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IoT Integration for Enhanced Turmeric Cultivation: A Case Study in Smart Agriculture

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Abstract. The agricultural sector serves as a fundamental cornerstone of the economies of numerous countries, necessitating technological advancements despite limited financial resources. The Internet of Things (IoT) presents a novel aspect within the field of soil health monitoring, which has significant implications for advancing smart agriculture and farming practices. Integrating conventional agricultural practices with cutting-edge technologies, such as the IoT and Wireless Sensor Networks (WSN), can foster Smart Agriculture (SA). This paper presents IoT Integration for Enhanced Turmeric Cultivation (IoT-ETmC) in the context of SA. The TurmFox IoT and Edge-to-Cloud (ETC) technology can analyze gathered data and send it to the user through internet connectivity. The work involves the implementation of TurmFox in experiments focused on turmeric cultivation. The results demonstrate a notable improvement in the quality of turmeric as a direct outcome of this intervention. The curcumin levels in the given product are notably higher, ranging from 4450 to 5450 mg per 120g. This paper also aims to demonstrate the intuitive configuration of sensor-to-actuator connections for implementing desired SA. The real-time data obtained from Turmfox provides information on the pH values, moisture levels, and temperature, allowing for observing dynamic variations in environmental conditions within the specified period. The pH level was 6.5 at 09:00, with a moisture content of 51 g/m^3 and a temperature of 293 K.

1 Introduction

Currently, most arable lands have been effectively utilized for agricultural purposes. To enhance crop yield, given the constraints of limited cultivation resources, it is imperative to enhance production efficiency through the implementation of precision farming techniques. Several IoT techniques have been employed to enhance the practice of raising crops [1]. IoT sensors gather data about various aspects such as soil conditions, atmospheric conditions, and crop development. IoT switch devices are utilized to regulate agricultural actuators, including but not limited to spray mechanisms, drip irrigation systems, and repellent lights. Integrating fertilization, watering, and pest management processes in an IoT system is facilitated by collaboration among sensors, controllers, and actuators. This integration contributes to improving crop development, thereby enabling precise distribution of crop products.

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By identifying irregularities in the growth patterns of crops, we can effectively reduce the potential risks associated with crop yield. According to estimates, the SA market is projected to experience an annual growth rate of 12.7%. Nevertheless, several factors substantially impact the advancement of the SA sector. Numerous studies on intelligent agriculture have been undertaken to establish evidence of theory or execute small-scale practical trials. A sophisticated hydroponics system has been devised to streamline the cultivation process of crops through the utilization of the Bayesian Network algorithm. A significant increase of 60% in lettuce production has been observed. The direct applicability of small-scale trials to large-scale business processes remains uncertain. Commercial solutions have promoted the practice of large-scale soil farming [2]. Commercial Internet of Things (IoT) products for agricultural applications exhibit a high-cost factor. In addition, certain products pose challenges in terms of installation and incur substantial maintenance expenses. The concerns mentioned above impede the farmers' acceptance of the implementation of SA [3].

Turmeric, scientifically known as Curcuma longa, has been widely utilized in conventional healthcare and culinary applications for an extensive period. It is highly esteemed for its unique flavor and vivid hue and its perceived potential in promoting health and well-being. Nevertheless, the growing of turmeric encounters various challenges, including climate shifts and the supervision of soil health. Incorporating IoT technologies offers a potential solution for overcoming these obstacles, as it can revolutionize traditional agricultural methods by making them more intelligent and adaptable. The optimal range for soil moisture typically falls within 60% to 70%. These factors directly impact the condition of plants and the functioning of microbial populations in the rhizosphere. The regulation of pH levels and adequate aeration are crucial for maintaining optimal conditions in the soil ecosystem [4].

A balanced soil ecology is crucial in promoting optimal turmeric yield. Several microorganisms, including Plant Growth-Promoting Rhizobacteria (PGPR) and ectomycorrhizal fungi, establish a symbiotic association with plant roots, facilitating the transfer of intractable minerals to enhance plant nutrient uptake [5]. Employing a system that gathers current information on Electrical Conductivity (EC), pH levels, and soil moisture makes it possible to train a fertilizer control model to cater to the unique requirements of a particular farm. The model mentioned above subsequently offers a suitable fertilizer solution for the farmer to maximize the yield of turmeric during the entire cultivation process. The correlation between salt quantity and EC can be mathematically represented by a quadratic equation, as stated in reference [6].

This study's main aim is to examine IoT's potential in enhancing the efficiency of turmeric cultivation practices. Implementing a network comprising sensors and actuators within turmeric fields allows for collecting real-time data pertaining to significant environmental factors, including temperature, soil moisture, and humidity. This data can provide helpful information about the crop's growth cycle and overall condition when combined with sophisticated analytics and ML algorithms. Consequently, farmers are empowered to make well-informed decisions regarding SA [7].

This paper presents a case study that centers on the practical application of IoT technology in turmeric cultivation. This study aims to utilize smart sensors and IoT devices to effectively monitor and regulate environmental variables, thereby establishing an optimal growth condition for turmeric. Furthermore, the incorporation of automated systems for watering and handling nutrients, guided by insights from the IoT, aims to improve resource usage efficiency, minimize waste, and ultimately maximize crop yield [8]. Additionally, this study examines the financial and ecological impacts associated with implementing IoT technology in the production of turmeric. Implementing IoT technologies in agriculture seeks to enhance sustainability and promote sustainable methods by optimizing resource utilization and reducing ecological impact. The present study not only tackles the immediate obstacles encountered by turmeric farmers but also reflects the broader objectives of global SA.

2 Related works

The review comprehensively analyzes pertinent studies, research articles, and innovations in SA, establishing the foundation for the subsequent discourse on the practical application and results of IoT integration in the case study.

In their study, Rokade et al. (2022) put forth an Intelligent Data Analytics Framework for Precision Farming that leverages the IoT and regressor ML algorithms [9]. The methodology encompasses the integration of IoT devices to gather data and the utilization of regressor ML algorithms for predictive analytics in the field of precision farming. The implementation demonstrates the practical utilization of the framework in real-world contexts. The output encompasses enhanced decision-making in agricultural practices, as evidenced by improved crop yield and optimized resource utilization. Data-driven decision support offers numerous benefits. However, it is important to acknowledge potential drawbacks, such as the requirement for a reliable IoT infrastructure and the availability of high-quality training data for models.

The authors Sengupta et al. (2021) introduced FarmFox, an IoT device equipped with four sensors explicitly designed for precision agriculture purposes. The methodology encompasses creating an IoT device outfitted with sensors to monitor a range of agricultural parameters [10]. The process of implementation entails the deployment of FarmFox within agricultural fields. The resulting data provides real-time information regarding environmental conditions.

In their recent study, Ponnusamy and Natarajan (2021) put forward the concept of precision agriculture, which leverages cutting-edge technologies such as the IoT, Unmanned Aerial Vehicles (UAVs), Augmented Reality (AR), and Machine Learning (ML) [11]. The methodology incorporates a variety of technologies to facilitate holistic farming operations. The resulting outcomes encompass enhanced crop monitoring and management. Holistic farming administration offers various advantages. However, the seamless integration of diverse technologies may present challenges. Kour and Arora (2020) conducted a comprehensive survey that focused on the latest advancements in the IoT field, specifically in agriculture [12]. The methodology thoroughly examines the current body of literature on the utilization of IoT applications within the agricultural sector. The resulting output is a comprehensive survey paper that delineates the diverse applications of the IoT within the agricultural sector.

The authors Chaganti et al. (2022) proposed implementing a security monitoring system in the field of SA, utilizing blockchain technology and the IoT. The methodology encompasses the integration of blockchain, cloud computing, and IoT to augment security [13]. The implementation demonstrates a monitoring system that prioritizes security. The output encompasses enhanced security measures within agricultural operations. Utilizing blockchain technology in agriculture offers notable benefits in terms of heightened data security. However, it is important to acknowledge that there may be potential drawbacks associated with implementing blockchain in this industry, particularly its inherent complexity.

The study conducted by Lin et al. (2022) introduced a method for predicting Bacillus numbers in smart turmeric farms using small data sets based on an IoT framework. The methodology employed in this study entails using IoT devices for data collection, coupled with the application of machine learning techniques to predict Bacillus numbers [17]. The implementation primarily centers around intelligent turmeric farms. The results encompass predictive models for the quantification of Bacillus populations [18].

In their study, Rokade and Singh (2021) analyzed a greenhouse management system that employed ML-based IoT technology to enhance efficiency and productivity in the field of SA. The methodology examines a greenhouse management system that utilizes IoT and ML techniques [15]. The execution showcases the efficacy of the system within greenhouse environments. The results encompass enhanced techniques for managing greenhouses. The advantages enhance the utilization of resources, while the potential drawbacks may arise from the requirement of advanced IoT and ML models.

In their study, Chen et al. (2019) introduced AgriTalk, an IoT system designed to manage soil conditions in turmeric cultivation precisely. The methodology incorporates IoT devices to monitor soil conditions and utilizes data analytics techniques for precision farming [16]. The execution of the project entails the deployment of AgriTalk within turmeric farms. The results encompass improved techniques for managing soil. One of the notable benefits of precision farming is its ability to enhance accuracy and efficiency in agricultural practices.

In summary, the literature review thoroughly examines the present status of IoT integration in the agricultural sector, focusing particularly on the cultivation of turmeric. The synthesis of findings from multiple studies demonstrates a collective trend toward adopting precision farming techniques and incorporating intelligent technologies. The survey underscores the wide array of IoT applications, such as the deployment of sensors, data analytics, and automation, thereby demonstrating their capacity to transform conventional farming practices.

3 IoT Integration for Enhanced Turmeric Cultivation (IoT-ETmC) in the context of SA

Turmeric, a tropical perpetual herb, thrives in regions characterized by warm and humid climates. The rhizomes of this plant are collected every year following the cultivation process. Several factors have been identified as influential in determining the amount and quality of turmeric cultivation. The optimal temperature range for the cultivation of turmeric falls between 25 °C and 35 °C, accompanied by an annual rainfall of 15.50 cm or greater. The optimal range for soil moisture is typically observed to be within the 65% to 75% interval. These factors directly influence the condition of plants and the functioning of microbial populations at the rhizosphere. The regulation of soil conditions, specifically pH levels and adequate aeration, is crucial for maintaining a suitable soil environment [14].

By employing a system for collecting real-time data on temperature, EC, pH levels, and soil moisture, it becomes possible to develop a fertilizer control model tailored to a particular farm's unique requirements. This model subsequently offers a suitable fertilizer option to the farmer to maximize the turmeric yield during the entire cultivation procedure. A quadratic equation can mathematically represent the correlation between the quantity of salt and EC. Through the utilization of this concept, we initially deduced overarching equations to articulate the correlation between the EC as the independent variable and the nitrogen (N), phosphorus (P), and potassium (K) values as the dependent variables. Subsequently, experiments were conducted in Bao fields, wherein different combinations of N, P, and K were employed, and the corresponding EC values were measured. These experiments were undertaken to calibrate the overarching equations. Ultimately, the equations representing the variables N, P, and K were derived in the following manner. The given equations are as follows:

$$F_N(x) = 64.36x^2 + 15.32x + 0.18 \tag{1}$$

$$F_P(x) = F_K(x) = 32.73x^2 + 8.21x + 0.19 \tag{2}$$

Equations (1) and (2) are employed within a three-layer neural network framework to forecast the turmeric yield, specifically the weight of the rhizosphere. The input layer consists of the volumes $[x_k(1 \leq k \leq 3)]$ of N, P, and K that are applied to the soil, measured in kilograms per hectare $(\frac{kg}{ha})$. The hidden layer is comprised of three neurons. The output layer of the model consists of the anticipated efficiency, denoted as y, measured in metric tons per hectare $\left(\frac{MT}{ha}\right)$. The standard derivation is omitted in this analysis. Instead, we present the final equation iterated in the framework as follows: The equation for the dependent variable y at point q is represented as a linear function, where it is determined by the sum of the products of the independent variables x and their corresponding weights m, subtracted by the threshold value θ.

The symbol $y(q)$ represents the estimated turmeric yield acquired at the q-th iteration. Similarly, $x_k(q)$ denotes the input for the k^{th} neuron in the hidden layer, $m_k(q)$ represents the weight of the k^{th} neuron in the hidden layer, and θ symbolizes the bias of the output layer. The equation mentioned above is iterated until the variable θ reaches convergence. The relationship between the weight of the rhizosphere (denoted as y) and the curcumin content (expressed as a percentage, denoted as z) in the Bao-3 field is determined using the equation as follows:

$$z = 0.102y + 1.152 \tag{3}$$

In crop harvesting, a comparison is made between the actual yield and the estimated productivity z to verify Equations (1) and (2). After several rounds of verification, the equations that describe the link between EC and yield will become more precise and tailored to a specific farm. In essence, the variable y (and also z) is employed to assess the growth rate. Subsequently, Turmfox regulates fertilizer application by employing Equations (1) and (2), considering the value of y concerning the desired target range, denoted as $z = 4550 \sim 5550$ mg/150g. The user's text does not contain any information to be rewritten. In the Bao-3 field, the N fertilizer threshold is approximately 135 g/m^2 per week, while the P and K thresholds are around 65 g/m^2 per week.

3.1 IoT-ETmC

This section provides a comprehensive presentation of the architecture of TurmFox. Fig. 1 depicts the hypothetical architecture of IoT-ETmC. The conventional conceptual framework of WSN has been adhered to in the transition towards the architecture of the IoT.

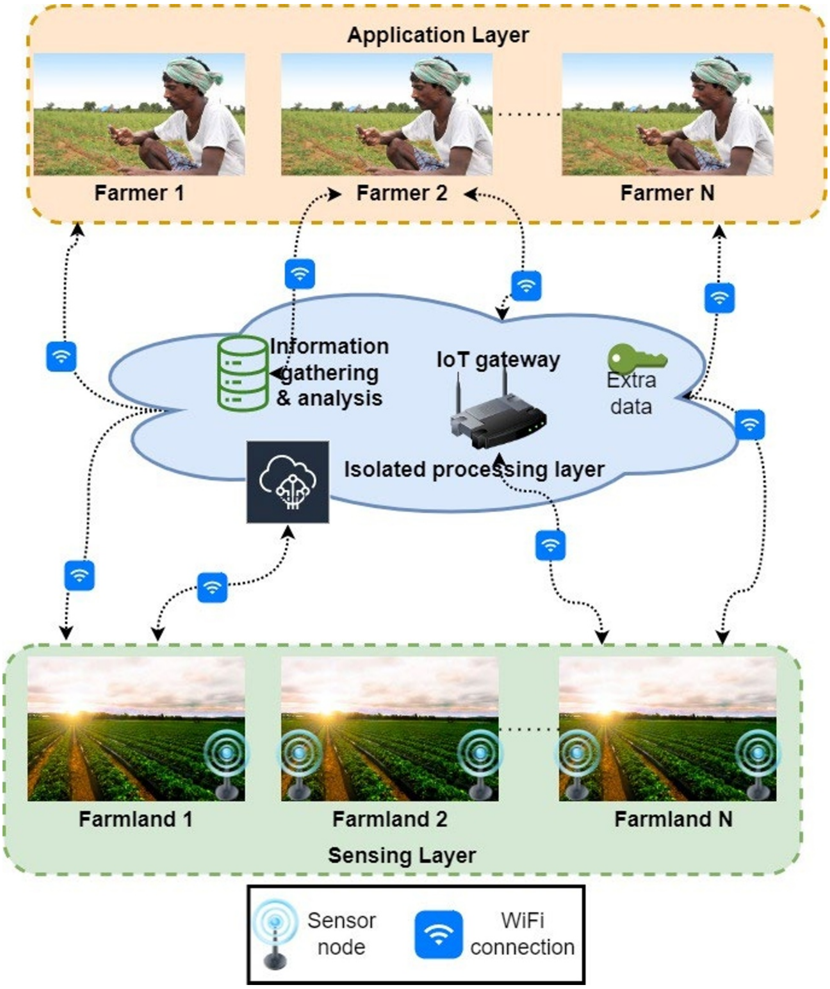

Fig. 1. Overall architecture of IoT-ETmC

The principal structure can be categorized into three distinct layers:

Sensing Layer:

The Sensing layer serves as the central component of this device. Within this particular stratum, sensor nodes are strategically deployed across the designated area to detect and gather pertinent data. The data is transmitted to the IoT gateway via a WiFi connection. The gateway nodes subsequently transmit information to the remote server through packets. Integrating WiFi within the architecture of the IoT facilitates the essential communication required for the seamless integration and interaction between physical and digital components, forming a cyber-physical system. The USP of this system lies in its utilization of Electronic Programmable Read-Only Memory (EPROM) to save sensing information, thereby guaranteeing data integrity in the event of a power outage.

Isolated processing layer:

The layer serves as the device's central processing unit, facilitating the connection between the application layer and the sensor layer. This layer is responsible for processing the requests received from the upper and lower layers of IoT-ETmC. The isolated processing layer is responsible for managing and overseeing operations in the field from a distant location.

Application layer:

The application layer is a crucial component of the network protocol stack. It is responsible for providing services and applications that enable user interactions with the network. The application layer facilitates the visualization of information gathered by farmers and analytics personnel on their mobile devices and computers. Farmers can trace the precise position of a specific node by utilizing a web connection and a GPS tracking system. The application layer plays a crucial role in retrieving outputs that can be analyzed to identify actionable insights, thus strengthening the decision-making process and improving soil quality.

3.2 Unified design of Turmfox

Four pre-tuned electronic sensors were utilized to measure four essential parameters: moisture, temperature, EC, and pH. These metrics facilitate soil health tracking, enabling farmers to leverage this information to enhance crop productivity. The IoT-ETmC development incorporates four sensors: the V2 soil moisture sensor, soil temperature sensor, EC sensor, and soil pH sensor. The sensors are linked to the Arduino Nano R3 microcontroller, which can be submerged up to a depth of 25cm within the soil to assess moisture, temperature, and pH levels. The EC sensors are strategically deployed in the field to accurately assess the level of precipitation in the water utilized for watering applications. The determination of EC, in conjunction with pH measurement, can provide valuable insights into the present state of soil health for analysis. This demonstrates the robustness of the IoT-ETmC system.

By continuously monitoring the changes in electrical conductivity (EC) values, it is possible to determine the optimal timing for fertilization using Equations (1) and (2). This approach can effectively enhance the chlorophyll content in turmeric plants. Chlorophyll levels in leaves were quantified using the Soil-Plant Analyses Development (SPAD) method.

The IoT gateway holds significant importance within any IoT ecosystem. The device functions as a means of facilitating communication between various components, such as sensors and the Internet, as well as Bluetooth devices equipped with a cloud interface. Additionally, pre-processing the raw data aids in reducing latency and enhancing capacity at the edge. The TurmFox system employs an IoT gateway to facilitate the transmission of information from the field location to the sink node, enabling the subsequent analysis of the collected data. Two widely utilized protocols, WiFi and Transmission Control Protocol (TCP), are employed to fulfill the abovementioned objective. A website has been developed to manage and oversee sensor operations.

Additionally, it facilitates the acquisition of sensor information. Upon registration on the website, each gateway acquires a unique user ID that is assigned arbitrarily. A solar panel with a lithium-ion battery has been employed to provide power to the sensor nodes.

In the context of the proposed design, two distinct server systems have been successfully implemented. The two types of servers referred to are the storage and web servers. Storage servers are a hub for storing all data, regardless of relevance. The web server is utilized to store web server software and the individual files of a website. The servers are deployed within a cloud infrastructure. Utilizing these two servers facilitates the TurmFox system in remotely monitoring soil conditions.

4 Results and discussion

Turmfox has been implemented in the fields near Erode, Tamilnadu, India, from January 2022 to February 2022. The sensors utilized in the examined area of the study gather data about soil moisture, temperature, EC, and pH. This data is subsequently stored within the FarmFox system's internal EPROM, which has a capacity of 512 bytes. The collected data is promptly transmitted to a linked cloud repository. Therefore, the collective can be remotely accessed using a personal computer connected to the Internet. The parameters used for testing Turmfox have been shown in Table 1.

Table 1. Parameters used for testing Turmfox

Parameter	**Value**
Area of the field	0.004 Acre
Number of sensor nodes	4
Sensing interval	240 seconds
Transmitting interval	120 minutes
Transmission range	150 m
Transmission protocol	WiFi, TCP
Experiment interval	40 days

One notable characteristic of the FarmFox model is its ability to retain sensed data without a reliable internet connection. Instead of losing the data, it is securely stored in the EPROM. Once the internet connection is restored, the information will be transferred to the cloud storage. Therefore, evaluating time-series data and applying various statistical and ML techniques are significantly facilitated. Furthermore, accumulating data over an extended period will establish the foundation for a future database dedicated to the analysis of big data. This, in turn, will contribute to the progression of a SA system.

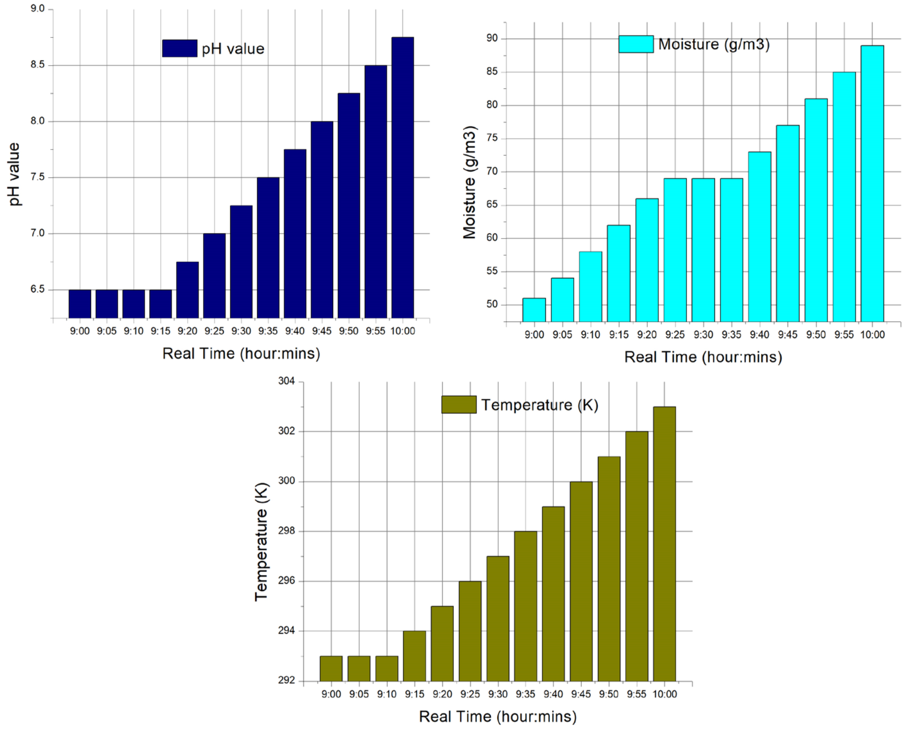

Fig. 2. Real-time sensor output for pH values, moisture, and temperature using Turmfox

Fig. 2 shows the real-time sensor output for pH values, moisture, and temperature using Turmfox. The real-time data obtained from Turmfox provides information on the pH values, moisture levels, and temperature, allowing for observing dynamic variations in environmental conditions within the specified period. The pH level was measured to be 6.5 at 09:00, accompanied by a moisture content of 51 g/m^3 and a temperature of 293 K. Following this, there is a progressive rise in pH levels, culminating in a value of 8.75 at 10:00. The observed increase in moisture content, which varies between 51 g/m^3 and 89 g/m^3, is concurrent with the upward trend. Concurrently, the temperature gradually increases from 293 K to 303 K. The observed correlation among these parameters implies a potential impact on the cultivation of turmeric, as the maintenance of optimal pH, moisture, and temperature levels is crucial for the overall well-being and productivity of the crop. The utilization of real-time sensor data acquired via Turmfox provides significant and valuable insights into the dynamics of the environment. This, in turn, facilitates informed decision-making in agriculture and allows for precise real-time adjustments to cultivation practices.

a) Conventional SPAD: 21.2, b) Turmfox SPAD: 32.7, c) Conventional SPAD: 31.4, d) Turmfox SPAD: 44.7

Fig. 3. The quantification of chlorophyll levels in turmeric leaves using conventional and IoT-ETmC method

Fig. 3 depicts the quantification of chlorophyll levels in turmeric leaves using conventional and IoT-ETmC methods. Fig. 3 illustrates the impact of increasing chlorophyll levels through implementing flexible fertilization management via IoT-ETmC. The utilization of IoT-ETmC significantly increases the SPAD value, ranging from 42% to 53%. Turmeric rhizome with IoT-ETmC has up to 4450 to 5450 mg per 120g of curcumin, five times more than conventional products.

5 Conclusion

This paper introduces the concept of IoT Integration for Enhanced Turmeric Cultivation (IoT-ETmC) within the context of SA. The TurmFox IoT, ETC technology can analyze collected data and transmit it to the user via internet connectivity. The study entails the utilization of TurmFox in experimental trials centered on the cultivation of turmeric. The findings indicate a significant enhancement in the quality of turmeric as a direct consequence of this intervention. The curcumin concentrations in the provided product are considerably increased, with values ranging between 4450 and 5450 mg per 120g. This paper aims to illustrate the intuitive arrangement of sensor-to-actuator connections to achieve the desired sensor-actuator configuration. The data collected in real time from Turmfox offers insights into pH values, moisture levels, and temperature, enabling the examination of dynamic fluctuations in environmental conditions during the designated timeframe. At 09:00, the pH level was determined to be 6.5, while the moisture content was recorded as 51 g/m^{3,} and the temperature was measured at 293 K.

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