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Smart Irrigation System using IOT Device and Machine Learning

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Abstract: ***Agriculture utilizes a considerable quantity of freshwater resources, and conventional irrigation techniques frequently lead to water being wasted because of poor scheduling and insufficient environmental oversight. This document introduces a Smart Irrigation System that combines Internet of Things (IoT) technology and Machine Learning (ML) to enhance irrigation efficiency and promote sustainable farming practices. The system consistently observes factors such as soil moisture, temperature, and humidity through the use of sensors [6]. A Linear Regression model is utilized to forecast soil moisture levels, whereas a Random Forest model suggests appropriate crops based on the conditions of the soil and climate. By using real-time information and predictive analysis, the system decreases water waste, reduces the need for manual work, and improves agricultural productivity.***

Keywords: Smart Irrigation System, ESP32, Internet of Things (IoT), Machine Learning, Linear Regression, Random Forest, Crop Prediction, Firebase, Sustainable Agriculture.

I. INTRODUCTION

Agriculture is important in the provision of a continuous flow of food, as well as contributing to the financial stability of developing nations [3]. Water is widely used for agricultural purposes. Much water used in agriculture is wasted because of inefficiency in current irrigation practices [2]. The management of water is an extremely challenging task for farmers today. As the population increases and climate change occurs, it is necessary to find better irrigation systems [3].

The conventional irrigation practices are not efficient. They involve manual labor or sticking to certain schedules without taking into account the current environmental conditions, like the moisture level in the soil, temperature, and humidity [2]. Sometimes, the crops get too much water or insufficient quantities; hence, much water is wasted, the soil gets harmed, and the yield is reduced [2]. Since it is impossible to predict the weather, the farmer cannot make appropriate decisions on when to irrigate the crops.

Indeed, in recent times, there have been advances in technology that have allowed us to enhance agricultural production. In particular, the Internet of Things, abbreviated as IoT, allows for constant monitoring through sensors of various environmental parameters in the field [2]. On the other hand, Machine Learning, or ML, helps us to analyze the data obtained from sensors and predict future scenarios with accuracy [2]. Therefore, by applying the above technologies, we manage to design irrigation systems that react appropriately to changes in the environment [1]. Irrigation implies using water in the optimal way possible. Irrigation implies the provision of water to the plants when they require it most. Instead of responding to the present conditions, as detected through sensors, irrigation systems use models that predict future events. Prediction about the moisture levels in the soil before the need for water is very essential in knowing when to irrigate crops [9]. With knowledge in advance, farmers know when to take action without wasting water [2]. As a matter of fact, we have had technological developments over time, which have helped us boost our production in agriculture. For instance, we have the Internet of Things (IoT), which monitors different environmental parameters in the field through sensors [2]. Secondly, we have Machine Learning (ML), which enables us to get predictions for the future from sensor data [2]. Therefore, through the application of such technologies, we are able to develop appropriate irrigation systems, which respond to different environmental changes. The term irrigation refers to the optimal utilization of water. It refers to the provision of water to plants whenever necessary. Unlike when we respond to current environmental issues through sensors, irrigation systems work on predictive models. Predictions of moisture in the soil are very important prior to taking any actions. Predictions help farmers to plan and know when they should act without necessarily wasting water [9].

II. PROBLEM STATEMENT

The main drawback in crop irrigation is that it is performed improperly, with no proper tools available for making rational decisions on irrigation [2], [3]. The following three distinct problems can be highlighted in this case.

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A. *Excessive Waste of Water through Improper Irrigation*

Current irrigation practices involve daily watering of crops at a certain time or once the soil becomes dry [2]. They ignore such important parameters as weather temperature and conditions, amount of water consumption by crops, and precipitation rate. As a result, during low-temperature conditions and precipitation, these irrigation practices involve excessive use of water. During high temperatures, they involve insufficient water supply. This leads to an enormous waste of water resources, which is harmful for soil condition and crops themselves [3]. In some cases, improper irrigation leads to excessive moisture levels in the soil that make roots unable to receive oxygen, thus harming crop growth [2], [3].

B. *Irrigation Systems That React*

The irrigation technologies that are based on sensors that detect soil moisture are switched on once the soil becomes excessively dry [1], [6]. As a result, there is a risk that the crops are subjected to the negative effects of drought by the time they are irrigated. The systems that water the crops regularly every day or every night at a certain time, or once the soil becomes excessively dry, cannot take into account the temperature conditions, evaporation level, and precipitation. In case there was a way to predict the time when the soil will become excessively dry, one could begin irrigating the field earlier than expected [9]. Such an approach would allow maintaining appropriate conditions for the crops and preventing them from becoming stressed [2], [9].

C. *Not Choosing the Right Crops*

Another issue that leads to poor water management is the fact that people plant inappropriate crops on their lands. In this case, the yield is likely to be low, and a significant amount of water will be wasted [4], [5]. However, most irrigation technologies do not offer assistance in choosing suitable crops. If we had a system that could recommend crops based on the soil, climate, and other factors, it would make farming more efficient and sustainable [4], [5], [10]. Irrigation and crop selection are closely related to farming operations, and farming operations would benefit from irrigation and crop selection. We need to think about irrigation and crop selection to make farming better.

III. LITERATURE SURVEY

The research works concerning Internet of Things, Machine Learning, and cloud computing have been conducted widely to discover their applications to improve agricultural irrigation [1], [2], [6]. The topic has been analyzed from different angles, but there are four main areas that concern the use of these technologies in agriculture. These are Internet of Things application in automation of irrigation, Machine Learning application in determining if irrigation is required, systems that recommend what crop should be grown, and cloud computing application in monitoring agricultural processes [4], [5], [6].

A. *Using the Internet of Things to Automate Irrigation*

At the beginning, people tried to create systems that would make it easier to irrigate the land by creating sensors controlling water flow. They have used ESP32 – computer for collecting data about soil and air humidity and regulating irrigation pumps on or off [1], [6]. Several research works mentioned these systems, indicating that automation of irrigation could help to decrease manual work and maintain soil humidity constantly without changing water flow rate, which is better than the manual irrigation process [1], [6]. Nevertheless, these systems worked depending on current soil moisture level but did not try to predict what will happen next [2]. Subsequently, humans have developed sophisticated irrigation management systems that have integrated sensors and communicators to facilitate irrigation management. With the aid of sensors and communicators, people were able to control the irrigation system remotely via the internet and mobile devices while utilizing fewer amounts of water [6]. It was found that Machine Learning algorithms could effectively predict soil moisture levels with the help of basic computer systems, thereby reducing water consumption [2], [3], [9].

B. *Determining the optimal time for irrigation with machine learning.*

Machine Learning algorithms have gained significant attention recently due to their ability to determine optimal irrigation times [2]. Studies have shown that machine learning algorithms can produce irrigation programs that consume fewer amounts of water than conventional methods [2], [3]. Linear regression, which is a machine learning algorithm, is often used since it is uncomplicated, easily understood, and efficient when there is a strong relationship between environmental factors and soil moisture levels [9]. Scientists have found that parameters such as temperature and humidity are beneficial in predicting short-term changes in soil moisture levels [9].

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This shows that regression-based models are capable of determining when irrigation should be carried out. Despite some attempts to apply advanced Machine Learning methods, such as deep learning models, these approaches are too intricate for use on basic devices [2], [3].

C. Crop Recommendation Using Machine Learning

The Crop Recommendation System is an innovative technique that helps farmers in deciding the right crop to plant based on the soil condition and climate [4], [5]. In some research studies, machine learning algorithms like the Random Forest have been found useful in dealing with big data sets [5], [10]. These algorithms take into consideration factors like soil PH, soil nutrients, temperature, humidity, and rain to suggest the right crops to grow [4], [5]. The Random Forest model is one such algorithm that is used effectively in agriculture because it handles complex relationships and is not vulnerable to large data sets [10]. But it must be noted that most crop recommendation systems work independently and do not integrate with automated irrigation systems and sensors [4], [5].

D. Cloud Integration and Remote Monitoring

Cloud services are indispensable in designing agricultural monitoring systems that can be accessed remotely [6], [7]. They are important as they facilitate the storage and real-time access of data through various devices. Moreover, cloud services facilitate data analytics, which is vital for improving machine learning models [7]. When crop recommendation systems are linked to the cloud and Internet of Things devices, farmers can keep track of their fields from a distance and make well-informed choices by using real-time and historical data [6], [7]. Services such as real-time databases enable effective communication between sensors, processing units, and user interfaces, which simplifies the overall system experience [7].

E. Research Gap and Motivation

From the analysis carried out concerning other existing solutions to the problem, one can easily tell that most of these systems are designed to solve just one side of the problem. The irrigation automation systems have been created with the intention of giving farmers an opportunity to control the process in real time without making any predictions [1], [6]. Predictive irrigation systems, on their part, give no indication concerning what kind of crops can be grown in the particular environment [2], [9]. Most crop recommendation systems rely on old information and are therefore unable to utilize available sensor information at present [4], [5].
From all this, one can conclude that there is a need for a system where the three processes discussed above are combined. In this case, the proposed system is designed to help solve this particular problem by providing an integrated platform whereby one can improve his/her irrigation practices, choose crops effectively and remotely monitor them through the cloud network [2], [6], [7]. As indicated earlier, the main motivation for this project is a need for having one single system for farming. The crop recommendation systems will therefore play a very critical role.

F. Comparison Table

Study	Approach Used	Advantages	Limitations
Boralkar et al. [1]	IoT-based irrigation using ESP32	Low-cost implementation, real-time monitoring	No predictive capability, limited automation
Thote et al. [2]	IoT + Machine Learning	Improved irrigation efficiency, data-driven decisions	No crop recommendation system
Morchid et al. [3]	Regression-based ML for irrigation	Accurate soil moisture prediction	Limited integration with IoT devices
Kumar et al. [4]	ML-based crop recommendation	Improves crop selection accuracy	Not integrated with irrigation systems
Patel et al. [5]	Random Forest for crop prediction	Handles complex data, high accuracy	Works independently of real-time data
Ramírez et al. [6]	IoT + Cloud-based irrigation	Remote monitoring and automation	Lacks predictive analytics
Proposed System	IoT + ML + Cloud Integration	Predictive irrigation + crop recommendation + real-time monitoring	Requires real-world deployment validation

From the comparison, it is clear that current systems focus on specific areas like automated irrigation or suggesting crops. There is currently no system that effectively combines the ability to predict outcomes, monitor situations in real time, and make intelligent decisions. The proposed system is designed to address this gap.

IV. PROPOSED SYSTEM: CONCEPTUAL OVERVIEW

The Smart Irrigation System consists of four layers. Each layer operates in its own capacity in assisting farmers to irrigate crops. These layers include sensing, storing of data in the cloud, monitoring of decisions through machine learning, and allowing users to view the state of irrigation. Thus, the Smart Irrigation System is capable of making sense of the environment, processing data stored in the cloud, and decision-making processes via machine learning [1].

A. Sensing Layer: Collecting Field Information

This layer forms the foundation of the Smart Irrigation System. Farmers can use this layer for gathering real-time information concerning their farmland. Such information includes soil moisture levels, ambient temperature, and humidity. The data collected at this level enables the system to determine the extent of water that each crop requires [1], [6]. The system also monitors the water content in the tank to prevent the pump from malfunctioning due to lack of water [6].

Data collected from the sensing layer is transmitted to the control unit of the system. The control unit is responsible for analyzing the data and coming up with predictions. Without data collected in this layer, there would be no information to predict any decision in the Smart Irrigation System [2].

B. Cloud Infrastructure: Storing and Sharing Data

The control unit will transmit the data to the cloud. All the data is stored in the cloud, and it helps the system make informed decisions. It acts as a library for storing all the data collected [6], [7]. Cloud computing also assists farmers in monitoring their farm from wherever they are using a smartphone or computer. They are able to know how much moisture and temperature there is in the soil [7].

This method proves to be very effective due to its capability of being scalable. Farmers can add more sensors if they need and monitor larger farms without making any modifications [7]. Cloud computing also enables the system to get better in terms of predicting the amount of water needed by the crops with time. This will assist farmers in utilizing the water effectively and cultivating.

C. Machine Learning Layer: The Intelligence of the Machine Learning Layer

The Machine Learning Layer forms the heart of the intelligent system. It contains two models. Both of them solve a particular issue that farmers deal with [2]. The first one helps to make predictions about the soil moisture. This model is called the Linear Regression Model. The process involves learning from data on how temperature and humidity influence the moisture level of the soil [9]. After training, it learns to apply temperature and humidity data to predict soil moisture levels for the near future. This is the main difference between this irrigation system and traditional ones [2]. In the former case, the system does not wait until moisture drops down to some certain level; rather, it acts in advance. Linear Regression will be the second appropriate machine learning model for this purpose. First, the relation between the variables (temperature, humidity, and soil moisture) is rather clear [9]. Secondly, the algorithm is quite fast; thus, it may be executed by computing devices [2].

The next model makes predictions regarding crop compatibility with weather. Random Forest machine learning algorithm is chosen. It is based on the data about the growth conditions of various crops in terms of temperature, humidity, precipitation, pH of soil, as well as the amounts of nitrogen, phosphorus, and potassium [4], [5]. Having considered all these variables, the algorithm gives recommendations concerning optimal crops [4], [5], [10]. It is efficient when dealing with interdependence of numerous factors and noisy data [10]. Moreover, it is able to produce the list of crops. So, the Machine Learning Layer includes two algorithms providing answers to two crucial questions in agriculture: how much water is needed for a particular crop, and which crop is suitable for the specific field conditions [2], [4], [9].

D. User Interface: Accessibility and Control

Results from the model are presented to the farmers via a web-based or mobile interface linked to the cloud [6], [7]. Information on the sensor data, soil moisture prediction values, and recommended crops is available. The status of the irrigation pump is also available. The interface operates in real time, ensuring that all information presented is up-to-date [7].

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Farmers have the option to intervene at times when they have better knowledge than what the system suggests. Farmers have the option of overriding the system's suggestions [6].

V. EXPECTED OUTCOMES

The system has benefits for agriculture, including managing water, making farming more productive, efficient, and sustainable.

A. Efficient Water Management

The system allows for more efficient management of water usage by employing sophisticated modeling techniques to estimate water levels in the soil prior to irrigation. The irrigation process is not done on a regular basis but depends on whether the plants require it, hence saving a considerable amount of water. Therefore, no water is wasted due to overwatering since all of it goes into the soil, not losing it through runoff and evaporation. By maintaining the required moisture levels in the soil, the system ensures maximum utilization of the available water resources. Some previous systems have proven to be able to save water effectively compared to conventional methods [2].

B. Improved Crop Yield

Watering in a proper way in relation to plants' needs is essential to ensure optimal growth of plants. Therefore, the system takes care of ensuring proper watering of the plants in terms of quantity and frequency, thus ensuring they neither lack nor have excess water. Moreover, it provides recommendations concerning the appropriate type of crop for the specific soil type and climatic conditions. In other words, it promotes productivity because healthy plants result from proper choice of crops to be planted based on environmental conditions. It has been proven that automated systems making such recommendations lead to increased productivity in terms of agricultural yield as a result of proper selection of the crops that fit the specific environmental condition [4].

C. Reduced Human Effort

The automation of the process of watering implies no need to check soil moisture levels and switch water supply manually. The irrigation process is managed automatically through decision-making processes based on available data and forecasts, hence saving time for manual control and supervision. What is more, the whole process is remotely accessible online. Similar solutions have already demonstrated efficiency in reducing human efforts and enhancing productivity [1].

D. Sustainable Agriculture

Sustainable agriculture implies the rational consumption of water resources and other elements [3]. Avoiding the waste of water is critical for maintaining high-quality water and avoiding excess moisture and degradation of the soil [3]. The effectiveness of using water leads to an economization of fresh water due to its growing scarcity [3]. Cultivating different plants and crops is another example of effective agricultural practice, as it helps to rationalize the use of land and soil components [4]. Thus, we can develop sustainable agriculture, which will be ecologically friendly and long-lasting.

E. Data-Driven Decision Making

The system has been created with the purpose of helping farmers in making decisions on the basis of data obtained from the system [2]. They will not have to make guesses anymore but will be able to rely only on the collected data. The system continuously collects information about environment-related issues and makes predictions based on this data [1]. Farmers will be able to use these predictions when making decisions on irrigation and cultivating crops [2]. The use of the Internet and machine learning in these systems is very helpful.

F. Risk Reduction

Farm production and data-based decisions decrease uncertainties in agriculture. There is a lower possibility of low productivity of plants due to bad weather conditions or poor crop quality due to a rational system [4]. The system advises on appropriate agricultural products that will be suitable according to weather conditions and soil quality. In such a way, a lower level of failures occurs [4]. Another point is that the system monitors the level of watering for each plant, which results in better crop growth [2]. The constant monitoring process allows solving problems before they become severe. Such a conclusion can be drawn based on existing literature on the use of machine learning techniques in agriculture [2].

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VI. CONCLUSION

The survey is centered around the Smart Irrigation System. The Smart Irrigation System relies on Internet and IoT technologies to assess the environmental situation [1]. It consists of two interacting components. The Smart Irrigation System attempts to address three issues that farmers experience. They include the excessive waste of water due to the inability to estimate the moment when watering should occur, the use of devices which react to certain events instead of preventing them from happening, and the absence of a recommendation system to assist the farmer in choosing the appropriate crop [2], [6].

From the literature review, it is evident that much effort has been dedicated to the use of Internet-based automation of irrigation practices, IoT-based soil moisture forecasting, recommendation systems of crop selection, and cloud-based farming monitoring [1], [4], [6], [9]. However, these efforts usually remain independent from each other. The Smart Irrigation System seeks to integrate these ideas into one system. One component is responsible for predicting soil moisture content to schedule irrigation activities in advance [9]. Another component is focused on providing recommendations regarding the crops which should be used, taking into consideration soil type and weather conditions [4].

Our hypothesis is that the Smart Irrigation System would facilitate conservation of water, growth of crops, and reduced labor intensity [2]. It would also ensure sustainable use of the land for agricultural purposes [3]. Since it is cloud-based, its use would be flexible, and farmers could use it in any place of their convenience [6]. The smart irrigation systems would be useful in small farms and large farms. They are also easily adaptable in nature and may incorporate such functions like weather forecasts and predictive analysis in the future using advanced machines, as well as facilitating management of water distribution in different fields.

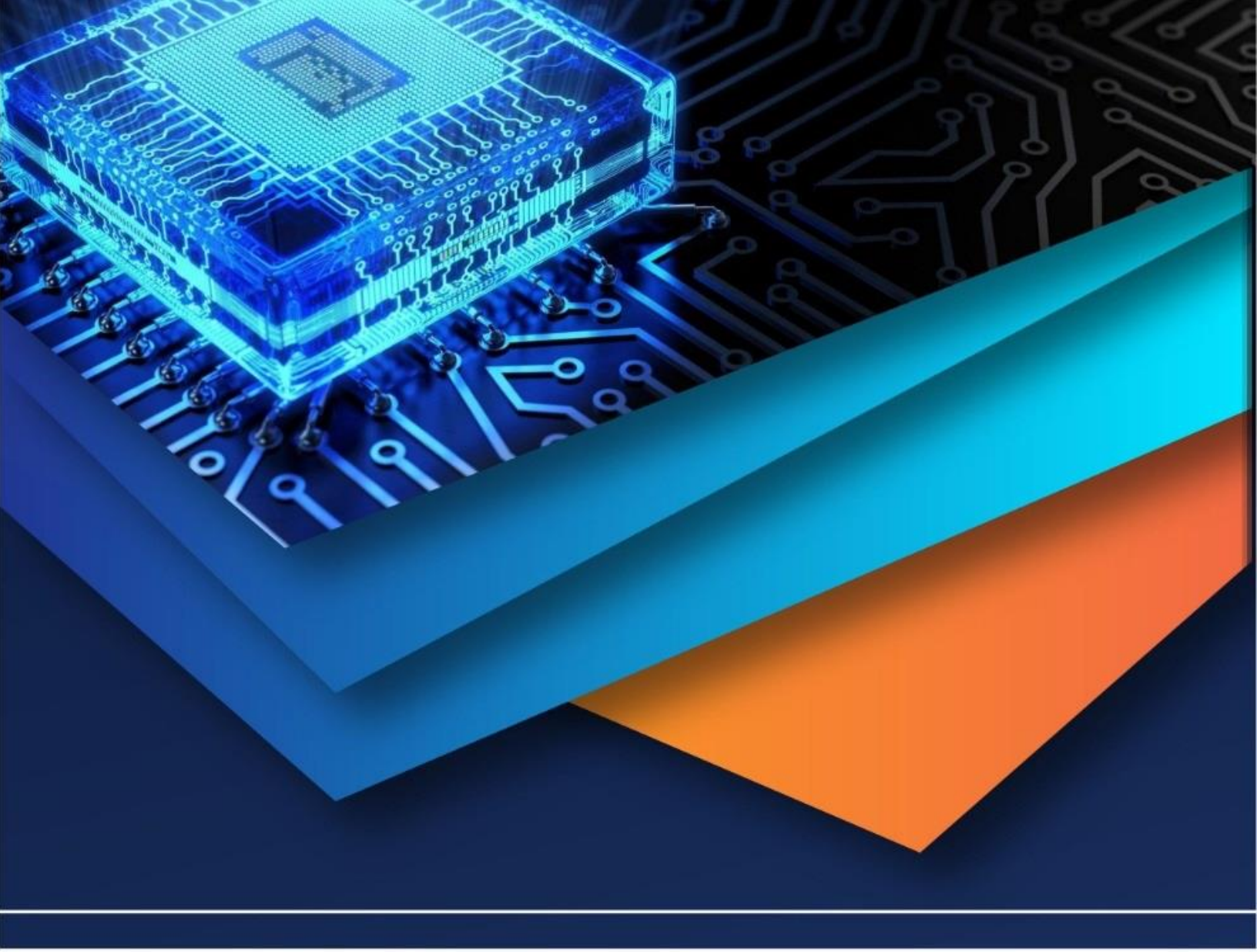
Ultimately, the Smart Irrigation System represents an evolution towards smart technology [1]. It consists of integration of internet technology and machine learning in conjunction with cloud monitoring for the benefit of farmers [1]. These qualities make the smart irrigation system an important technological tool in helping farmers conserve water, cultivate crops, and manage the earth.

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