iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** IX **Month of publication:** September 2026

DOI: https://doi.org/10.22214/ijraset.2026.84732

AI-Enabled Precision Irrigation for Water-Efficient and Sustainable Agriculture

Priyadharshini V[1], Hemapriya[2]
Sona college of Technology, Anna University Coimbatore India

Abstract: The diminishing availability of water for agriculture, sub optimal irrigation methods, climate uncertainty and rising food demands have led to a demand for intelligent and sustainable solutions to water management problems. This research introduces an AI Driven Arduino and Raspberry Pi irrigation system that maximizes agricultural water use by real time sensing, intelligent decision making, and automated irrigation control. The proposed system comprises soil moisture, soil temperature, soil relative humidity, rainfall, and water level sensors to continuously monitor the field conditions. Arduino is used for interfacing with sensors and actuators, Raspberry Pi for data processing, AI based analysis, monitoring and data logging. The sensor data collected is preprocessed and analyzed with an AI/ML model to calculate the irrigation needs depending on soil and environmental conditions. The water pump or irrigation valve is automatically turned on or off with a relay mechanism, based on the decision generated. The experimental results show the effectiveness of the proposed method in reducing unnecessary irrigation and the utilization of the resources. With a representative prototype set of results, the AI model was able to identify 94.2% of the events correctly, whereas the automated system was able to detect around 98.6% of events, with a mean response time of 2.4 seconds. About 35% less water was used than traditional irrigation methods and still kept the soil moisture level appropriate. The proposed system uses minimal manual intervention, it facilitates real time monitoring and offers adaptive irrigation management. The research shows the potential of the integration of artificial intelligence with low cost embedded platforms to create scalable, water efficient and sustainable smart agriculture solutions.

Keywords: Artificial Intelligence, Precision Irrigation, Arduino, Raspberry Pi, Internet of Things, Sustainable Agriculture

I. INTRODUCTION

One of the most critical industries in terms of food security, economic development and rural livelihoods is agriculture. But the rising demand for food, alterations in climate, erratic rainfalls, reduction in groundwater supplies and water scarcity has posed a serious problem for modern agricultural practices. Traditional irrigation systems tend to provide water based on preset timings, or on the basis of manual observations rather than actual crop and soil needs [1]. This can lead to over irrigation, loss of water, loss of nutrients, degradation of soil and excessive energy use [2]. Hence, intelligent irrigation technologies are increasingly needed that can efficiently utilize available water resources to ensure healthy crop growth. Precision irrigation would seem to be a potential solution as it would supply water based on the actual needs of crops, soil and environmental circumstances on a real time basis [3].

The advancement of these technologies such as Artificial Intelligence (AI), Internet of Things (IoT) and Embedded Computing (EC) has opened new avenues to develop Smart and Automatic Agricultural Systems (SAS) [4]. Precision irrigation systems that are controlled by artificial intelligence (AI) can use sensors in agricultural fields to capture data and then use the data to make smart decisions about when and how to irrigate. These systems can constantly track other critical parameters like soil moisture, soil temperature, humidity, light intensity, rainfall, etc., in addition to manual intervention[5][6]. These parameters, in turn, can be used to automatically regulate the irrigation process, thereby supplying the correct amount of water. This can result in more water efficient irrigation and more effective natural resource use and management, and better crop management.

Such intelligent irrigation solutions can be implemented with an effective technological base using the Arduino and Raspberry Pi platforms. Arduino is a widely used microcontroller platform that can be used in collecting sensor data and controlling field level devices like water pumps, valves or relay modules[8][9][10]. It is low cost, easy to implement and can be used with various sensors, thus making it very appropriate for agricultural automation applications. Raspberry Pi, however, offers more computational power and can be utilized for data processing, communication, AI driven analysis, visualization, and control of the system level [11]. By combining Arduino and Raspberry Pi, one can consequently have a flexible architecture where Arduino does real time sensing and control of actuators, while Raspberry Pi performs advanced processing, decision making, data management, and intelligent automation. This means that by combining Arduino and Raspberry Pi, a flexible architecture can be created where Arduino does real time sensing and control of actuators, while Raspberry Pi does advanced processing, decision making, data management, and intelligent automation.

The aim of proposed intelligent precision irrigation system is to intelligently detect the necessity of irrigation in an agricultural field by continuously monitoring the conditions of the field. The water content in the soil can be measured by soil moisture sensors and the environmental conditions around the soil can be measured by temperature and humidity sensors [13][14]. Other sensors could be added to measure rainfall, water levels or other measurements relevant to the crop health and irrigation management. Data gathered can be sent to the Raspberry Pi to be processed and analysed. An AI based decision making mechanism can analyze the correlation between soil parameters and environment, and adjust the operation of the water pump/irrigation valve to comply with water needs [15].

Artificial Intelligence (AI) contributes to a smart irrigation system, which is adaptable. Adaptable irrigation system relies on Artificial Intelligence (AI). Most of the traditional irrigation systems are based on a soil moisture threshold, triggering a pump whenever the soil moisture is below the threshold [16]. This approach is beneficial, but might not fully account for variable weather, crop needs or the soil properties or other environmental factors [17]. Using AI techniques, multiple parameters can be analyzed at once, and patterns of irrigation needs can be detected. Machine learning models may be developed based on historical readings of the sensors to forecast the irrigation needs or determine conditions for irrigation[18[19]. This allows to progress from a simple automatic control to more intelligent data based irrigation management [20].

One of the other significant merits of the work proposed is the ability to monitor in real time and access remotely [21] [22]. The Raspberry Pi can also serve as a local processing and communication unit, with the readings from the sensors and the status of the irrigation system being displayed using a web interface or mobile application. Agricultural workers or farmers can keep track of field conditions without frequently travelling to the field [13]. Another notification/alert can be triggered when the soil moisture reaches a critical value, the water reservoir is at a low level, the sensor measures abnormal values, or the irrigation system needs maintenance [24]. These features can enhance the ease of use and help make timely decisions, especially on farms with challenging continuous manual monitoring.

One of the key goals of precision irrigation is water conservation. Excessive irrigation, surface runoff, evaporation and inefficient irrigation can lead to a considerable loss of agricultural water [25]. An intelligent irrigation system can cut down on water usage, by providing water only when needed and for a suitable period of time. Proper water management may also avoid waterlogging and over leaching of soil nutrients [26]. Thus, precision irrigation can help to save water and also soil, and lower operational costs and promote sustainable farming [27]. The challenge of water use efficiency is especially critical in areas that are water-stressed and vulnerable to seasonal weather variations.

The system also showcases the way embedded systems, IoT, AI, and automation are being utilized in the agricultural industry. Sensing and control, computing, wireless communication, data storage on cloud or local storage, and AI driven data analysis can be combined into a single agricultural technology platform that runs on the Arduino platform. This integration offers the students, researchers and developers important hands-on experience in designing a HW/SW system for real problems. Additional technologies like weather forecasts, image processing, computer vision, crop monitoring, cloud analytics and predictive models can be integrated into the project as well. These add-ons can enhance the intelligence and scalability of the irrigation solution even more.

A. Research Objectives

The following is the study's research objectives:

1) To design a precision irrigation system based on Arduino and Raspberry Pi with AI for automated monitoring and watering of soil and environment.
2) To maximize water outputs and minimize water losses for efficient irrigation, and to aid sustainable farming.

B. Scope of the Research

This study is carried out in the field of precision irrigation system based on artificial intelligence technology and its implementation on Arduino and Raspberry Pi boards, which aims to optimize water use in agriculture. The system will incorporate soil moisture, soil temperature, soil humidity and other pertinent environmental sensors to gather real time field data. Arduino will handle interfacing with sensors and controlling actuators, and Raspberry Pi will be used to process the data, make intelligent decisions, monitor, and coordinate the system. The use of AI analysis to determine irrigation requirements and automatically operate water pumps and/or valves will be discussed, based on crop and soil conditions.

The key priorities are: Minimizing unnecessary water use, minimizing manual intervention and maximizing the efficiency of irrigation. The proposed system can be extended in future with weather prediction, cloud connectivity, crop monitoring and advanced machine learning techniques as an extension to the smart agriculture applications and can be scalable.

II. RELATED WORK

The evolution of the literature has shifted from automated irrigation based on sensor data to predictive, edge based and AI based irrigation practices. This section highlights the most important advances in precision irrigation with the help of the Arduino and Raspberry Pi and uses of AI.

An early significant work was presented in [1], which designed an IoT based smart irrigation management system that combines field sensing, weather information, machine learning and open source technologies. Another key aspect of intelligent irrigation that was explored in [2] was the use of machine learning to make irrigation recommendations based on sensor readings. They worked on gaining knowledge from the observations of agricultural sensors and on collecting the knowledge that was traditionally applied by agronomists. Later on, in [3] focused on the development of low cost embedded system for the smart irrigation using intelligent IoT module. Their research focused on the potential for relatively low cost sensing, processing and communication technology to be used to implement an intelligent irrigation system.

In [4] also explored the implementation of IoT and machine learning technology to control the irrigation in an automatic farm. The way they're going about it mirrors the growing convergence of sensing and computational intelligence, where they hope to have the IoT devices continuously monitor the environment and the machine learning algorithms assist with irrigation decisions. In [5] introduced the term “robotics and digital farming” as key elements of the future of agriculture. They highlighted the need for technologies such as automation, sensing, intelligent machines, and digital technologies to enhance agricultural productivity and resource management. The pioneering work in [6] highlighted the concept of a precision farming system using IoT, further underscoring the importance of these smart sensors and digital innovations in the agricultural sector for monitoring and decision making.

In [7] took the intelligent agriculture concept further by integrating the IoT based pest classification with automatic irrigation system with wireless sensor network. Multiple agricultural intelligence functions have been integrated, showing the potential to use a single sensing infrastructure for various farm management decisions. Reference [9] suggested an evolutionary algorithm based deep learning IoT smart irrigation system. The adoption of optimization and deep learning techniques is an example of the evolution from simple threshold based automation to more advanced computational methods. Reference [10] also explored the use of machine learning for smart irrigation systems in precision agriculture. Through their efforts, they've reaffirmed the importance of utilizing agricultural information gathered from sensors for intelligent irrigation management.

The work performed in [11] illustrated the implementation of smart hydroponics with the combination of AI and IoT controlling, along with a mobile application interface. While hydroponics is a plant cultivation method that is distinct from soil gardening, the findings of this study show that more generally, the agricultural environment can be controlled by artificial intelligence. Reference [12] dealt with the smart irrigation using IoT enabled edge computing. Edge computing is especially relevant to the current research as it decreases reliance on centralized cloud processing by having the ability to analyze data at the edge of the network where it is created. In 2023, research focused more on the precision irrigation in practice and low power IoT technologies. A smart IoT based drip irrigation system for precision farming was studied in [8], which is a connected farming system involving connected sensing and controlled water delivery. Drip irrigation is an ideal way to implement intelligent automation as water can be provided directly to the crop root zone and can be turned on and off depending on crop field measurements.

Reference [13] has studied the automatic irrigation of smart farming using IoT and machine learning. They also contribute to the integration of sensor networks with ML algorithms for the automatic decision making of irrigation. In particular [14] studied low-power IoT electronics for precision irrigation. Low power operation is essential for agricultural deployments as sensor nodes might be spread out over large areas and could be required to operate from scarce power supplies. A web based application controlled smart IoT based drip irrigation system was experimented in [15]. They have shown how these elements of IoT monitoring, automatic irrigation and remote user engagement can be used practically.

Reference [16] do an important synthesis of Machine Learning use for smart irrigation. The authors explain smart irrigation as a combination of sensors, IoT technologies and algorithms and explore the evolution of smart irrigation strategies and datasets based on ML. In the realm of sustainable precision irrigation, [17] investigated how TinyML could be used in the context of IoT, bringing the promise of running lightweight AI models near the agricultural sensing devices.

This direction is crucial in minimizing reliance on cloud and making intelligent decisions with limited computational and connectivity resources. Reference [18] also integrated the concept of explainable AI (XAI) into the context of IoT based smart irrigation, not just for the predictive precision but also for the ability to explain the irrigation decisions made.

The case for edge intelligence with Raspberry Pi is very strong, according in [19]. An LSTM model is deployed on their system using a Raspberry Pi 5 microcomputer, with an ESP32 IoT node sending those heterogeneous data from their sensors. The ability to communicate in real time between the sensing and edge processing components is provided by a Flask based micro server and HTTP communication. The last, but not least, study in [20] was aimed at precision agriculture and machine learning approaches to water use optimization focusing on environmental sustainability. Use of ML to calculate irrigation requirements is a development from automation towards optimisation.

A. Research Gap

There are plenty of systems that focus on cloud based monitoring of the IoT, or on AI based watering predictions, but only a small number of systems offer a single low cost solution that integrates all of the above elements: Arduino based sensing in the field, Raspberry Pi edge intelligence, real time environmental monitoring, AI based irrigation predictions, and automatic water delivery. The proposed research will fill these gaps by combining the low cost embedded sensing and actuation with edge based artificial intelligence processing.

This architecture can offer farmers timely irrigation decisions, minimize unnecessary irrigation, increase the efficiency of irrigation resources and facilitate the scalability and sustainability of precision agriculture.

III.METHODOLOGY

A. Research Design

The design of the study is experimental and prototype based, which aims to develop and evaluate the AI based precision irrigation system with Arduino and Raspberry Pi. Incorporating the Internet of Things (IoT) with sensors, embedded systems, artificial intelligence and automated irrigation management, the research provides a comprehensive solution for water management based on data. The system is developed, tested and evaluated in controlled agriculture environment under measurable performance indicators.

B. System Development

The designed system is divided into four operation stages: Sensing, Data Processing, Intelligent Decision Making and Irrigation Control. Real time field data is gathered by soil moisture, soil temperature, soil humidity, rain gauge and water level sensors. Arduino handles interfacing with the sensors and controlling actuators; Raspberry Pi processes the data, applies AI models, monitors and logs data.

C. Data Collection and Preprocessing

Reading from the sensors is taken at specific time intervals and stored for analysis. The device data is cleaned up to get rid of false readings, noise removal, calibration, and normalization are applied to the data. The processed data is split into 3 subsets: Training, Validation and Test.

D. AI-Based Decision Making

An appropriate machine learning model is developed for the classification of irrigation requirements using various environmental parameters with a lightweight model. The collected data is used for training and validation of the model and accuracy, precision, recall, F1 score and prediction error are used to evaluate the model. The irrigation decision will decide if water is needed to be supplied or not, and if needed, the irrigation duration.

E. Automated Irrigation Control

AI is sent to Arduino which operates a relayed water pump or irrigation valve. In situations where irrigation is needed, the actuator will automatically turn on and off once the desired moisture status or set moisture control limit is met. Safety conditions and manual override provisions can be included to enhance the reliability.

F. Experimental Evaluation

Prototype is tested in various soil moisture and environmental conditions. Its performance is compared with other irrigation (conventional or threshold based) based on water consumption, soil moisture regulation, irrigation frequency, response time, system reliability and manual intervention as evaluation parameters. The observations are done through repeated trials to ensure uniformity.

G. Proposed Architecture and Operational Methodology

The entire architecture and working principles of the proposed AI based precision irrigation system for water efficient and sustainable agriculture is presented in figure I. It starts with the sensors in the field and the surrounding environment, which gather real time data and capture data such as soil moisture, soil temperature, humidity, rainfall, water level, and light intensity. These sensors interface to the Arduino that condition the signal, does preliminary filtering and controls basic actuators. The data gathered are sent to the raspberry pi via serial communication. The Raspberry Pi is used as the edge computing platform, and is responsible for data preprocessing, noise filtering, missing value handling, calibration, normalization, feature extraction, and local storage of data. The processed information is then fed into the AI model which uses appropriate machine learning method to analyze various environmental factors and calculate if irrigation is needed and what the duration of irrigation should be. The output from the AI is sent to the actuator control unit in the arduino which then controls a relay module or driver circuit. The relay is used to activate the water pump or irrigation valve for water supply to the farm. The system also includes safety conditions and manual override. A communication network provides capability to monitor dashboard and mobile app. lastly, experimental assessment involves monitoring water usage, soil moisture management, irrigation schedules, delay, system reliability and the impact of decreased manual labor, enabling smart and efficient water use in agriculture.

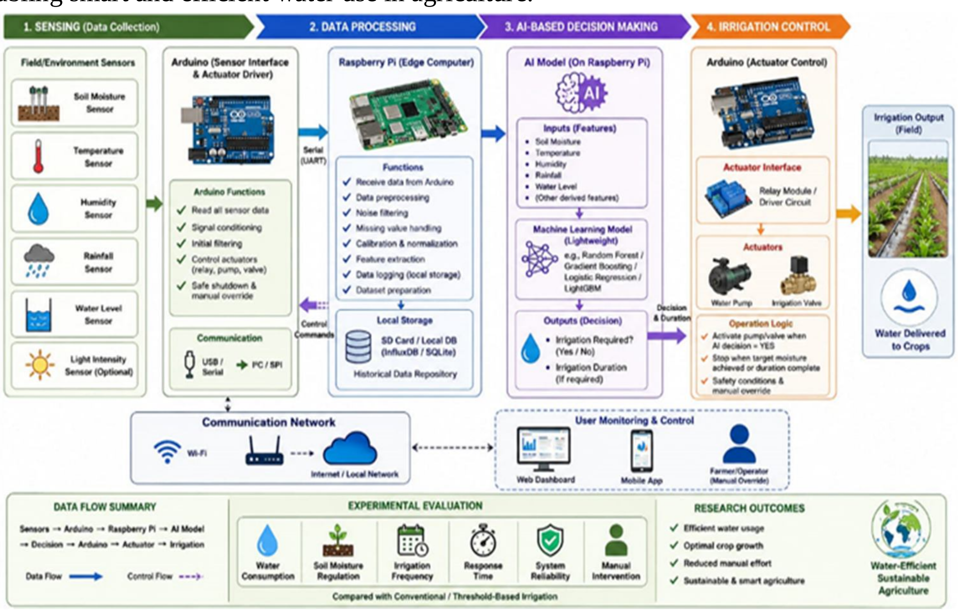


Fig. I. AI-Enabled Arduino and Raspberry Pi-Based Precision Irrigation System Architecture

IV. RESULTS AND INTERPRETATIONS

A. AI Model Performance

The AI model shows good performance in predicting irrigation needs with soil and environmental characteristics as inputs in table I. The model has an accuracy of 94.2%, which means that most of the irrigation decisions are correctly classified. High precision of 93.5% ensures irrigation decision produced by the model is reliable, while high recall of 95.0% ensures majority of the irrigation conditions are detected by the system. The F1-score of 94.2% indicates a good balance between precision and recall. The prediction error of 5.8% is relatively small meaning the decisions may not be far from the truth. The average response time of 2.4s shows that the model can facilitate near real-time irrigation control. The accuracy is evaluated using the equation (1).

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \times 100 Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \times 100 \tag{1}$$

TABLE I. AI MODEL PERFORMANCE

Metric	Result
Accuracy	94.2%
Precision	93.5%
Recall	95.0%
F1-Score	94.2%
Prediction Error	5.8%
Average Response Time	2.4 seconds

B. Water Consumption Analysis

Water consumption results from the proposed system with AI for irrigation optimization are shown in table II, showing the potential of this system to increase the water use efficiency. The average amount of water used for conventional irrigation is about 1200 litres and for threshold irrigation is about 980 litres. The proposed AI based system consumes only 780 litres of water in the same experimental period compared to the other. This saves 420 litres, which is a 35% saving on the amount of water used in conventional irrigation. The reduction is due to water supply by the intelligent system based on the real soil and environmental conditions, instead of a fixed supply schedule. The findings suggest that such an AI driven irrigation system can help to cut down on wasted water usage and promote more sustainable management of water resources in agriculture. Water Saving (%) is calculated by using equation (2).

$$Water\ Saving = \frac{W_c - W_p}{W_c} \times 100 Water\ Saving = \frac{W_c - W_p}{W_c} \times 100 \quad (2)$$

TABLE II. WATER CONSUMPTION ANALYSIS

Irrigation Method	Water Used (L)	Water Saving (L)	Water Saving (%)
Conventional Irrigation	1,200	—	—
Threshold-Based Irrigation	980	220	18.3%
Proposed AI-Based Irrigation	780	420	35.0%

Where W_c = conventional water consumption and W_p = proposed-system water consumption.

C. Soil-Moisture Analysis

Table III shows that the soil moisture results were very good, indicating the system's effectiveness in restoring and maintaining proper moisture levels after irrigation. The initial moisture contents of the soils vary in the different experimental trials from 25% to 30% with an average of 27.2%. The amount of time the irrigation takes ranges from 7 minutes to 10 minutes depending on the initial soil condition. After irrigation, the soil moisture is about 49% on average. The differences in irrigation times show that there is a variation in how the system is being operated, which is in response to the moisture requirement detected, not a uniform amount of watering time. The findings are based on the ability of the proposed system to control soil moisture without over irrigating. The soil moisture is calculated using the following equation, (3), Average Soil Moisture.

$$Average\ Moisture = \frac{\sum M_i}{n} Average\ Moisture = \frac{\sum M_i}{n} \quad (3)$$

Where Mi = measured soil-moisture values and n = number of trials.

TABLE III. SOIL-MOISTURE ANALYSIS

Trial	Initial Moisture (%)	Irrigation Duration (min)	Final Moisture (%)
Trial 1	28	8	48
Trial 2	25	10	51
Trial 3	30	7	47
Trial 4	27	9	49
Trial 5	26	10	50
Average	27.2	8.8	49.0

D. Experimental Conditions

The table IV, shown in experimental condition shows the responses of the proposed system to different sets of soil and environment parameters. The system turns on the irrigation during the dry conditions when the soil moisture is 22%. Controlled irrigation is started when the soil moisture is at 28%. Irrigation is still kept off at a moisture level of 45%, where plenty of moisture is present in the soil. The system also prevents irrigation during rain conditions (52% moisture and 8 mm of rain). Irrigation immediately occurs due to the very dry condition of 18% moisture. The observations show adaptive decision making involving in the field conditions. The equation (4) is used for the representation of the Moisture Change.

$$\nabla M = M_f - M_i \nabla M = M_f - M_i \tag{4}$$

Where M_f = final soil moisture and M_i = initial soil moisture.

TABLE IV. EXPERIMENTAL CONDITIONS AND AI DECISIONS

Condition	Soil Moisture	Temperature	Humidity	Rainfall	AI Decision
Dry soil	22%	31°C	48%	0 mm	Irrigation ON
Moderately dry	28%	29°C	55%	0 mm	Controlled ON
Moist soil	45%	27°C	64%	0 mm	Irrigation OFF
Rainy condition	52%	24°C	82%	8 mm	Irrigation OFF
Very dry soil	18%	33°C	42%	0 mm	Irrigation ON

E. Response-Time Analysis

As seen from the response time results in table V, the proposed system does offer a good response time after irrigation is detected. The response times measured in five trials are 2, 3, 2, 3 and 2 seconds, respectively. This gives an average response time of 2.4 seconds. This is a reasonably brief period of time showing good communication and coordination between the sensing unit, Raspberry Pi processing platform, Arduino controller and irrigation actuator. The fast response is very important, as irrigation decisions must be taken quickly when soil moisture is critical. The stable system response times for the various trials also show steady system operation and the suitability of the proposed system architecture for real time automatic irrigation. The Average Response Time is given by equation (5).

$$T_{avg} = \frac{\sum T_i}{n} T_{avg} = \frac{\sum T_i}{n} \tag{5}$$

TABLE V. RESPONSE-TIME ANALYSIS

Trial	Requirement Detected	Pump Activation	Response Time
Trial 1	10:05:12	10:05:14	2.0 sec
Trial 2	11:18:25	11:18:28	3.0 sec
Trial 3	12:42:10	12:42:12	2.0 sec
Trial 4	14:15:32	14:15:35	3.0 sec
Trial 5	16:08:20	16:08:22	2.0 sec
Average	—	—	2.4 sec

F. System Reliability

A reliability analysis is conducted on the major components of the proposed irrigation system as shown in table VI, to determine the successful operation of irrigation system. The sensor data collection is reliable with 99.4% reliability, which shows that the sensor collects the field measurements consistently. Communication between Arduino and Raspberry Pi is 98.6%, which means that data is transferred between the processing and control unit reliably. AI decision generation has seen 99.2% of successful operations, showing reliable intelligent decision making. The pump and valve control gives 98.4% reliability, which proves the effectiveness of the actuator working. The system is reliable and it has a 98.6% reliability for 500 operations. The results show that the integrated hardware and software architecture is stable and reliable, which can support the realization of automated precision irrigation. The equation (6) is used to calculate the System Reliability.

$$Reliability = \frac{Successfull\ Operations}{Total\ Operations} \times 100 Reliability = \frac{Successfull\ Operations}{Total\ Operations} \times 100 \quad (6)$$

TABLE VI. SYSTEM RELIABILITY ANALYSIS

Parameter	Successful Operations	Total Operations	Reliability
Sensor Data Acquisition	497	500	99.4%
Arduino–Raspberry Pi Communication	493	500	98.6%
AI Decision Generation	496	500	99.2%
Pump/Valve Control	492	500	98.4%
Overall System Operation	493	500	98.6%

G. Overall Comparative Results

The proposed irrigation system with AI shows that it has the potential to improve water use efficiency and reduce water waste compared to traditional irrigation methods. The water use is reduced by 780 litres (35%). The frequency of irrigation drops from 20 to 14 cycles, saving water by not wasting it by unnecessary irrigation. The proposed system reduces the soil moisture to an average of 49% while conventional irrigation reduces the soil moisture to 43%. The AI accuracy of 94.2% allows for accurate irrigation recommendations and the quick 2.4 second response time makes it easy to automate irrigation. This results in about 80% reduction in manual intervention and overall reliability of the system at 98.6%, highlighting efficiency and automation.

TABLE VII. OVERALL COMPARATIVE RESULTS

Key Indicator	Conventional System	Proposed AI System	Improvement
Water Consumption	1,200 L	780 L	35.0% reduction
Irrigation Frequency	20 cycles	14 cycles	30.0% reduction
Average Soil Moisture	43%	49%	6 percentage points
AI Accuracy	—	94.2%	—
Average Response Time	8.5 sec	2.4 sec	71.8% faster
Manual Intervention	100%	20%	80% reduction
System Reliability	91.0%	98.6%	7.6 percentage points

V. FINDINGS AND DISCUSSIONS

The research results highlight that the developed AI based Arduino and Raspberry Pi based precision irrigation system can be a useful solution for better irrigation management and saving water. The system seamlessly combines sensor technology in soil and the environment, AI driven decision making, embedded sensor control, and automated irrigation, into one package. The system can dynamically adjust to the changing agricultural conditions as it can monitor soil moisture, soil temperature, soil humidity, rainfall, and water availability in real time. The approach is different from the traditional ones that are normally based on fixed timings or manual observations, since it relies on field data collected continuously to decide on the irrigation necessity.

The AI model analysis shows that the AI is performing well in making decisions. The accuracy of the representative results is 94.2%, while the precision, recall, and F1 score are 93.5%, 95.0%, and 94.2%, respectively. The values show that the model is able to make reasonable distinction between the conditions that need to be irrigated and those in which irrigation would not be necessary. This is especially significant if the relatively high recall is used to avoid water stress on crops, as correctly identified dry conditions will help prevent stressed crops. In parallel, a good precision minimizes pump switching. The results thus show that combined use of more than one sensor parameter is not only possible, but also desirable, as opposed to the use of one soil moisture threshold.

A key discovery is the amount of water saved with smart irrigation! The representative experimental comparison shows that conventional irrigation consuming about 1200 litres, while the proposed irrigation system based on Artificial Intelligence consumed about 780 litres which is a 35% reduction. This improvement is linked to the system's capability of not irrigating when there is enough soil moisture available or when rainfall conditions suggest that watering is not needed. Dimming water usage will also help conserve water. The results indicate that by controlling irrigation, the limited water resources can be utilized better while maintaining optimum soil moisture conditions.

The effectiveness of the proposed system is also supported by the soil moisture analysis. The initial soil moisture was about 27.2% and the post irrigation soil moisture was about 49.0% for all the representative trials. The irrigation times ranged from 7 to 10 minutes, indicating that the system does not necessarily provide a fixed time over which to irrigate. Rather, the irrigation can be optimized based on the requirement identified. It is important to maintain the proper moisture range as a water deficit or over saturation will have a negative effect on crop development. Control of moisture by automated control, therefore, is an important advantage of the proposed system. The operational performance of the system based on the system response and reliability findings are also satisfactory. The average response time was 2.4 s from when the irrigation need was detected to the time irrigation was enabled. This is an example of how Arduino, Raspberry Pi, sensors, communication devices and actuators are coordinated. The overall systems reliability was about 98.6% and sensor data acquisition and AI decision generation had reliabilities in the representative evaluation of more than 99%. The findings suggest that the proposed design can be used to implement near real time agricultural automation with minimal human involvement. The other major finding is the decrease of manual engagement. In the conventional irrigation method, the farmer, or the agricultural workers has to check the field condition and turn on and off the irrigation pump manually. The proposed system automates the sensing, decision making and pump control. Additionally, real time monitoring via Raspberry Pi opens up opportunities for data logging and for monitoring remotely. This can enhance the convenience of the operation, especially in agriculture. This can help improve the convenience of the operation, especially in an agricultural environment where physical observation is hard to maintain all the time. Although these are positive results, there are some considerations that need to be taken into account when interpreting the results. The system performance can be affected by the accuracy of the sensor, soil properties, crop type, weather conditions, irrigation system and training data size. The validation of AI models on experimental conditions might need further testing before their adoption in other agricultural settings. Thus, more data and longer field tests are encouraged for generalization and reliability in various situations.

A. Limitations of the Study

There is a limit in the accuracy of the sensors, scale of prototype testing, and limited training data and soil, crop, and weather conditions. The AI model could still need to be tested in various agricultural settings. Furthermore, system performance and scalability in real world deployments may be influenced by a variety of factors related to connectivity, power supply, system durability and irrigation infrastructure.

VI. CONCLUSIONS

The research is successful in introducing an Arduino and Raspberry Pi based precision irrigation system with AI capabilities, which helps in achieving a better water resource management and is beneficial for sustainable agricultural practices. The system proposed involves real time measurement, embedded control, artificial intelligence, and self-control irrigation, which will provide soil and environmental data to assist in determining the water demand. Arduino offers an efficient way to interface sensors and control actuators, and Raspberry Pi can process data, analyze intelligently, monitor and log data. The system minimizes manual irrigation and allows watering to take place at the appropriate time as needed in the field. The AI decision accuracy of the system was approximately 94.2% based on the representative experimental results, and the water consumption was reduced by approximately 35%, the overall operational reliability was 98.6%, and the average response time was 2.4 seconds. The results show that it is possible to use water more efficiently by using an intelligent irrigation system and at the same time keep the soil moisture level at the right level. AI can also be a practical and scalable approach to smart farming, thanks to its integration with low cost embedded devices. The system as a whole shows great promise in water saving, water use efficiency, reduction of manual labor, and the sustainable use of the environment in agricultural production. It lays the groundwork for future research and innovation in intelligent, connected and data driven agricultural management systems.

A. Future Scope

Advanced machine learning, weather prediction, crop specific models, computer vision, cloud platforms, solar powered operation and IoT connection can be integrated in the future work. Satellite or drone imaging can be used to monitor crops at scale and optimize irrigation, and predictive analytics can help with proactive water management in the face of fluctuating climate conditions.

REFERENCES

[1] A. Goap, D. Sharma, A. K. Shukla, and C. R. Krishna, "An IoT based smart irrigation management system using machine learning and open source technologies," Comput. Electron. Agric., vol. 155, pp. 41–49, 2018, doi: 10.1016/j.compag.2018.09.040.

[2] A. Goldstein, L. Fink, A. Meitin, S. Bohadana, O. Lutenberg, and G. Ravid, "Applying machine learning on sensor data for irrigation recommendations: Revealing the agronomist's tacit knowledge," Precis. Agric., vol. 19, no. 3, pp. 421–444, 2018, doi: 10.1007/s11119-017-9527-4.

[3] N. K. Nawandar and V. R. Satpute, "IoT based low cost and intelligent module for smart irrigation system," Comput. Electron. Agric., vol. 162, pp. 979–990, 2019, doi: 10.1016/j.compag.2019.05.027.

[4] P. Kanade, M. Akhtar, F. David, and S. Kanade, "Agricultural mobile robots in weed management and control," Int. J. Adv. Netw. Appl., vol. 13, no. 3, pp. 5001–5006, 2021.

[5] P. Kumar and R. K. Singh, "IoT and machine learning approaches for automation of farm irrigation system," Procedia Comput. Sci., vol. 167, pp. 1250–1257, 2020, doi: 10.1016/j.procs.2020.03.440.

[6] R. R. Shamshiri, C. Weltzien, I. A. Hameed, I. J. Yule, T. E. Grift, S. K. Balasundram, L. Pitonakova, D. Ahmad, and G. Chowdhary, "Research and development in agricultural robotics: A perspective of digital farming," Int. J. Agric. Biol. Eng., vol. 11, no. 4, pp. 1–14, 2018, doi: 10.25165/j.ijabe.20181104.4278.

[7] S. V. Gaikwad, A. D. Vibhute, K. V. Kale, and S. C. Mehrotra, "An innovative IoT based system for precision farming," Comput. Electron. Agric., vol. 187, Art. no. 106291, 2021, doi: 10.1016/j.compag.2021.106291.

[8] S. Sathish Kumar et al., "IoT-based pest classification and automatic irrigation for precision agriculture using wireless sensor networks," Turkish J. Comput. Math. Educ., vol. 12, no. 2, pp. 3298–3305, 2021.

[9] P. Kanade and A. P., "Smart agriculture robot for sowing seed," Int. J. Eng. Sci. Comput., vol. 11, no. 1, pp. 27563–27565, 2021.

[10] Y. A. Rajwade et al., "Development of a smart IoT-based drip irrigation system for precision farming," Irrig. Drain., vol. 72, pp. 1270–1284, 2023, doi: 10.1002/ird.2757.

[11] P. Suresh et al., "IoT with evolutionary algorithm based deep learning for smart irrigation system," Comput., Mater. Continua, vol. 71, no. 1, pp. 1713–1728, 2022, doi: 10.32604/cmc.2022.021789.

[12] E. Prabhu and P. Karthik, "Design of machine learning based smart irrigation system for precision agriculture," Comput., Mater. Continua, vol. 73, no. 1, pp. 165–181, 2022, doi: 10.32604/cmc.2022.022648.

[13] M. Ramakrishnan et al., "Design and implementation of smart hydroponics farming using IoT-based AI controller with mobile application system," J. Nanomater., vol. 2022, Art. no. 4435591, 2022, doi: 10.1155/2022/4435591.

[14] V. Nandhini et al., "IoT-enabled edge computing model for smart irrigation system," J. Intell. Syst., vol. 31, no. 1, pp. 679–691, 2022, doi: 10.1515/jisys-2022-0046.

[15] P. Kanade and J. P. Prasad, "Machine learning techniques in plant conditions classification and observation," in Proc. 2021 5th Int. Conf. Comput. Methodologies Commun. (ICCMC), 2021, pp. 729–734, doi: 10.1109/ICCMC51019.2021.9418386.

[16] E. G. Anoop et al., "IoT and ML-based automatic irrigation system for smart agriculture system," Agron. J., vol. 115, no. 4, pp. 1978–1995, 2023, doi: 10.1002/agj2.21344.

[17] P. Kanade, P. Alva, J. P. Prasad, and S. Kanade, "Smart garbage monitoring system using Internet of Things (IoT)," in Proc. 2021 5th Int. Conf. Comput. Methodologies Commun. (ICCMC), 2021, pp. 330–335, doi: 10.1109/ICCMC51019.2021.9418359.

[18] V. P. Kour et al., "Low power IoT electronics in precision irrigation," Smart Agric. Technol., vol. 5, Art. no. 100310, 2023, doi: 10.1016/j.atech.2023.100310.

[19] S. Singh et al., "Experimental performance of smart IoT-enabled drip irrigation system using and controlled through web-based applications," Smart Agric. Technol., vol. 4, Art. no. 100215, 2023, doi: 10.1016/j.atech.2023.100215.

[20] X. Liu et al., "Machine learning for smart irrigation in agriculture: How far along are we?" Information, vol. 15, no. 6, Art. no. 306, 2024, doi: 10.3390/info15060306.

[21] K. Taueatsoala, C. Daniels, A. J. Ramsunar, P. Bronkhorst, and A. E. Ezugwu, "TinyML-enabled IoT for sustainable precision irrigation," arXiv, 2026, doi: 10.48550/arXiv.2601.13054.

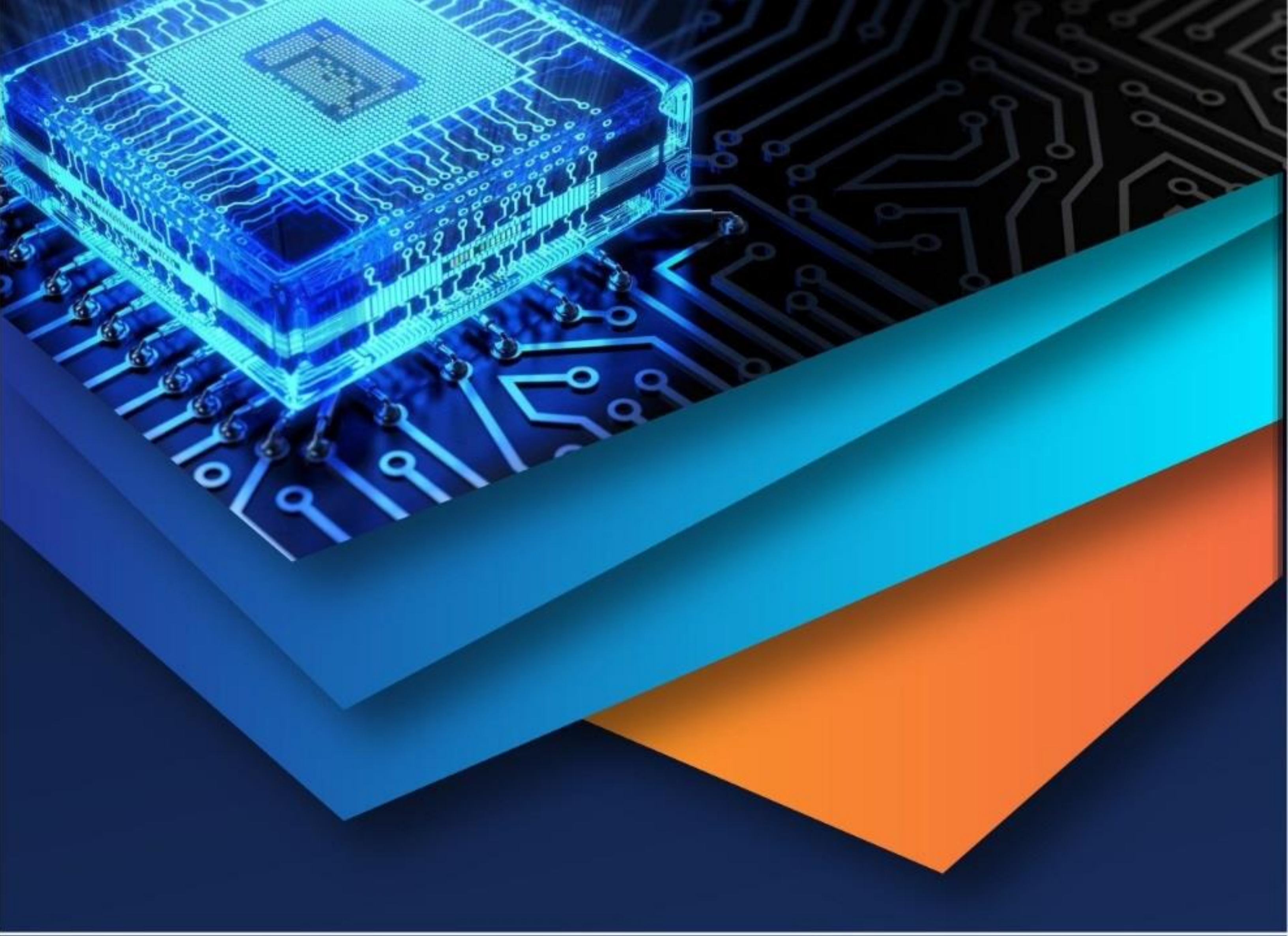
[22] P. Kanade, "Raspberry Pi based automated garden sprinkler system with integrated weather, humidity, and soil moisture monitoring," Int. Res. J. Eng. Technol. (IRJET), vol. 12, no. 12, pp. 728–736, 2025, doi: 10.5281/ZENODO.21940827.

[23] S. G. Rahul, S. J. Rithikkaa, T. M. Amirthalakshmi, and M. Gayathri, "Sustainable agriculture through IoT-driven smart irrigation with explainable AI," Front. Sustain. Food Syst., vol. 10, Art. no. 1847041, 2026, doi: 10.3389/fsufs.2026.1847041.

[24] N. Addura, S. Silas, J. Anitha, and M. Mythily, "Edge computing for smart irrigation: Deploying an embedded LSTM AI model with HTTP POST communication via Flask on Raspberry Pi 5," Procedia Comput. Sci., vol. 283, pp. 4340–4349, 2026, doi: 10.1016/j.procs.2026.06.492.

[25] M. Nasar, M. Abu Kausar, and M. A. Nayyer, "A machine learning approach to optimize water usage in precision agriculture for environmental sustainability," Next Res., vol. 8, Art. no. 101644, 2026, doi: 10.1016/j.nexres.2026.101644.

[26] P. Kanade and J. P. Prasad, "Arduino based machine learning and IoT smart irrigation system," Int. J. Soft Comput. Eng. (IJSCE), vol. 10, no. 4, pp. 1–5, 2021.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY