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A Study on the Standardization of Smart Farm Communication

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ABSTRACT

Background: Smart farming uses information and communication technology (ICT) to optimize crop and livestock environments. It is applied in greenhouses, vinyl houses, and livestock barns. By collecting data on crop growth and environmental conditions, smart farms create optimal growth environments. This leads to higher productivity and better quality with less labor, energy, and nutrient input than traditional farming methods. In Korea, crop production has declined due to fewer farmers, and over 80% of agricultural products are imported. The low birth rate and aging population are worsening the shortage of agricultural workers. It is predicted that Korea could face a food shortage in three years due to low self-sufficiency. Smart farms are seen as a solution. They can be implemented in urban areas and are considered a profitable model due to their high production potential.

Methods: Nutrient machines are a vital part of smart farming. They dilute and supply essential nutrients for crop growth. However, different machines require varying nutrient ratios, which complicates crop management. To address this, a recipe program has been developed. It automatically adjusts nutrient ratios according to the user's standard settings. This ensures uniform nutrient delivery, regardless of the type of machine used.

Result: The recipe program is expected to improve crop production. It ensures consistent nutrient supply, optimizing growth conditions. It also enhances user convenience by standardizing nutrient management across different machines, reducing complexity in crop cultivation.

Key words: 485 communication, Agriculture and fisheries, Ict integration, Smart farm.

INTRODUCTION

In Korea, there has been an overall weakening of the primary sector, including agriculture, due to a shortage of agricultural workers and a decrease in production and production area caused by climate change, as well as investment contraction. According to Statistics Korea, the lowest point was recorded in 2010 with 8.75 million people and then increased to 9.76 million people by 202 due to the revitalization effects of returning to farming and rural areas. However, the growth trend was broken in 2021, decreasing to 9.71 million people, and it is expected to decrease to 8.45 million people by 2030 at the current pace (Cheon, 2023; Jong-Dae and Dong-su, 2014).

The area of farmland has been decreasing for the tenth consecutive year since 2013. The decrease is directly attributed to the decline in rice consumption due to changes in dietary habits. Per capita rice consumption has plummeted by 15.6% over nine years, from 67.2 kg in 2013 to 56.7 kg last year. Recently, the increase in idle land due to the aging population has accelerated the decrease in farmland area. As the aging population and rural depopulation worsen in the future, the decline in farmland areas is expected to further accelerate (Semara *et al.,* 2024; Maltare *et al*., 2023; Bagga *et al.,* 2024; AlZubi, 2023). To address agricultural issues such as youth influx into rural areas and securing agricultural competitiveness through export industries, the introduction of smart farms has been implemented as a measure (Jeong, 2023; Cho, 2024; Hai and Duong, 2024).

In 2022, the global SMART FARM industry was estimated to be worth $148 billion and it is expected to reach $220 billion by 2025. Continuous development is anticipated due to the encouragement of environmentally friendly production activities by inhibiting the emission of chemical substances and carbon dioxide, while simultaneously preserving the cleanliness of farms and groundwater (Kim and AlZubi, 2024; Lee and Yeo 2016; Porwal *et al.,* 2024; Wirawan and Mahendra, 2024).

In this environment, one of the SMART FARM technologies, the nutrient solution mixer, particularly in the area of nutrient solution ratio and control systems, holds significant potential for sustainable development (Table 1). It is expected to play a significant role in future global market penetration (Zweig, 2005; Moses, 2022).

A nutrient solution mixer helps to ensure optimal absorption of nutrients and moisture, including concentration, pH, temperature and dissolved oxygen, for plants. It is a device designed to supply nutrient solutions tailored for

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soil cultivation, combining irrigation and fertilization. In other words, it refers to supplying water and nutrients through the irrigation system. The nutrient solution mixer consists of operational components such as pumps, valves and pipelines, as well as sensor components that measure the composition of the nutrient solution, water quantity, soil temperature and moisture status. These sensors analyze the data they collect and based on that analysis, the control unit, which includes components like electric pumps and valves, issues commands for their operation.

A nutrient solution mixer is a device that continuously supplies a nutrient solution to the medium by mixing it with water and delivering it to the substrate. When desired time, flow rate, EC and pH values are set on the computer, the solution is automatically supplied to the substrate and data such as time, irrigation volume, EC and pH values are stored in the computer. If the supplied data does not match the set parameters, an alarm may be triggered, or the operation may be stopped. It can be accessed from a complex environmental control system or a computer for remote control via the Internet (HPNSS, 2024).

Plant factories can be broadly categorized into solar-powered and fully controlled types. Solar-powered plant factories utilize sunlight as the primary light source, often based on greenhouses, to improve lighting conditions. On the other hand, fully controlled plant factories cultivate plants in completely enclosed spaces using artificial light. They come in various forms such as vertical plant factories, container-based plant factories and hybrid smart farms integrating vinyl houses. In rural areas, vinyl house-based plant factories are the most prevalent, while container-based ones are common in suburban areas and vertical plant factories are utilized in urban settings.

The main problems with traditional nutrient solution systems are inconsistency in the presentation of nutrient ratio data depending on the manufacturer of the nutrient solution mixer, variability in the methods for adjusting nutrient solution volume, and discrepancies in nutrient ratio due to different settings required for each nutrient solution mixer manufacturer. Additionally, there is a significant margin of error in the sensors used to measure these parameters. Addressing these monitoring issues of nutrient solution mixers requires the application of a superior control system in smart greenhouses, which can regulate the nutrient ratio and volume to produce crops of uniform quality. Moreover, the cultivation effects in a uniform nutrient solution can be utilized as data for future quality improvement and increased production. These data can also be applied in the future to big data analysis in smart farms.

MATERIALS AND METHODS

Fig 1 below demonstrates the integration of nutrient solution mixers into the SMART FARM field using data integration register map design, linked with the upper control system. To establish a system that supplies the optimal nutrient solution ratio for plant growth by operating dedicated sensors on existing nutrient solution mixers, it is necessary to adjust the dilution ratio of each nutrient solution mixer manufacturer separately for each farm and each product (Seo, 2023).

To achieve this, a register map for various greenhouse integrated controllers and nutrient solution mixer nodes is created. Standardized protocols between greenhouse integrated controllers and nutrient solution mixer nodes are established, and a register map is developed. This allows for the integration of nutrient solution mixer nodes in smart greenhouses with the upper control system through a data integration interface, as proposed in Fig 2. using the RS485 communication mode bus (MODBUS) method. This enables mutual interaction, as shown in Fig 3.

Table 1: Status of industrial of smart farms domestically by year.

Yearly	'14	'20
Cumulative area (ha)	405	5,985
Area for the year (ha)	60	602



Fig 1: Smart farm nutrient solution system.

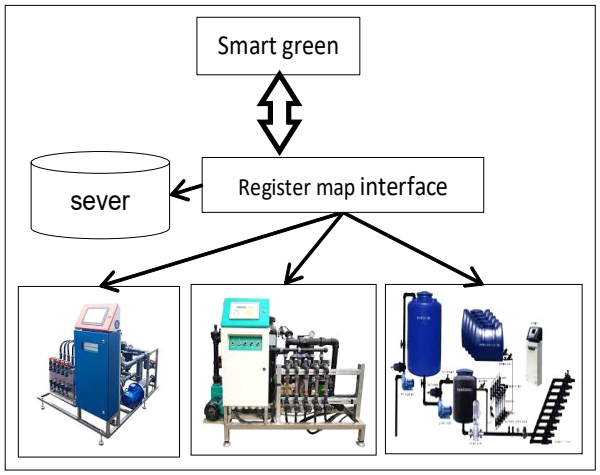


Fig 2: Data register map for smart farm nutrient solution system.

Integrated nutrient solution mixer nodes can be remotely controlled by the upper smart greenhouse environmental control system, managing all data acquired from the lower nutrient solution mixer nodes. Utilizing big data analytics, AI analysis can be conducted and visualized, contributing to the utilization of smart farm systems (Kim, 2017).

RESULTS AND DISCUSSION

The integrated nutrient solution mixer nodes can be remotely controlled by the upper smart greenhouse environmental control system. They manage all data acquired from the lower nutrient solution mixer nodes, enabling AI analysis utilizing big data. This data can then be visualized and utilized in smart farm systems.

Creating the most suitable business for the certified nutrient solution facility in a SMART FARM setup, as depicted in Fig 4. involves storing data generated in the field on a web server. This data, along with additional inputs such as production quantity and quality data, undergoes analysis and processing. By establishing benchmarks based on the analyzed data, performance evaluation criteria for the nutrient solution system are provided. Operating on a

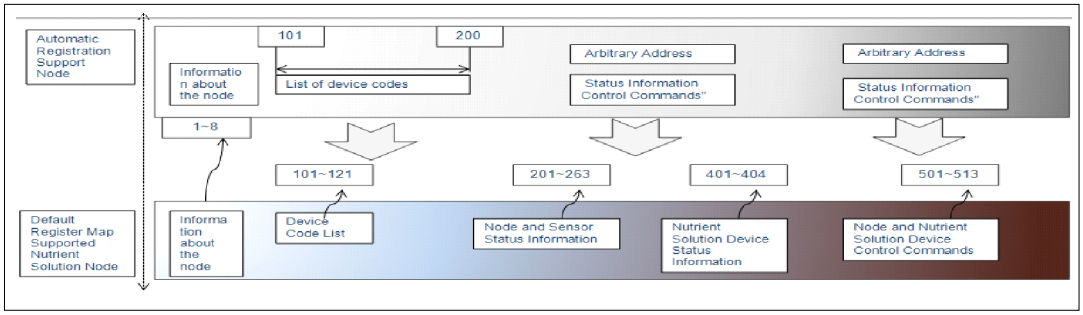


Fig 3: Configuration diagram of the nutrient solution mixer and greenhouse integrated controller.

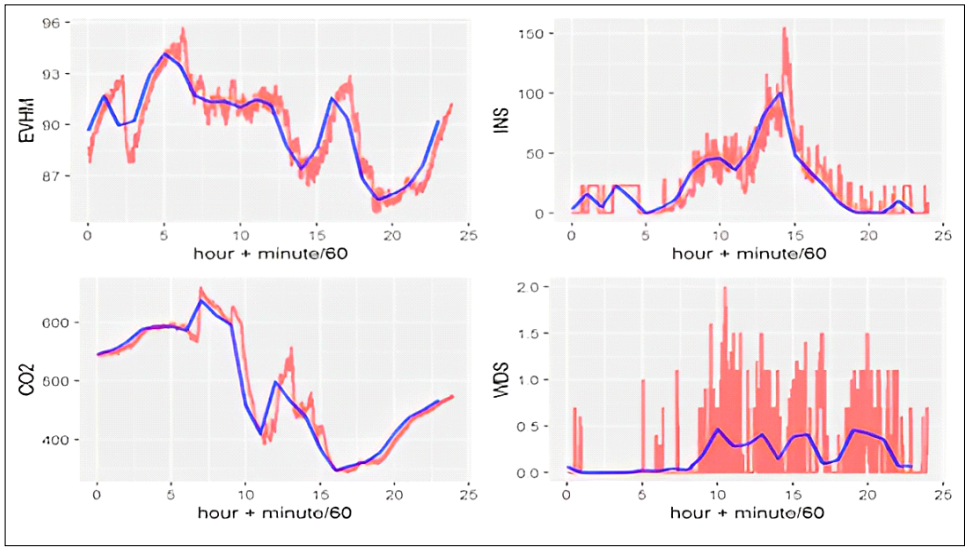


Fig 4: Nutrient solution mixer data.

Table 2: The effect of light wavelength on plants.

Wave length (nm)	The application effects can be summarized as follows:	
Infrared.	780	The wavelength that promotes special growth effects in plants.
Visible light	700	The maximum wavelengths for photosynthesis action, which are 670 nm (red light) and 730 nm (far-red light).
	660	The maximum wavelengths for chlorophyll action, which are 655 nm (red light) for absorption and 660 nm for leaf distribution.
	610	Wavelengths ranging from 580 to 650 nm, which are not beneficial for photosynthesis but can be used for pest prevention.
	440	The maximum wavelengths for photosynthesis action are at 430 nm and for chlorophyll action, they are at 440 nm.
Ultraviolet (UV) radiation	350	Promotion of pigment coloring and attraction of pests.

foundation of reliable data, it is anticipated that this approach will not only facilitate nutrient solution facility certification but also lead to improved quality.

As depicted in Fig 4, data obtained from sensors includes basic values such as temperature, pH, CO_2, light intensity and humidity. These values are fundamental for plant growth, as they encompass essential elements such as nitrogen, sulfur, magnesium, calcium, boron and others, which significantly influence plant growth. By analyzing the nutrient content of major elements that have a significant impact on the growth of each organism, productivity can be enhanced using tracked data.

Furthermore, considering that the wavelength of light affects plant growth, by combining appropriate data from the plant's light absorption spectrum and pattern with data from the nutrient solution mixer, effective data for growth can be extracted (Table 2). Utilizing this data, adjustments can be made to the wavelength and sunlight exposure based on the growth stage of the crops, establishing optimal conditions for factors such as sweetness, texture and taste, thereby enhancing the quality of the crops.

To ensure scalability in SMART FARM systems, services are configured to provide functionalities similar to those of touch screens in indoor smart cultivation machines. These services are designed to be processed through Open APIs, creating user-friendly programs for universal use. Remote control features are designed to monitor and control crop growth status and various environmental information in indoor smart cultivation machines. Additionally, in the event of abnormalities in indoor smart cultivation machines, it is essential to have the capability for users to receive information externally. Therefore, functionalities allowing users to set alert transmission conditions for sensors and devices are necessary.

Utilizing an integrated control configuration, a register map and middleware server are set up to enable consistent operation regardless of the type of nutrient solution mixer. This ensures that the same conditions can be applied even with different types of nutrient solution mixers, allowing for uniform operation according to user instructions.

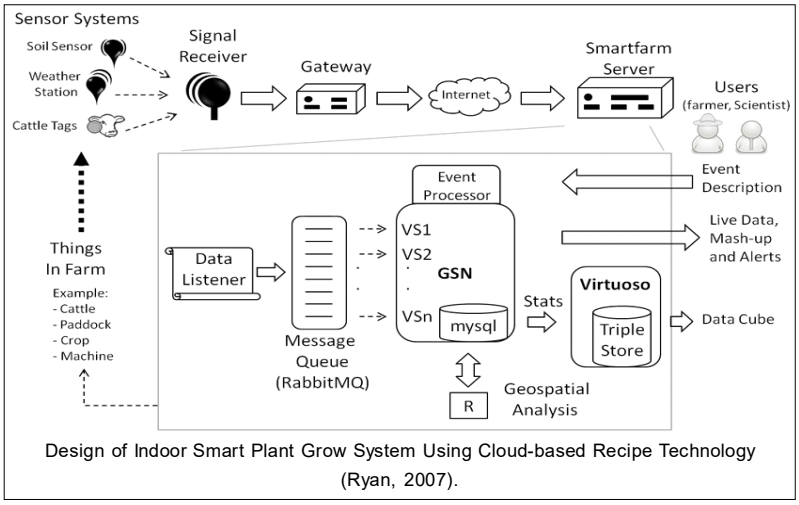


Fig 5: SMART FARM integrated control configuration diagram.

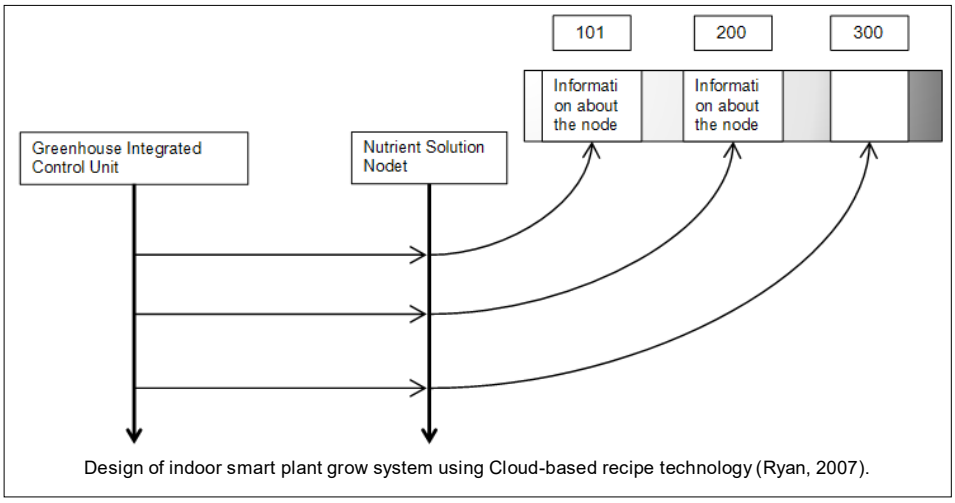


Fig 6: Greenhouse integrated control unit and standardization scope.

Furthermore, this system is accessible for monitoring through a SMART FARM dedicated dashboard (Fig 5 and 6). It enables bi-directional communication for monitoring and control, allowing sensing of nutrient solution, light wavelengths, and additional nutrients. Users and testers can directly observe and verify this information.

Further-more, by pursuing diversity in sensor nodes, various sensing capabilities are accommodated. The design includes expansion ports numbered from 1 to 10, allowing for the addition of various sensors in the future with scalable functionality. This configuration enables not only nutrient solution mixers but also optical generators and control of actuators such as valves to be incorporated, enhancing versatility by facilitating the addition of various types of data (Choi *et al*., 2020).

Nutrient solution system performance evaluation methods

The types of nutrient solutions vary widely, and they should be selectively used depending on the type of crops and their growth stage. In this study, a method is employed where concentrated fertilizers added to supply a required amount of ions to the drainage are diluted with water and distributed to crops. Additionally, the concentration ratio of the fertilizer is adjusted and maintained under uniform light conditions in the SMART FARM implementation site to measure the growth status.

The nutrient mixing system is composed of a control unit and a supply unit. To control the entire system, a PC-based dashboard control method is employed and the control program is accessible through various applications *via* direct communication with the dashboard. To accurately supply the required amount of concentrated nutrient solution determined by algorithms, the supply unit utilizes valves with flow control capability and metering pumps equipped with motors. Additionally, a dilution motor is installed to eliminate pulsations generated during the repeated discharge and suction of the pump and to dilute the nutrient solution. Dilution and supply are carried out simultaneously after a 10-minute dilution period, thereby increasing productivity.

To evaluate the performance of the system, the accuracy and effectiveness of nutrient adjustment in the recirculating nutrient solution system are examined. This involves investigating the pH and electrical conductivity (EC) of the nutrient solution during the lettuce growth period. During actual nutrient adjustment, the amounts of each major element required, based on the algorithm, are checked against the amounts of nutrients automatically dispensed by the nutrient solution system. Finally, the ion content of the nutrient solution dispensed during irrigation and the target values for each element are compared and analyzed for evaluation.

Additionally, for each supplementation, the supplied nutrient solution is prepared in batches of 50 liters and calculated accordingly. Drainage is measured precisely using a scale to dilute the nutrient solution according to a predetermined ratio.

$$\text{Error} = \frac{\text{Measured ppm by ICP (ion-chromatography) -Target ppm}}{\text{Target ppm}}$$

To evaluate the performance, the growth status of each crop under different nutrient compositions is measured quantitatively using overall size and weight (Table 3). Additionally, measurements of moisture content and sugar content are taken. These data are then combined with cultivation environment data to quantitatively measure growth under each condition, necessitating performance evaluation.

Moreover, all crops in the entire chamber must utilize the same species and seed conditions. Additionally, artificial light wavelengths and frequencies must be consistent across the experiments.

Based on such performance evaluations, data on nutrient system configurations and composition should be accumulated on a dashboard for a period ranging from 3 to 6 months with the same crop. Additionally, a server for storing accumulated data must be configured. Since there may be interruptions in power or changes in temperature conditions due to weather fluctuations during the test period, thorough supervision and management are necessary. Implementing such a performance evaluation system is expected to accurately identify the growth factors of nutrients and crops, thereby increasing productivity (Jong-Dae and Dong-Su, 2014).

The biggest advantage of utilizing such data-driven tests is the ability to cultivate and produce crops directly in SMART FARM fields while simultaneously conducting testing and sales. It is expected that the improvement in crop quality will increase annually, and by collecting performance evaluation indicators of SMART FARM data among agricultural associations and conducting big data analysis, the reliability of the nutrient solution system

Table 3: Examples of performance evaluation metrics include.

Item	Nutrient solution (L)	Dilution volume (L)	Sugar content (Brix)	Weight (g)	Others material (Phosphorus potassium)
A chamber	700	70	25%	40	-
B chamber	700	60	15%	45	-
C chamber	700	50	10%	50	-
D chamber	700	40	9%	50	-

evaluation is expected to further increase (Jong-Dae and Dong-Su, 2014a).

CONCLUSION

This study highlighted the integration of advanced nutrient solution systems and SMART FARM technologies to optimize plant cultivation and data-driven growth management. By using AI algorithms, user-friendly interfaces and unified communication systems, smart farming enables year-round crop production in controlled environments, addressing food security and labor challenges. Promoting urban agriculture, standardizing nutrient delivery, and supporting government incentives will enhance sustainability, innovation, and accessibility. These advancements promise to improve agricultural efficiency, competitiveness, and resilience, paving the way for a sustainable future in farming.

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Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all the aspects of this work.

Data availability

The data analysed/generated in the present study will be made available from corresponding authors upon reasonable request.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Availability of data and materials

Not applicable.

Use of artificial intelligence

Not applicable.

Declarations

Authors declare that all works are original and this manuscript has not been published in any other journal.

Conflict of interest

Authors declare that they have no conflict of interest.

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