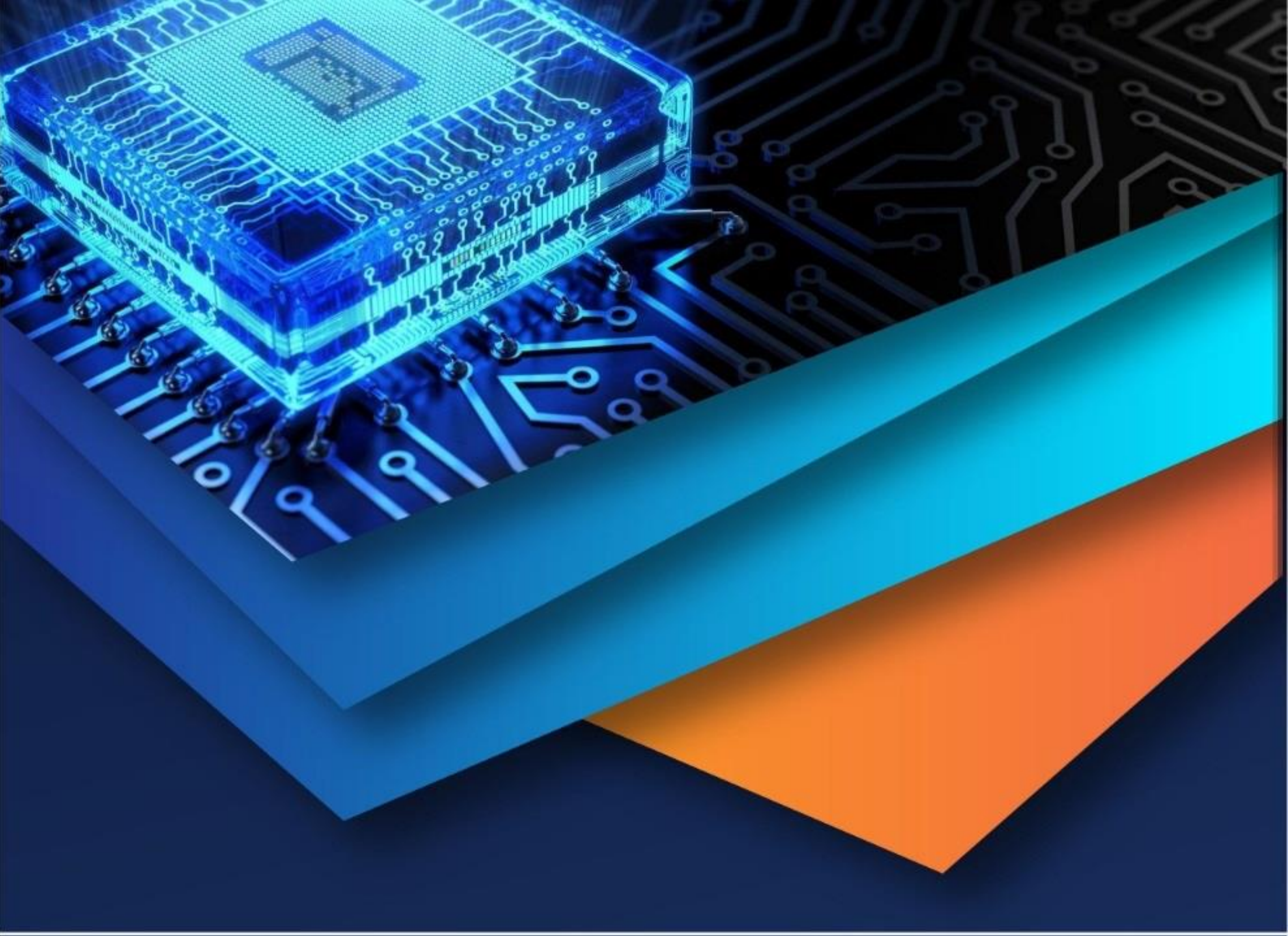

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