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Enhancing Agricultural Practices in a Globalized World through Digital Technology

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Abstract: With the rapid progress of basic sciences, the role of digital technology has gained increasing importance, particularly in the field of agriculture. In a globalized context, agriculture stands at a crossroads where digital technology emerges as an essential ally to strengthen this sector vital for economies such as Colombia. Digital agriculture encompasses a range of tools, including data collection and analysis, the implementation of the internet of things (IoT), automation, robotics, and artificial intelligence. These technologies empower farmers to make informed decisions, optimize resources, and increase efficiency. The fundamental purpose of this article is to preserve water and mitigate climate change through the implementation of digital agriculture practices. This study was conducted in the locality of Tuluá, Colombia, with a specific focus on the cultivation of medicinal, aromatic, and condimentary plants (PMAC). An intelligent irrigation system was conceived that collects data through specialized sensors that monitor irrigation flow, soil moisture, weather conditions, pH, water level, and water quality. This system, supported by PLC and IoT technology, enables remote control of the valves. The results underscore the reasonability, reliability, and viability of this solution, addressing the inefficiencies inherent in traditional water usage in agriculture and promoting sustainable irrigation practices. The emphasis on soil moisture management as a determining factor in irrigation decision-making is not only adaptable to various crop varieties but also represents a substantial improvement in regional agricultural development, benefiting the local community. It is anticipated that this initiative could also have a significant impact on water preservation, which is an essential element in agricultural processes, thereby contributing to the sustainability and resilience of the sector.

Keywords: programable logic controller, smart irrigation, the internet of things, digital agriculture, water preservation.

利用数字技术改善全球化世界中的农业实践

摘要：随着基础科学的快速发展，数字技术的作用日益重要，尤其是在农业领域。在全球化背景下，农业正处于十字路口，数字技术成为加强这一对哥伦比亚等经济体至关重要的部门的重要盟友。数字农业涵盖一系列工具，包括数据收集和分析、物联网(物联网)的实施、自动化、机器人技术和人工智能。这些技术使农民能够做出明智的决策、优化资源并提高效率。本文的基本目的是通过实施数字农业实践来保护水资源并减缓气候变化。这项研究是在哥伦比亚图卢阿地区进行的，特别关注药用、芳香和调味植物(太平洋航空委员会)的种植。设计了一种智能灌溉系统，该系统通过专门的传感器收集数据，监测灌溉流量、土壤湿度、天气条件、pH 值、水位和水质。该系统由 PLC 和物联网技术提供支持，可以远程控制阀

门。研究结果强调了该解决方案的合理性、可靠性和可行性，解决了传统农业用水固有的低效率问题，并促进了可持续灌溉实践。强调土壤水分管理是灌溉决策的决定性因素，这不仅适用于各种作物品种，而且代表了区域农业发展的显著改善，使当地社区受益。预计这一举措还将对水资源保护产生重大影响，水资源保护是农业过程中必不可少的要素，从而有助于该部门的可持续性和复原力。

关键词：可编程逻辑控制器、智能灌溉、物联网、数字农业、水资源保护。

1. Introduction

In history, the development of agriculture has been closely linked to the evolution and dynamics of rural territories in both Latin America and Colombia [1]. Agriculture has the capacity to exercise multiple functions for the development of people, economic growth, environmental sustainability, poverty reduction, and achievement of higher levels of equity and food security. In this way, agriculture is not only based on elementary primary activities but also considers a set of interrelations that are established from it. This set of economic activities is called the agri-food industry or agro-business complex [2]. However, although agriculture is of great importance in a country like Colombia, it should not be forgotten that this activity constitutes around 70% of the world's water use. On the one hand, it is necessary to use less water for agricultural practices; on the other hand, the more intensive use of water in agriculture is a basic element in the sustainable increase of food production [3]. To resolve this dilemma, it is necessary to reconsider the management of water in the agricultural sector and, in a broad sense, the general management of water resources and water security [2].

Effective water management in irrigation practices relies on selecting appropriate systems to ensure the adequate quantity, quality, and timing of water delivery to crops, thereby meeting their needs and enhancing agricultural productivity [4]–[6]. The use of modern technology makes it possible to implement an intelligent and efficient irrigation system, improve efficiency in the use of water resources, and reduce production costs, thus transforming traditional irrigation agriculture into precision agriculture [7], [8].

In recent years, the internet of things (IoT) has become a promising technology that combines computers, sensors, and networks to monitor and control different devices, taking advantage of advances in computing power, miniaturized electronic components, and network interconnections to exchange information [3], [9], [10].

This article outlines a blueprint for developing an intelligent irrigation system using a programable logic controller (PLC) and the IoT technology for the cultivation of medicinal, aromatic, and condimentary plants. The setup incorporates sensors to establish a real-time monitoring network, which gathers data on parameters like irrigation flow, soil moisture, meteorological conditions, pH levels, container water level, and water quality. The collected information is overseen by specialized computer monitoring software. On the basis of decision factors derived from soil moisture levels, the system optimizes irrigation water usage, minimizing wastage within a manageable range. This design ensures a high-performance, efficient, and water-saving operation for enhanced quality in crop cultivation. Currently, a smart irrigation system has been designed for medicinal, aromatic, and condimentary plants located in the agroecological farm of the Unidad Central del Valle del Cauca in a rural area of Tulua city in Colombia. By employing a comprehensive array of technologies encompassing communication, sensing, networks, computer hardware and software, water resource management, and agricultural water conservancy engineering, a smart irrigation system has been devised. This system integrates functions such as prioritizing water conservation, intelligent monitoring, automatic control, and visual display directly within the crop area and remotely.

The research at hand explores the dynamic intersection of agriculture and digital technology in the context of a globalized world, with a specific focus on its significance for economies like Colombia [11]-[13]. Digital agriculture encompasses an array of innovative tools, including data collection and analysis, the integration of the IoT, automation, robotics, and artificial intelligence. These technological advancements provide farmers with the means to make informed decisions, optimize resource utilization, and enhance overall operational efficiency [14]. This study primarily focuses on addressing the pressing challenges of water conservation and climate change mitigation through the lens of digital agriculture. It unfolds within the setting of Tulua, Colombia, with a particular emphasis on the cultivation of medicinal, aromatic, and condimentary plants. This research focuses on the design and implementation of an intelligent irrigation system that employs an array of sensors to monitor key parameters such as irrigation flow, soil moisture, climatic conditions, pH levels, water levels, and water quality. Moreover, the incorporation of software facilitates remote valve control. The findings of this investigation underscore the reasonability, reliability, and viability of the proposed PLC and IoT-based system. It successfully addresses longstanding inefficiencies in traditional agricultural water usage, thereby promoting sustainable irrigation practices. In addition, the study emphasizes the adaptability of soil moisture as a critical determinant in the decision-making process for irrigation, making it a valuable model for a wide range of crop varieties.

2. Methodology

2.1. General System Structure

The smart irrigation system comprises five units:

Data collection unit: Real-time monitoring and extraction of information in the irrigation area is conducted through various monitoring points. These points include monitoring the water level in the containers, water quality, flow rate, humidity levels, pH levels in the field, meteorological data, and the operation of solenoid valves.

Data processing and visual display unit in the crop area: based on the IoT technology and using the Siemens LOGO 8 PLC. This union technology allows the automation, control, and establishment of the internal communication network of the system through Ethernet/communication technology and an embedded web server. This system utilizes an optical fiber communication network and a video monitoring system to achieve centralized network monitoring and visual display of the crop system.

Real-time data collection and statistics unit: Using the B/S structure, the webpage is designed to present historical and current monitoring point data.

Decision factor monitoring unit: In the smart irrigation system, the determination of irrigation necessity relies on the soil moisture level in the field. Using a pre-established soil moisture threshold, the system automatically assesses any deviation from this set value, predicting the required irrigation flow based on the magnitude of the disparity. Users can then regulate the opening or closing of the relevant solenoid valve and simultaneously monitor the flow, guided by real-time monitoring outcomes.

Remote engineering station: In the Faculty of Engineering of the Unidad Central del Valle del Cauca, a remote data visual display unit is projected through SCADA, with which the irrigation area can be remotely monitored. In addition, it provides interfaces for downloading and printing files, graphics for basic information, and information from the monitoring points in the crop.

2.2. Hardware Design

Electrical-electronic system: This system is equipped with an analog signal card that connects to the network sensors for monitoring the flow rate, soil moisture levels, meteorological data, pH levels, container water levels, and water quality. Following logical operations, the system transmits control signals to individual execution elements, overseeing the regulation of the associated solenoid valves and flow. The system features an extension of digital inputs and outputs, enabling scalability. This scalability implies the capacity to expand the number of solenoid valves without necessitating alterations to the electronic systems—only adjustments to the physical hydraulic systems and PLC programing software are required.

Simultaneously, to achieve remote control functionality, the central control unit is linked to a server to receive data from the on-site control within the agricultural field. The primary board operates on a single-phase 110 VAC power grid and draws power from a 450-watt photovoltaic system equipped with a 1000-watt inverter. This setup enables system expansion to accommodate growing electrical demands. In the same way, to ensure that the crop is not affected during failures or preventive maintenance of the panel and battery system, the system is equipped with both panel power and local power network connectivity through an electronic transfer with manual/automatic selection. A LOGO TDE touch screen was installed on the local control board to control and monitor the corresponding valve and display the working status of the filling pump. The visual display shows the sensors for humidity, pH levels, temperature, container water level, and flow valve position. In addition, you can view and control all the above parameters through remote monitoring software in administrator mode that will have all accesses for security reasons.

2.3. Hydraulic System

The hydraulic mechanism functions by utilizing gravity. An elevated reservoir is filled by a pen-type pump submerged in the farm tank. Two hydraulic supply lines are then created: one with a 4" diameter for the drip irrigation system, which is later reduced to 1/2" for the distributed valve system (SDV). This system functions in parallel with double ball valves and solenoid valves. The valve assembly comprises 10 normally closed solenoid valves operating at 110 VAC, with a 4" valve (before the reduction from 4" to 1/2") responsible for regulating water pressure and flow; the second line is dedicated to the hydroflow system, which oversees sprinkler irrigation. This system is especially crucial during the summer season to combat the high temperatures that medicinal plant crops are exposed to.

2.4. Software Design

The system operates on hybrid C/S and B/S software architecture. The development language utilized is .Net (C#), as depicted in Fig. 1, and the development environment is Microsoft Visual Studio 2010. A dedicated server is responsible for collecting information from the PLC and sending it to a dynamic table displayed in the web application for human-machine interaction. The system takes into account variations in soil moisture after irrigation, with a sampling interval set at 5 min. The operational procedure of the intelligent irrigation water-saving system is as follows: it gathers soil moisture data through a sensor network and subsequently assesses this value against a predetermined lower limit. If the value falls below the set threshold, the system proportionally opens the valve based on the plant type within the irrigation zone. Recognizing the gradual nature of soil seepage and preventing inaccuracies, it is imperative to select the soil moisture value post-irrigation for output determination. The system then proceeds to continuously collect and store soil moisture data, repeating the comparison with the lower limit. If the value remains below the specified threshold, the system proceeds with the subsequent cycle. This is achieved by designing a finite machine of logic states within the PLC.

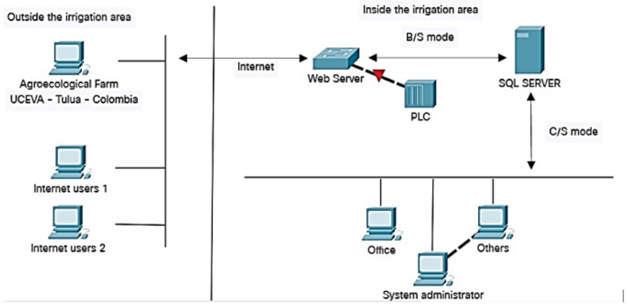

Fig. 1 Software architecture of C/S and B/S (The authors)

2.5. Data Monitoring System

An interface for human-computer interaction is developed utilizing TIA Portal 16 software, LOGO Soft Comfort V3.0, and datalogger equipment to collect meteorological, humidity, and pH data. This setup facilitates data collection and valve monitoring. The software specifications encompass the following:

(1) Real-time reception and storage of data;

(2) Alerting for data exceeding predefined limits;

(3) Continuous real-time display of the switch status and flow for each valve, pumping station, soil moisture station, automatic water quality monitoring station, and weather station.

The information platform integrates real-time data from switch statuses, valve flows, pumping stations, soil moisture stations, automatic water quality monitoring stations, and weather stations.

The database architecture involves three components: a monitoring database, a decision database, and a basic database. The monitoring database includes real-time data tables for monitoring points and records of valve switches. The decision database includes tables for flow data, water level records, water quality records, sentiment data, and weather data. The basic database comprises tables for basic information, user information, and fundamental parameters essential for real-time irrigation forecasting. The basic information table stores the corresponding monitoring point details.

3. Results

The medicinal, aromatic, and condimentary plant area is situated within the agroecological realm of UCEVA in Tulua, Valle del Cauca, Colombia. This area boasts an irrigated expanse of 287.12 m^2. The irrigation type is by sprinkling and dripping. The project area is divided into 10 cultivation beds (Fig. 2). Altogether, there are 66 species of medicinal, aromatic, and condimentary plants. The irrigation water source consists of an elevated tank that is supplied by a submersible pen-type pump located within the 10-hp three-phase farm tank. This system is connected to a direct start system that includes a contactor and thermal protection for added safety. The elevated reservoir is fed by the pen-type pump, ensuring a reliable water source for irrigation. The 10-hp three-phase motor provides sufficient power for efficient water distribution. The direct start system, equipped with a contactor and thermal protection, further enhances the system's reliability and safety measures.

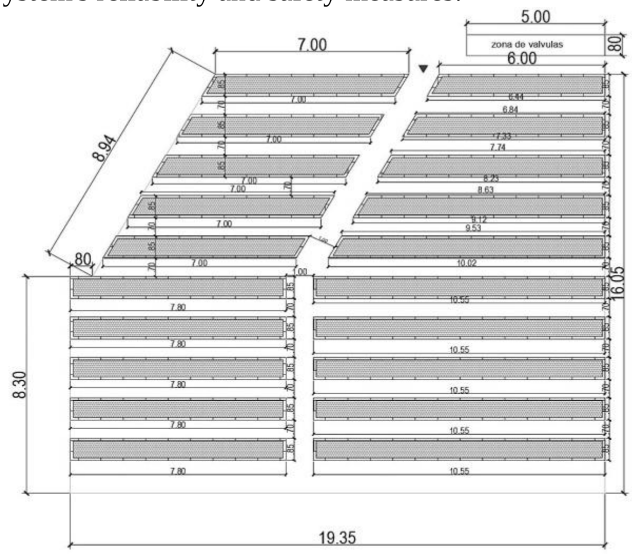

Fig. 2 PMAC area (The authors)

3.1. Monitoring Points

Due to the historical significance and cultural importance of medicinal, aromatic, and condimentary plants in various ancestral societies across the globe, the cultivation of these plant species is conducted using practices that prevent the depletion of natural resources. This approach enables the growth of plants while reducing the environmental impact associated with the production [7]. In this sense, the implementation of technologies with which an appropriate balance can be maintained in the plant-soil-atmosphere relationships becomes important. Water plays a crucial role in the production of PMAC and the development of living organisms [8]. Therefore, implementing automatic irrigation systems is essential. Factors to consider include soil moisture levels, plant wilting points, topography, climatic conditions, and the specific water requirements of each species. The arrangement of the monitoring points, as illustrated in Fig. 3, dictates their type and placement. This includes 10 points for monitoring pipeline flow, 8 points for remotely controlling valves, 4 points for monitoring soil moisture, 1 point for tracking water levels, 1 point for monitoring water quality, and 1 point for meteorological observations.

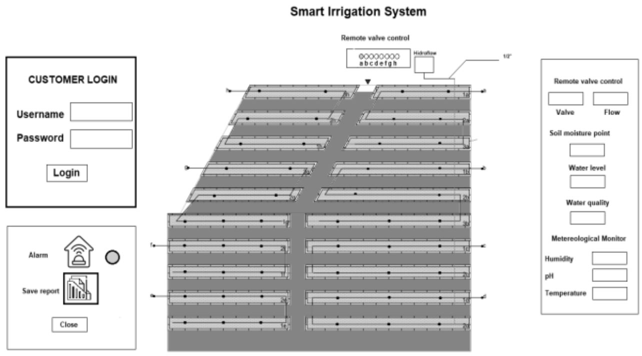

Fig. 3 Irrigation system integrated into the PMAC area (The authors)

3.2. System Application

The smart irrigation system can be applied to medicinal, aromatic, and condimentary plants of the agroecological farm of UCEVA. The automatic irrigation system will mainly control the irrigation water consumption and the 2” valve with proportional control and/or PID. This valve is responsible for managing pressure by adjusting the flow of water. The design incorporates solenoid valves that are automatically controlled by the PLC. To address potential issues with electronic control failures or scheduled maintenance, a manual operation system is also available, ensuring uninterrupted functionality of the drip irrigation system. The system design focuses on minimizing water wastage within the controllable range of the PLC while meeting the humidity requirements essential for crop growth and productivity. Furthermore, the design features an extension of digital inputs and outputs, providing scalability. This means that the number of solenoid valves can be increased without necessitating modifications to the electronic systems; only adjustments to the physical hydraulic systems and the PLC programing software are required. This adaptability component enhances the system’s versatility, allowing it to accommodate different crops or expand to cover additional growing areas.

In Fig. 4, the test results of the meteorological station deployed in the PMAC crop are presented. This data was collected continuously for 24 days.

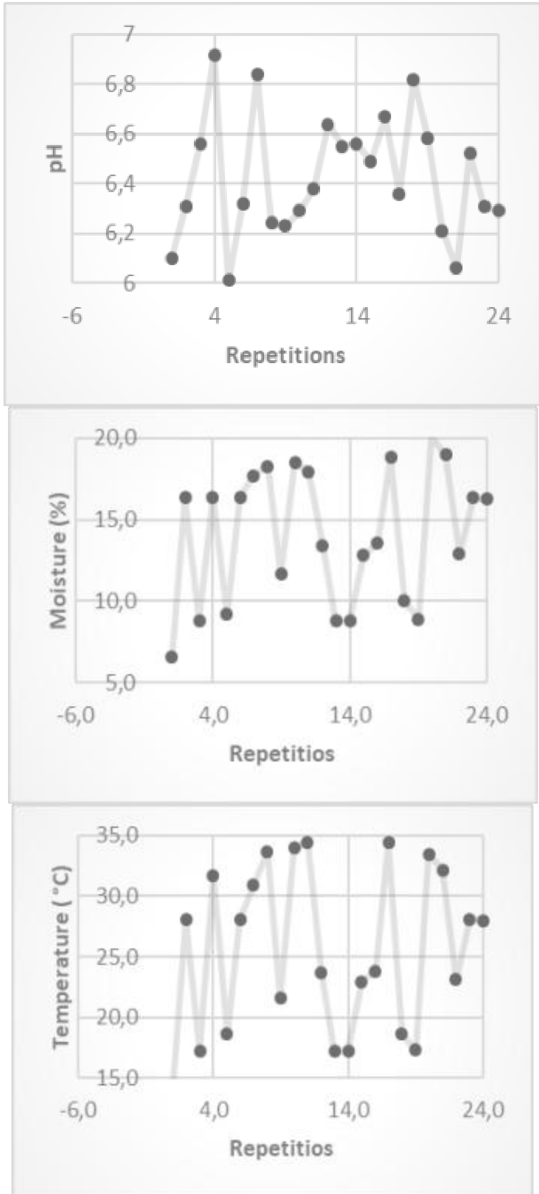

Fig. 4 Meteorological test results (The authors)

It can be observed that humidity, temperature, and pH are monitored optimally with the implemented system. Based on the above, irrigation conditions are established for the crop three times a day (7:00 a.m., 4:00 p.m., and 7:00 p.m.) for 30 min each time.

Henceforth, the integration of the smart irrigation system into a segment of the UCEVA farm serves as a tangible demonstration of the transformative potential of digital technology within the agricultural sector. In our ever-evolving globalized world, this implementation showcases how digital advancements have become pivotal in reshaping traditional farming practices. A comprehensive analysis of the interplay between agriculture and digital technology yields valuable insights, specifically emphasizing the advantages and far-reaching consequences of this combination for the agricultural domain. This expansive viewpoint on digital agriculture underscores the intricate facets of this technological revolution and its capability to overhaul entrenched agricultural methodologies.

The outcomes derived from this initiative significantly underscore the pivotal role of digital agriculture in empowering farmers to make well-informed decisions, particularly when grappling with urgent concerns such as water conservation and climate change mitigation [14], [15]. The intelligent irrigation system, harnessed by digital technology as delineated in this paper, emerges as an invaluable resource for confronting these challenges head-on. By continuously monitoring and responding to real-time data on soil moisture, climatic conditions, and other pertinent parameters, these smart irrigation systems efficiently curtail water wastage. This not only fosters a more judicious use of water resources but also aligns with global efforts to combat climate change by diminishing the carbon footprint associated with agricultural practices. The specific focus on the Tulua region in Colombia in this study serves as a compelling illustration of the adaptability and relevance of digital agriculture across diverse social and economic landscapes. When delving into the specifics of the Tulua case study, which focuses on the cultivation of medicinal, aromatic, and condiment plants, the research highlights the incredible adaptability of digital technology. It showcases how digital tools can accommodate a wide range of crop varieties, meeting the unique requirements of regional agriculture. This adaptability positions digital agriculture as a dynamic solution that can be tailored to diverse geographical, climatic, and socioeconomic contexts. Moreover, by spotlighting the cultivation of plants with medicinal, aromatic, and culinary significance, the study illuminates the potential of digital agriculture to contribute not only to food production but also to sectors such as healthcare and culinary arts, amplifying its impact beyond traditional agricultural boundaries.

According to Zhang [3] and Chen [5], the use of systems with integrated control technology complements the concept of smart irrigation, thereby enhancing water efficiency in agriculture. Furthermore, it was observed that automation in irrigation systems is generally at a low level, resulting in significant water savings. These systems meet the design requirements because they are economical and practical, providing valuable references for the design of similar systems. It is important to emphasize that the system implemented in this study highlights the crucial role of soil moisture as a determining factor in the decision-making process. This finding is not only essential for system efficiency but also plays a significant role in conserving water resources.

In essence, the profound implications of digital agriculture extend beyond the immediate realm of water conservation and climate change mitigation. The intelligent integration of digital technology into agricultural practices transcends conventional boundaries, opening avenues for innovation and sustainability. The success of the smart irrigation system in Tulua offers a blueprint for how technology can be harnessed to address broader agricultural challenges. The synergy of data collection, analysis, and real-time response mechanisms exemplified in this study showcases the transformative potential of digital agriculture in fostering a resilient and efficient agricultural ecosystem.

Furthermore, the benefits of digital agriculture extend to the economic landscape, where enhanced efficiency and resource optimization translate into tangible economic gains for farmers and stakeholders. The automation and precision enabled by digital technologies contribute to increased yields, reduced operational costs, and improved overall profitability. This economic impact is not confined solely to individual farmers but ripples through the entire agricultural value chain, positively influencing suppliers, distributors, and consumers. The broader economic ramifications of digital agriculture underscore its potential as a catalyst for sustainable economic development, especially in regions heavily reliant on agriculture.

The accessibility and affordability of digital tools, coupled with their adaptability to different agricultural practices, can bridge existing socioeconomic gaps. Farmers, regardless of their scale of operation or geographical location, can harness the benefits of digital agriculture to elevate their productivity and economic standing. This democratization of technology ensures that the advantages of digital agriculture are not limited to large-scale commercial farms but extend to smallholder farmers, contributing to more inclusive and equitable agricultural development.

The success of the intelligent irrigation system in Tulua is a testament to the feasibility and scalability of digital agriculture initiatives. By addressing specific challenges related to water management and climate resilience in a localized context, this study provides a valuable template for the implementation of similar projects in other regions. The adaptability of the technology to diverse crops and geographical settings enhances its applicability on a global scale. This scalability positions digital agriculture as a transformative force capable of driving sustainable agricultural practices worldwide.

In addition to its immediate impact on agricultural practices, digital agriculture holds the promise of fostering innovation in related sectors. The integration of data-driven decision-making and automation into farming practices lays the groundwork for developing advanced technologies and services. This spurs growth and innovation in industries such as agtech, creating new opportunities for entrepreneurs, researchers, and technologists. The ripple effect of digital agriculture extends beyond the farm gates, influencing and shaping the broader landscape of technological innovation and economic development.

The comprehensive data collection and analysis facilitated by digital agriculture also contribute to the creation of a knowledge base that can inform future research and policymaking. The insights derived from monitoring soil moisture, climate conditions, and crop health can be utilized to refine agricultural practices, develop new technologies, and develop evidence-based policies. This integration of data-driven decision-making with scientific research enhances the overall resilience and adaptability of the agricultural sector in the face of evolving challenges, contributing to a more sustainable and future-ready industry.

4. Conclusion

The proposed design of the intelligent irrigation system, which utilizes a PLC and the IoT technology, incorporates industrial serial communication technology and data logging systems to capture essential variables in the process. This system is characterized by a well-thought-out design, reliable operation, and strong feasibility. It is capable of fulfilling the demands of intelligent irrigation control, addressing issues associated with substantial waste in traditional irrigation water usage and instability, ultimately achieving the objective of water-conserving irrigation.

The system considers various factors influencing irrigation decisions, meticulously addressing the requirements for precision, feasibility, and operability. It strategically opts for soil moisture as the fundamental criterion for irrigation decisions and is tailored to automate the irrigation of agricultural land, specifically focusing on the cultivation of PMAC at the agroecological farm of UCEVA. However, it is worth noting that the system is adaptable to suit the irrigation needs of any crop.

This system is crucial as it ensures the efficient utilization of water resources and promotes crop development while reducing water losses during the production process. This alternative tends toward sustainable development, and due to climate change, it is important to produce adequately while maintaining the efficiency of the resources used.

Digital technology represents a transformative force with the potential to revolutionize global agriculture. In the case study conducted at the UCEVA farm, the integral role of digital technology enhanced the efficiency, sustainability, and adaptability of agricultural practices, underscoring its capacity to empower farmers with data-driven decision-making tools that can address pressing challenges, such as water conservation and climate change.

This study highlights the adaptability of digital agriculture across diverse agricultural contexts, as demonstrated by its successful implementation in Tulua, Colombia. This adaptability underscores the versatility of digital technology in addressing region-specific agricultural needs, irrespective of their social and economic conditions, making it a valuable asset for economies worldwide seeking to fortify their agricultural sectors.

The implications arising from this study transcend the boundaries of conventional agriculture, leaving a significant footprint in various aspects. First, the successful implementation of the smart irrigation system at the UCEVA farm not only validates the effectiveness of digital agriculture in the specific context of Tuluá, Colombia, but also establishes a paradigm for the global application of similar technologies in agriculture. This study demonstrates that the adaptability and scalability of digital solutions not only enhance water management efficiency and climate resilience but also foster crop diversification and the inclusion of small-scale farmers in the technological realm. Furthermore, the positive economic ramifications and the drive for innovation in related sectors highlight digital agriculture as a catalyst for sustainable development at both local and international levels. Ultimately, this study not only addresses specific challenges in regional agriculture but also underscores the transformative potential of digital technology in redefining and fortifying the foundations of global agriculture.

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