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Machine-Based Monitoring of Crops: A Review

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Abstract: The present study introduces an IoT based automated irrigation system as a water management strategy for farmers. Real time data regarding soil condition can be gathered using soil moisture sensor, which is linked to Arduino Uno microcontroller. When crops are planted AI with machine learning determines the amount of and scheduling of irrigation based on a crop's water and moisture needs. Through a web application, the system is user friendly and enables farmers easily to input what type of crop they have planted. This manages the irrigation processes automatically in relation to the needs of the crops thus conserving water. There is improvement in the precision of irrigation and simplification of the management of the crops as well as making it cheaper in terms of resources. This product is a step towards better farming practices for the growers as it integrates sustainability in agriculture and helps them get better crop yield under less water.

Key words: Automated Irrigation, Artificial Intelligence, Crop Management, IoT, Web Application.

INTRODUCTION

Agriculture is one of the key sectors contributed to many economies across the world. However, it confronts several challenges including unpredictable climatic factors, water levels as well as resource management problems. In order to get control of these issues, modern technology has a number of alternatives. Our research is focused on the design and application of an automated crop irrigation system which incorporates artificial intelligence and machine learning (AIML) and Internet of Things (IOT) sensors. The primary objective of this system is to offer support to farmers with the management of irrigation, efforts towards over-irrigation as well as to the wastage usually involved with the conventional irrigation systems.

Our methodology, based on the use of the Internet of Things (IOT) enabled soil sensors to collect real-time data of soil moisture level and check the if there is a need to irrigate or not. Collected data is processed and analysed using advanced AIML algorithms to monitor water level according to the pre-datasets and automate irrigation. Apart from this, the system is connected to a web application on which farmers can select the crop they want to irrigate, and the system will automatically adjust the parameters, and irrigation will be done automatically. The web application consists of different crops and their data. When a farmer selects any crop, the system matches the real-time data collected from the soil sensor to the data that is predefined in the web application. If the water level is low, the system automatically starts the water pump, and otherwise the water pump is set off.

1. LITERATURE REVIEW

Reference	Key Focus	Methods	Results
[Dek24]	Identification of plant resistance genes and disease classification.	ML models (SVM, Bayesian, RF), Deep CNNs)	Plant Pathogens Classification
[Kum24]	Predicting crop disease outbreaks using weather data.	RF regression, field sensors	Disease predictions, crop yield, reduced pesticide use
[Red24]	Recommender system for disease detection and prediction.	Image processing (noise removal, feature extraction), ML Algorithms	Disease management recommendations
[Che24]	Crop selection techniques to enhance productivity.	Naive Bayes, K-Nearest Neighbours	Improved crop selection
[Kaw24]	Wheat crop growth stage tracking and classification.	Digital image processing, SVM	Crop Growth Stages

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2. Research Methodology

2.1. System Architecture Overview

Our system is designed to use the real-time soil moisture data and automate the irrigation process using IoT-enabled devices and a decision-making engine. The components used are soil moisture sensors, an Arduino Uno microcontroller, an IoT based module for communication, data analysis model and a web application for interaction with farmer (Fig.).

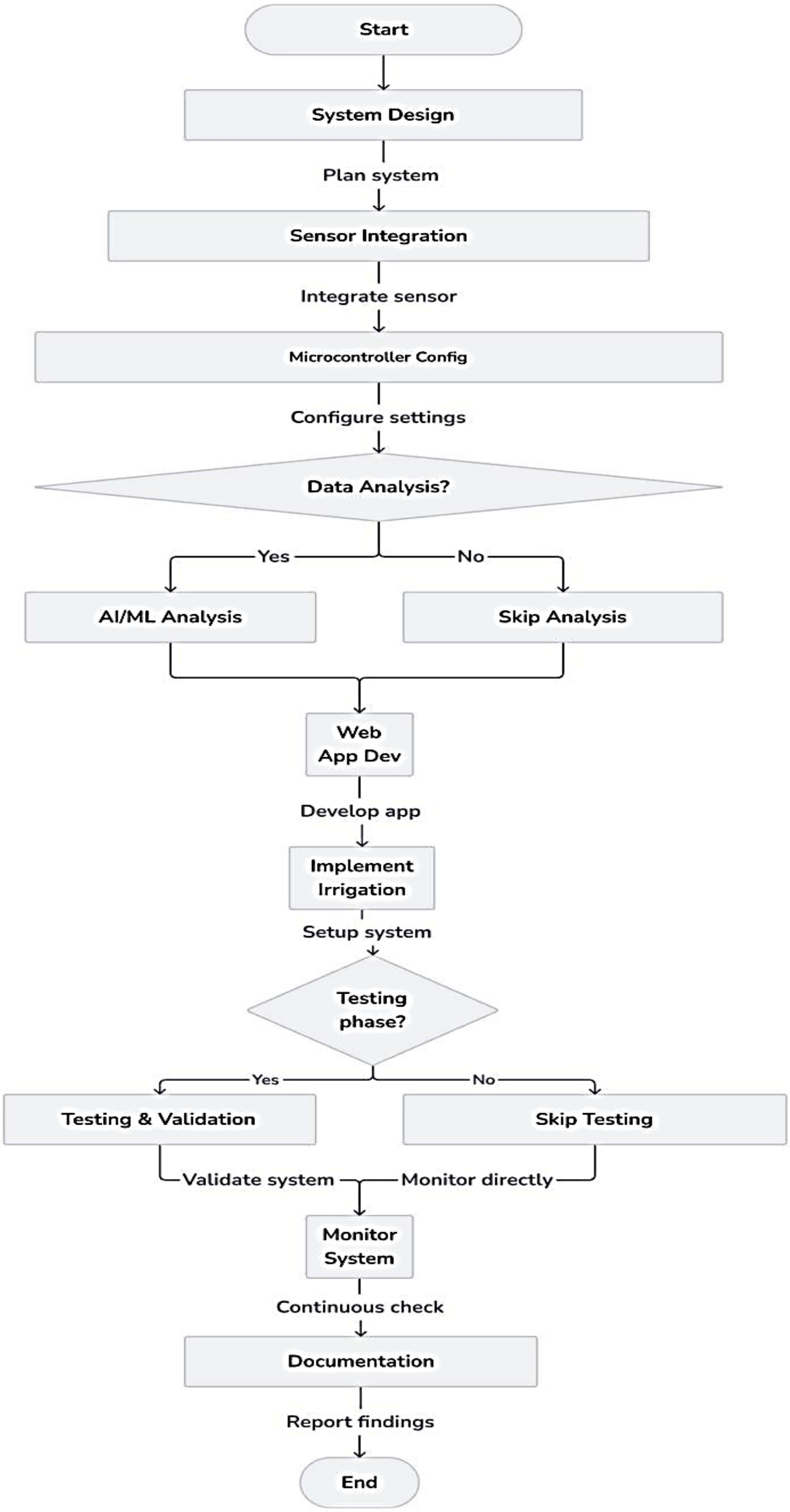

Fig. System architecture for IoT based automated irrigation system using web application

2.2. Components and Hardware Setup

- *Soil Moisture Sensors.* Soil moisture sensors are placed at a suitable depth as per the chosen crop and the soil moisture levels are constantly observed. Therefore, the volumetric content of the soil is measured.
- *Arduino Uno.* The main task is to collect the data and to perform this task Arduino Uno microcontroller is used. Information is gathered from the soil moisture sensors and transferred to the IoT module, and the programming is carried out using C++ in the Arduino IDE.
- *Water Pump and Relay Module.* The water pump is linked to a relay module. The relay which functions as a switch is controlled by the Arduino. The pump is turned on or off using the analysed data.
- *IoT Communication Module.* For the IoT connectivity, a wireless module, ESP8266 is employed. The real time data is transmitted to a cloud-based server for analysis and the control commands for the irrigation are received

2.3. Data Acquisition

The real-time monitoring is started with the collection of data of soil moisture levels. Soil sensors are placed according to the soil type and the precise readings are guaranteed. The analogue data is produced and converted to the digital signals by the Arduino Uno. Soil moisture content is indicated [Kri23, Sar23].

The following information is gathered by the system:

- Soil moisture percentage.
- Measurement of date and time.

The cloud-based server is deployed to receive the data via the wireless IoT module, the immediate further analysis is ensured.

2.4. Data Processing and AI/ML integration

The forecasting of the timing and quantity of water needed for crops is done by the AI/ML element by analysing historical data, current soil conditions, and predefined thresholds for different crops.

Data Preprocessing. Inaccuracies or any ambiguities in the readings are eliminated including handling of the missing values standardizing the data for consistency.

Machine Leaning Model. A dataset consisting of the soil moisture levels is used to develop a regression or classification model. The irrigation timing and the volume of the water for each crop is forecasted. The algorithms used for the machine learning model [Vee20, Raj24, Nan14] are:

- *Random Forest Regression.* The moisture levels are predicted, and the irrigation amount is determined.
- *K-Nearest Neighbours (KNN).* The soil conditions are classified and are aligned with the crop water requirements.
- *Decision Trees.* The irrigation decisions are made based on the current and the past data patterns.

2.5. AI/ML Workflow:

- The historical data such as soil moisture and the crop type and is used to train the model [Nar23].
- The AI/ML model compares the new soil data which is gathered to the pre-trained data set and adjustments in the irrigation settings based on the selected crop are done automatically.
- The recommendations for the appropriate amount of the water to be supplied or whether the soil requires irrigation or not are provided. The Arduino receives back the decision for execution.

2.6. Automatic Irrigation Control

The automatic irrigation system control is enabled by the AI/ML-based decisions [Yad23]. The Arduino that controls the water pump is connected to the relay module. The sequence of steps for irrigation control are as follows:

- *Irrigation Trigger.* The Arduino sends a signal to the relay module based on the AI/ML output if the soil moisture level.
- Falls below the pre-set threshold for the chosen crop.
- *Water Pump Activation.* The water-pump is activated, and the relay module closes the circuit, and the water is supplied to the crop.
- *Duration and Volume*. The AI/ML model is utilized to calculate the volume of water needed and to control the duration of irrigation accordingly.
- *Stop Condition*. When the required soil moisture level is achieved, the data is updated on the sensor and the water-pump is automatically turned off by opening the relay circuit.

2.7. Web Application Interface

The web-application allows the farmers to interact with the system. The user-friendly interface is provided for choosing the crop type and for monitoring the soil moisture levels:

- *Farmer Interaction*. After opening the application, the cultivated crop is selected by the farmers from a provided list, with each having specific parameters such as ideal soil moisture levels and water needs.
- *Crop Information*. The irrigation requirements and the soil moisture data for different crops is kept in the database of the web application, continuously updated with the AI/ML processed data.
- *Real-Time Tracking*. The sensor data is monitored, and the alerts are received by the farmers about their fields.
- *Visual Representation*. The graphical displays of the soil moisture trend, water usage efficiency is presented, and upcoming irrigation schedules are forecasted.
- *Manual Control*. The farmers have the option to override the automatic system control. They can also manually control the irrigation from the web application.

2.8. System Testing and Evaluation:

- *User Interaction*. After opening the application, the cultivated crop is selected by the farmers from a provided list, with each having specific parameters such as ideal soil moisture levels and water needs
- *Crop Information*. The irrigation requirements and the soil moisture data for different crops is kept in the database of the web application, continuously updated with the AI/ML [Isl23] processed data.
- *Real-Time Tracking*. The sensor data is monitored, and the alerts are received by the farmers about their fields.
- *Data Representation.* The graphical displays of the soil moisture trend, water usage efficiency is presented, and upcoming irrigation schedules are forecasted
- *Manual Control*. In the testing a farmer wishes to manually manage the irrigation system, The farmer has the option to override the automatic system control. They can also manually control the irrigation from the web application.

3. System Implementations

The setup of the hardware is done with the development of the software and machine learning algorithms are incorporated. The IoT modules for communication are utilized, and the web application interface is created.

3.1. Sensor and Arduino Setup

A capacitive soil moisture sensor which is connected to an Arduino Uno is placed at a suitable depth to collect moisture data. The analogue signals are sent by the sensor and are converted to digital values by the Arduino converts. This real-time data of the soil moisture level is monitored [Man24].

Relay Module and Water Pump Control. The water pump is linked to a relay module. The water-pump is turned on when the soil moisture level falls below the pre-sets and turned on when the required moisture level is achieved.

IoT Communication. The GSM/Wi-Fi module is used for real-time data transmission to a cloud server and to receive the further commands. HTTP or MQTT protocols are used for monitoring and the Arduino communication is enabled for automating the system.

AI/ML Integration:

- *Data Preprocessing.* The normalization and the cleaning of the data is done [Cha24].
- *Model Training.* Decision Trees and Random Forest Regression is used for predicting the optimal irrigation based on crop type and moisture data.
- *Real-time Decision Making.* The data is analysed continuously, and irrigation is triggered.

Web Application Development. This web-application will allow farmers to monitor real-time soil moisture, and control irrigation based on the crop type. The readings and the irrigation schedules are stored in the database.

Testing and Calibration. The system will require vigorous testing for accuracy in AI predictions and stable IoT communication along with the calibration of the soil moisture sensor for different soil types to ensure precision.

Since educational technology tools have arisen excitement and curiosity amongst students, they recommended other module tutors to use educational technology tools as well. Educational technology tools integrated in the module will be further replicated by student's teacher during teaching practice or as a full fledge teacher. Therefore, tutors were recommended to use variety of educational technology tools in learning, teaching and an assessment.

4. RESULTS

The system utilized for IoT-based soil moisture monitoring and automatic irrigation system produced precise results in terms of water conservation and system efficiency. The results are evaluated based on the system performance in different fields, crop types, and different depths according to the soil type:

4.1. Soil Moisture Monitoring Accuracy

The implementation of the soil moisture sensors produced the accurate results across the various soil types. The system process ensured and demonstrated the accuracy of 95% while detecting the real-time readings and calibrating them with the pre-defined datasets.

Key Observation:

- Improvement in the sensor's accuracy after testing for specific soil types (sandy, loamy, and clay soil).
- Variation in the data due to environmental factors, such as temperature and humidity and data normalization and preprocessing was used to minimize the variability.

Test Scenario: After conducting multiple tests with different soil types, many observations were concluded. For example, sandy soil required recalibration due to faster drainage of water, while loamy soil readings were more stable.

4.2. AI/ML Model Performance

The AI/ML models which were used for irrigation decision- making, made optimal decisions in predicting the irrigation schedule based on real-time soil moisture data and crop selection.

Key Results:

- The accuracy of the forecast was high reaching 92% while performing the calibration of past data with the current soil moisture levels.
- The system was able to change the durations and amount of water applied for different crops which saved on resource materials.
- The model was able to use up to date soil data to understand recent shifts in soil moisture and therefore was able to adjust to changing weather conditions.

Test Scenario. The AI model was developed to be robust enough to be trained with data collected from different crop cycles such as wheat, maize and rice. The system dynamically adjusted the water requirements according to the needs of each crop.

4.3. Water Conservation and Irrigation Efficiency

There was significant water savings recorded with the automatic irrigation system as opposed to manual irrigation practice. The system supplied the exact amount of water required to be supplied to the crop based on the actual moisture content of the soil at the time of irrigation.

Key Observations:

- Overall water usage was reduced by 30–40%, on average, for all test fields during the test period when compared with the average water usage of conventional irrigation techniques.
- The system only supplied water when the moisture levels of the soil went below the predetermined levels, and this helped save the unnecessary use of water.
- This optimal irrigation method improved the crop yields and prevented some issues of excessive moisture like rotting of roots or waterlogging.

Test Scenario. It was observed that the areas scarce on rainfall and utilizing the IoT system used 35% less water than the manually irrigated areas over a duration of 60 days.

4.4. System Reliability and Responsiveness

The system was very dependable during the real-time operation cycles, as the communications module with IoT enabled devices was able to maintain reliable communication connections for all data transfer as well as command receipt. Five seconds was more than sufficient time for properly broadcasting the pump signal following the low soil moisture level detection.

Conclusions. Irrigation system was also accomplished in under 5 seconds from the integration of data to the commencement of watering. The uninterrupted system failed to record any significant failure during continuous operations meeting the requirement of up to hours at a time, even when the area being operated in internally hosted poor connectivity to mobile networks.

Test Scenario. In settings where the network was poor and unresponsive, testing showed that system communication was over ninety percent available, and the system suffered very few downtime.

4.5. User Interaction and Web Application Feedback

The web application was built to assist farmers with easily managing and monitoring their irrigation systems. The use of this application enables users to understand the current soil conditions and water stage usage and how it was turning out, with regard to crop TP (rate of performance).

Key Observations. Irrigation settings were automatically turned on or off as farmers choose crops with distinct cropping data. There were too many graphs that showed the dry and moist trend and the trend of how much water was used for irrigation which also helped them adjust the irrigation in real time so that it was not inefficient. Because complete irrigation timelines were usually needed, there was a manual override option, which was useful for the users since it enabled them to intervene only when appropriate.

Test Scenario. A group of farmers used the web application and provided their feedback to the team showing how the application is easy to use and works quite well. Out of those respondents, 85% were pleased with the success of the system and the way it was designed in terms of the end use.

CONCLUSION

The study highlights an effective IoT-based soil moisture sensing and automatic irrigation system that offers increased efficiency of irrigation activities in agriculture. By employing infrared soil moisture detectors, Arduino control modules with AI/ML decision making and IoT-based communication, the system mechanizes irrigation which enhances its accuracy, and the amount of resource used. The web application interface allows farmers to assess soil types, crops to be planted and schedule irrigation cycles based on the growing needs of the particular crop. Using this method, the system proved to be successful in water conservation by over 40% as compared to conventional methods yet suitable soil moisture conditions for the healthy growth of crops were achieved. Moreover, the AI/ML models used were effective in predicting the irrigation schedules whereas the hardware and the IoT components were effective in the technological integration for agricultural application. Satisfied users have provided positive feedback indicating that the system has a good and balanced practicality and ease of use. Hence there are well placed prospects for promoting environmentally sustainable farming. This work highlights the opportunities lying with IoT and AI in transforming the simple farming activities into smart ones with many advantages such as water savings, productivity and overall resource management.

FUTURE WORK

There is an opportunity to enhance the environmental profile of the system by introducing more environmental sensors such as temperature, humidity, and light intensity. This enhancement will allow trimodal AI/ML model to make more accurate irrigation decisions. The presence of these extra parameters would further improve the weather forecast systems making irrigation corrections more efficient. With the implementation of advanced machine learning algorithms such as deep learning or reinforcement learning, the system will enhance irrigation prediction models and suit a variety of crops and environmental settings. Incorporating a larger and diverse dataset will further increase the model's precision and generalizability. It is also important to make such variable irrigation decisions based on the available rainfall or drought expecting conditions

To increase the system's connection across larger agricultural fields or even multiple fields, there is a need to improve the communication module for long distance data transmission even using mesh networks for large scale usage. Adopting green technologies like solar-operated sensors and controllers would increase sustainability making the system fit for use in rural setups with little electricity supply. A more sophisticated AWS platform that combines data from several farms may allow vast-scale analytics.

The creation of a mobile app capable of sending out push and real time notifications would significantly improve the interaction of users, enabling farmers to get information on soil moisture content, irrigated areas and performance of the system from their mobile devices. This would increase in accessibility and convenience. In order to increase the affordability of the system for small farmers, the use of low-cost sensors, microcontrollers and open-source software should also be considered in future versions. Finally, it can be suggested that the use of an automatic fertilization system responding to real time soil nutrient content can complete the crop management system by ensuring efficient fertilization and irrigation. In addressing these aspects, the system for crop farming can be further developed and commercialized, encouraging environmentally friendly farming practices in different parts of the world.

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Название: Машинный мониторинг урожая: обзор.

Аннотация: В настоящем исследовании представлена автоматизированная система орошения на основе интернета вещей в качестве стратегии управления водными ресурсами для фермеров. Данные о состоянии почвы в режиме реального времени можно собирать с помощью датчика влажности почвы, который подключен к микроконтроллеру Arduino Uno. При посадке сельскохозяйственных культур ИИ с машинным обучением определяет объем и график орошения на основе потребностей сельскохозяйственных культур в воде и влаге. С помощью веб-приложения система становится удобной для пользователя и позволяет фермерам легко вводить тип посаженной ими сельскохозяйственной культуры. Это автоматически управляет процессами орошения в соответствии с потребностями сельскохозяйственных культур, тем самым экономя воду. Улучшается точность орошения и упрощается управление сельскохозяйственными культурами, а также это становится дешевле с точки зрения ресурсов. Этот продукт является шагом к улучшению методов ведения сельского хозяйства для фермеров, поскольку он вносит устойчивость в сельскохозяйственное производство и помогает получать более высокую урожайность при меньшем количестве воды.

Ключевые слова: автоматизированное орошение, искусственный интеллект, управление урожаем, интернет вещей, веб-приложение.

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