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# GRID-BASED COMMUNICATION NETWORK FOR LARGE-SCALE CLOUD SMART FARMS: A COST-EFFECTIVE, SCALABLE SOLUTION FOR AGRICULTURE

Engineering

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## ABSTRACT

This study presents a Grid-Based Communication Network for Large-Scale Cloud Smart Farms, designed to provide a cost-effective and reliable smart farming solution, particularly suited for rural areas. Traditional smart farms rely heavily on on-site computing elements, leading to high setup costs and frequent hardware failures due to harsh agricultural environments. In contrast, this system centralizes computational processes in a remote server, eliminating the need for on-field computing. Implemented in Namwon, South Korea, the system reduced setup costs by over 80%, from $905 to $155 per square meter, and maintained stable, failure-free operation over two years. The grid-based network facilitated real-time monitoring and automated control of critical environmental factors, including soil moisture, pH, temperature, and $CO_2$ levels, enhancing resource efficiency and sustainability. This study highlights the scalability and adaptability of the system, providing a viable model for expanding smart agriculture in rural settings and paving the way for future advancements in predictive analytics and automation.

## KEYWORDS

Grid-based Cloud System, Cloud Smart Farms, Cost Reduction, Rural Infrastructure

## INTRODUCTION

The global population is projected to reach approximately 9.8 billion by 2050, necessitating a substantial increase in food production [1]. Traditional agricultural practices face challenges such as labor shortages, climate change, and resource depletion. Smart farming technologies offer innovative solutions to enhance productivity, reduce price, and promote sustainability, by integrating advanced technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), robotics, and cloud [2, 3].

IoT technologies enable the interconnection of devices, sensors, and systems in agricultural settings [4, 5]. Smart sensors collect real-time data on temperature [6, 7], soil pH [8-10], soil moisture [11, 12], humidity [13], and crop health [14-16] by the combination of cloud computing and edge computing [3]. IoT devices deployed in agricultural settings, such as sensors and motors, collect data such as temperature, soil conditions, crop image, weather, acidity, and equipment status. Vast amounts of collected data is sent to the computers inside the smart farm. In a smart farming system, the embedded computers utilize the collected data to efficiently operate the farm and provide a user interface. By analyzing this data, the system can make informed decisions regarding irrigation, fertilization, pest management, and so on. In addition, the user interface serves as a vital communication tool between the technology and the farmer. It presents actionable insights and recommendations in an easily understandable format, allowing users to monitor farm conditions and make adjustments as needed. This interface may include visual dashboards, alerts, and control options, empowering farmers to manage their operations effectively and respond promptly to any issues that arise. In recent, AI applications in smart farming can analyze data patterns and automate decision-making processes [17-19]. AI-powered systems decide the crop and environment status and assist in far automated agriculture by providing recommendations for irrigation, fertilization, and pest control, thereby increasing efficiency and reducing input costs [2]. To summarize, the deployment of IoT-based cloud systems and artificial intelligence (AI) technologies is essential for running smart agricultural operations. These systems rely on the continuous transmission of vast amounts of data to a central server, where it can be processed and analyzed to provide valuable insights for farmers.

**Figure 1:** Smart farm with built-in computing elements

However, agricultural fields often face significant communication challenges, including slow connectivity and limited bandwidth, which hinder the efficient transfer of large datasets. This limitation can result in latency issues, leading to delayed decision-making and reduced operational efficiency. To address these challenges, the integration of edge computing has emerged as a viable solution (Figure 1). By strategically placing high-performance computing resources at the edge of the network—closer to the data source—smart farming systems can process data locally. This approach minimizes the need for extensive data transmission to a central server, thereby alleviating bandwidth constraints and reducing latency. Edge computing enables real-time data analysis, allowing for immediate responses to changing conditions in the field, such as adjusting irrigation schedules or detecting pest infestations [2, 17-19].

Traditional computer network, while established in urban contexts, often prove inefficient for rural environments due to high setup and maintenance costs, as well as data loss and latency issues. By adopting a grid-based smart farm system, leveraging low-complexity, cost-effective routers, we aim to establish an extensive cloud-based infrastructure across smart farms, eliminating the need for costly computing elements on individual farms while ensuring high-speed, reliable connectivity. The integration of information and communication technologies (ICT) in agriculture has driven the development of smart farms. However, studies indicate that most solutions still rely on costly, complex hardware and lack scalability in rural applications. Researchers have explored protocols for reducing latency and enhancing connectivity, but rural areas still face challenges due to the high cost of infrastructure and the necessity of robust data transmission. The grid-based smart farm system offers a unique solution, leveraging a simplified router system that can be easily deployed and maintained.

## MATERIAL AND METHODS

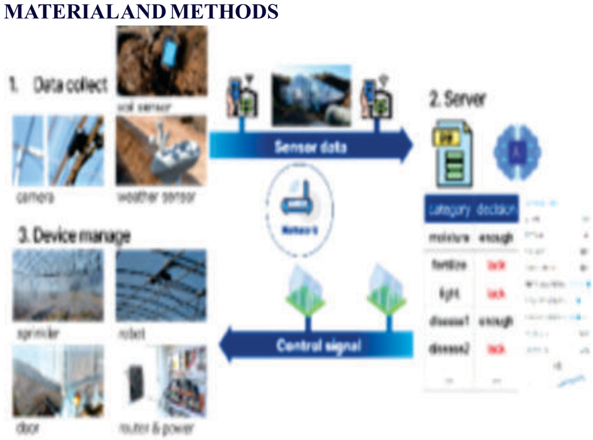


**Figure 2:** Architecture of grid-based communication network for large scale cloud smart farms

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The proposed smart farming system utilizes a grid-based communication network for large-scale, cloud-based smart farms, eliminating local computing components to reduce costs and failure points. It features a centralized server that collects sensor data from various farms through a robust network. Environmental sensors measure factors like soil moisture, temperature, and humidity, transmitting data in real-time for analysis (Figure 2).

Artificial intelligence (AI) processes this data, making decisions on irrigation, fertilization, and lighting adjustments, which are sent back as control signals to farm devices. This setup mitigates hardware failures caused by harsh agricultural conditions, as all processing occurs off-site.

The AI categorizes sensor data into actionable insights based on thresholds for moisture, fertilization, temperature, and disease indicators. The custom grid network optimizes data transmission speed and reliability, ensuring prompt control signal relay, making it a more resilient solution than traditional TCP/IP-based networks.

## CASE STUDY

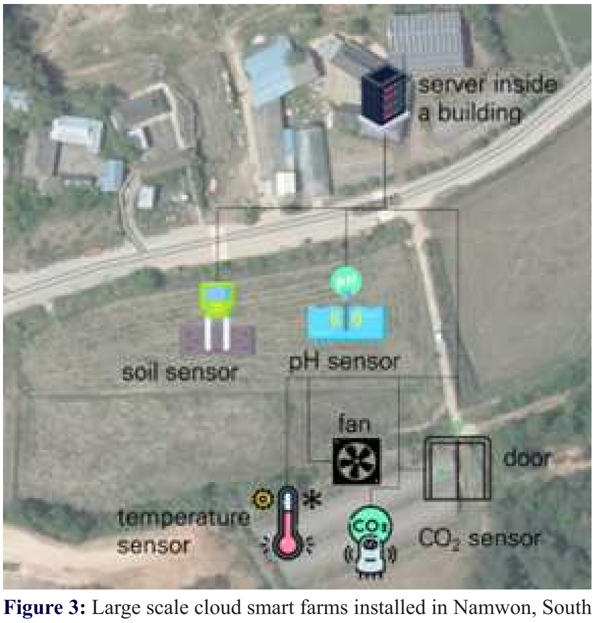


**Figure 3:** Large scale cloud smart farms installed in Namwon, South Korea

The Grid-Based Communication Network for Large-Scale Cloud Smart Farms was implemented in Namwon, South Korea, featuring a centralized server housed in a nearby facility. The agricultural field was outfitted with sensors and actuators, including soil, pH, temperature, and $CO_2$ sensors, enabling real-time data transmission for precise environmental control without on-site computing.

A key achievement was the reduction in setup costs from approximately $905 to $155 per square meter, making the system more accessible for larger agricultural operations. Over two years, the system demonstrated remarkable stability with no hardware failures, thanks to the centralization that removed vulnerable on-field components.

Real-time monitoring allowed adjustments in irrigation and nutrient levels, optimizing soil conditions and reducing waste. The system also regulated airflow and temperature by automatically activating fans and adjusting doors based on sensor data. This successful implementation validates the grid-based network as an effective, low-cost solution for smart farming, with potential for similar applications in other regions.

## CONCLUSIONS

The Grid-Based Communication Network for Large-Scale Cloud Smart Farms demonstrated a cost-effective, reliable, and scalable solution for advancing smart agriculture, particularly in rural settings. By centralizing computation and removing on-field hardware, the system achieved an 80% reduction in setup costs—dropping from $905 to $155 per square meter—and maintained stable, failure-free operation over two years, even in challenging environmental conditions. This network efficiently managed key environmental factors like soil moisture, pH, temperature, and $CO_2$ levels, promoting optimal resource use and sustainable farming practices. The successful implementation in Namwon, South Korea, highlights potential of this system to bridge technological gaps in agriculture and pave the way for broader adoption and further enhancements in predictive analytics and automation.

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