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SMART FARM REALIZATION BASED ON DIGITAL TWIN

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Abstract. *The advancement of ICT has been implemented to enhance the productivity and efficiency in many areas through digital twin technology. The application domains are product management engineering, smart factory, supply chain, and even in agriculture, to name a few. Recently, agriculture increasingly utilizes digital technologies such as monitoring device, sensing, smart farm technology, big data analytics and smart equipment. This transforms the concept of agriculture from soil, water, air and fertilizer to farm building, LED illumination, digital technology, and data analytics. Thus, digital twin removes fundamental constraints concerning place, time, environment and human observation. This paper proposes the architecture of digital twin-based smart farm and realization of the model in the laboratory level. Also, the model can be tested to be implemented in the real field for commercial production.*
Keywords: Digital twin, Smart farm, Cyber physical system, Big data analytics, IoT, LED light, Laser diode

1. **Introduction.** A Digital Twin (DT) refers to a digital replica of physical assets, processes and systems that can be applied for various purposes. The digital twin conceptual model contains three main parts: a) physical products in real space, b) virtual products in virtual space, and c) the connections of data and information that ties the virtual and real products together. DT mirrors its behavior and states over its lifetime in a virtual space. In the Industry 4.0 context, similar aspects may be referred to through adjacent concepts such as Cyber-Physical Systems (CPS). In many areas such as product development, manufacturing, supply chain and even in agriculture, CPS can be implemented based on the concept of a digital twin.

DT promises the best physical response via real-time digital awareness for smart farm tasks. Through the realization of the Internet of Things (IoT), connectivity is becoming ubiquitous. Thus, most of the processes in the smart farm can be tracked in real time – not just agricultural product but also tasks, weather condition, satellite information and supply chain process, etc.

In the vision of the IoT, high level of interoperability needs to be reached at the communication level as well as at the service and even knowledge levels across different platforms established on a common grounding [1].

Digital Twin Smart Farm (DTSF) transforms the concept of agriculture from soil, water, air and fertilizer to farm building, LED illumination, digital technology, and data analytics. Thus, DT removes fundamental constraints concerning place, time, environment and human touch.

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Basically, a DT architecture is composed of a physical object in real space, a digital representation of this object in the virtual space and the connection between the virtual and real space for transferring data and information.

The major contributions and significance of this study are suggesting digital twin smart farm architecture and implementing the concept in the laboratory environment for a practical point of view. This shows how the smart farm architecture can be realized based on the digital twin technology. The concept is also applied in the actual smart farm environment, which shows the possibility of a commercial success case.

This paper sets out to explore recent trend of digital twin modeling prevalent in the smart farm context. Following a literature review, conceptual framework of DTSF is proposed. Based on this framework, conceptual model of digital twin for smart farm is proposed. In the next section, the proposed DTSF model is implemented in the lab environment for growing ginseng berry. The paper closes with summary and directions for future research.

2. **Previous Research.** As DT is a digital equivalent of a real-life object, it removes the fundamental constraints in farming such as soil, water, air and environmental factors which reside in the physical system. Every object in the farm (e.g., crop, field, cow, farm equipment) is being virtualized and can be more and more remotely monitored and controlled.

Agricultural production is changing fast towards smart farming systems, driven by the rapid pace of technology development like cloud computing, IoT, big data, machine learning, augmented reality, robotics and drones. Smart farming can be seen as the next phase of precision agriculture, in which management tasks are not only based on precise location data but also on context data, situational awareness and event triggers [2].

A typology of six distinct DTs is presented by Verdouw et al. [3]. They are summarized as follows:

- Imaginary DT: A conceptual entity that depicts an object that does not yet exist in real-life.
- Monitoring DT: A digital representation of the actual state, behaviour and trajectory of a real-life physical object.
- Predictive DT: A digital projection of the future states and behavior of physical objects using predictive analytics.
- Prescriptive DT: A smart digital object that adds intelligence for recommending corrective and preventive actions on the real-life objects usually based on optimization algorithms and expert heuristics.
- Autonomous DT: Operate autonomously and fully control the behavior of real-life objects without on-site or remote intervention by humans.
- Recollection DT: Maintain the complete history of the physical object, which no longer exists in real-life.

A DT for smart farming using IoT to control an irrigation system is proposed in [4]. In the farm, there are multiple devices and systems deployed such as soil probes, weather stations, irrigation systems, seeders, and harvesters. These devices and equipment are connected to the cloud through a gateway that sends information to an IoT Agent. The system architecture is composed of farm, cloud service and digital environment. Digital environment is composed of dashboards, 3D visualization, satellite images, drone images and process visualization. The experiment indicates that the probe is able to send data to the cloud and that it is possible to show this data in a real-time dashboard.

To find answers for a potential application-based roadmap for the adoption of DTs in agriculture, Pylianidis et al. [5] have presented a literature review of existing DT in agriculture, and a survey of case studies. They have surveyed use cases regarding living plants or trees, animals, agricultural products, agricultural fields/farms/landscapes, agricultural buildings, agricultural machinery, and food supply chain/logistics. The use cases are analyzed according to the category of concept, prototype and deployed.

In order to implement smart farm, lighting system is one of the most important factors because the plants in the smart farm do not receive nutrients from the sunlight. Thus, lighting system in the building is crucial for the smart farm to be successful. Ok et al. [6] proposed Electrochemical Luminescent (ECL) device with a new structure and the ECL cell device with the proposed electrode configuration works reliably at AC voltage. The proposed ECL cell structure is expected to be utilized as a flexible display device by taking advantage of its characteristics and practicality.

A cloud-connected, Secure Multi-Crop Smart Irrigation System (SMCSIS) is proposed to address the excessive irrigation problem caused by precipitation after irrigation and to reduce water consumption. SMCSIS makes real-time watering decision on the basis of soil moisture predicted at the time of precipitation. The prediction depends on the data captured from soil moisture sensor and climate prediction-based estimated evaporation [7].

3. **Digital Twin Modeling Architecture for Smart Farm.** Connected system is typically characterized by a hierarchical structure. It is composed of three layers, data acquisition layer, local control layer, and service layer with respect to automation pyramid. Sensor, actuator data and machine log data in the farm field are inputs to local control layer.

Transferring those comprehensive data from the Operational Technology (OT) systems in the farm field to the Information Technology (IT) systems at the top floor would require special methodologies and techniques for big data analytics.

Eight rules for DT modeling are suggested in Tao et al. [8] as the following. They are data and knowledge based, modularization, light weight, hierarchy, standardization, servitization, openness and scalability and robustness. The eight rules seem to be appropriate principles for DT modeling when we consider various aspects of DT.

3.1. **Digital twin framework.** Key features of smart systems are connectivity, optimization, transparency, proactive and agility [9]. Smart systems require the underlying processes and materials to be connected to generate the data necessary to make real-time decisions. The optimized smart system can increase yield, uptime, quality, as well as reduce costs and waste.

A DT framework which is composed of physical world, digital world and connectivity is proposed by Kim [10]. In the physical world, various sensor data are acquired via wireless and wired sensor network. It is a hardware-dependent process with embedded system, multi sensors and IIoT (Industrial Internet of Things). In the cyber world, ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), SCM (Supply Chain Management), QMS (Quality Management System) and data analytics work to implement IoS (Internet of Service). These correspond to legacy system in the manufacturing industry.

3.2. **Digital twin architecture for smart farm.** The architecture of DTSF is composed of three layers, which are physical world, communication protocol and cyber world. In the physical world, various sensors are attached in the smart farm field, where sensor data are collected. From the environmental sensors, temperature, humidity, air velocity in the outside, light condition, ventilation data are collected. From the camera sensors, crop growth and farm status data can be gathered. CO_2 and energy use can be gathered from the chemical sensors.

Big data gathered in the smart farm can be transferred to the communication protocol, where data preprocessing can be processed. In this process, missing data are identified and adjustment of missing data is performed. The pre-processed data are transferred to the data analytics module.

In the data analytics module, data mining techniques are adopted and data classification, forecasting, reasoning and optimization techniques are applied to the pre-processed data. Any findings through this process can be fed back to the physical world, and corrective action can be performed for prompt correction. The architecture of DTSF is presented in Figure 1.

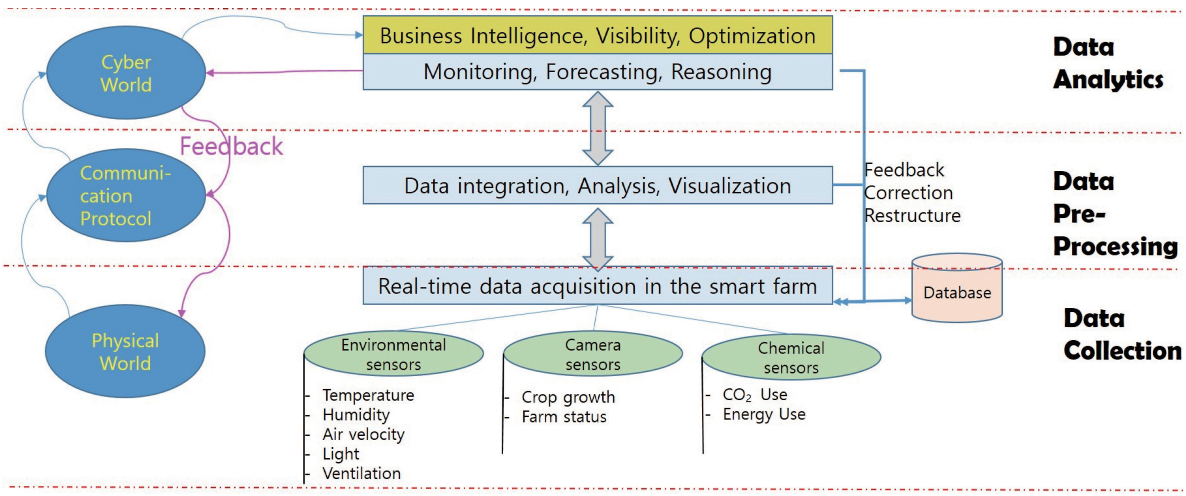


FIGURE 1. Three-layer architecture of DTSF

4. **Application of Digital Twin Smart Farm.** The proposed DTSF idea has been applied to the domain of smart farm in the laboratory level and in the field level.

All field crops need soil, light (sunshine), temperature, air, water and nourishment in order to grow. The soil gives stability to the plants; it also stores the water and nutrients which the plants can take up through their roots. The light (sunlight) provides the energy which is necessary for plant growth. The air allows the plants to "breath". Water provides humidity and nourishments. This is summarized in Table 1.

TABLE 1. Essentials in agriculture (Field crop)

Agriculture	Key elements: {Soil, Light, Temperature, Air, Water, Nourishment}
	- Soil: Provide stability, water and nutrients to the plants. - Light: Essentials of plant photosynthesis. - Temperature: Accelerate plant growth. - Air: Crucial for light compensation point and light saturation point. - Water: Adjust humidity by growth period (germination, flowering, fruiting) - Nourishment: No need of water when nutrient solution is used.

The practical architecture of DTSF is shown in Figure 2. The architecture is drawn from the actual smart farm in the laboratory. The smart farm is free from essential elements of agriculture which are soil, sun light, air, water and fertilizer. It is designed and operated inside the building where the plant is growing in the water with nourishment and without any fertilizer, soil and sun light.

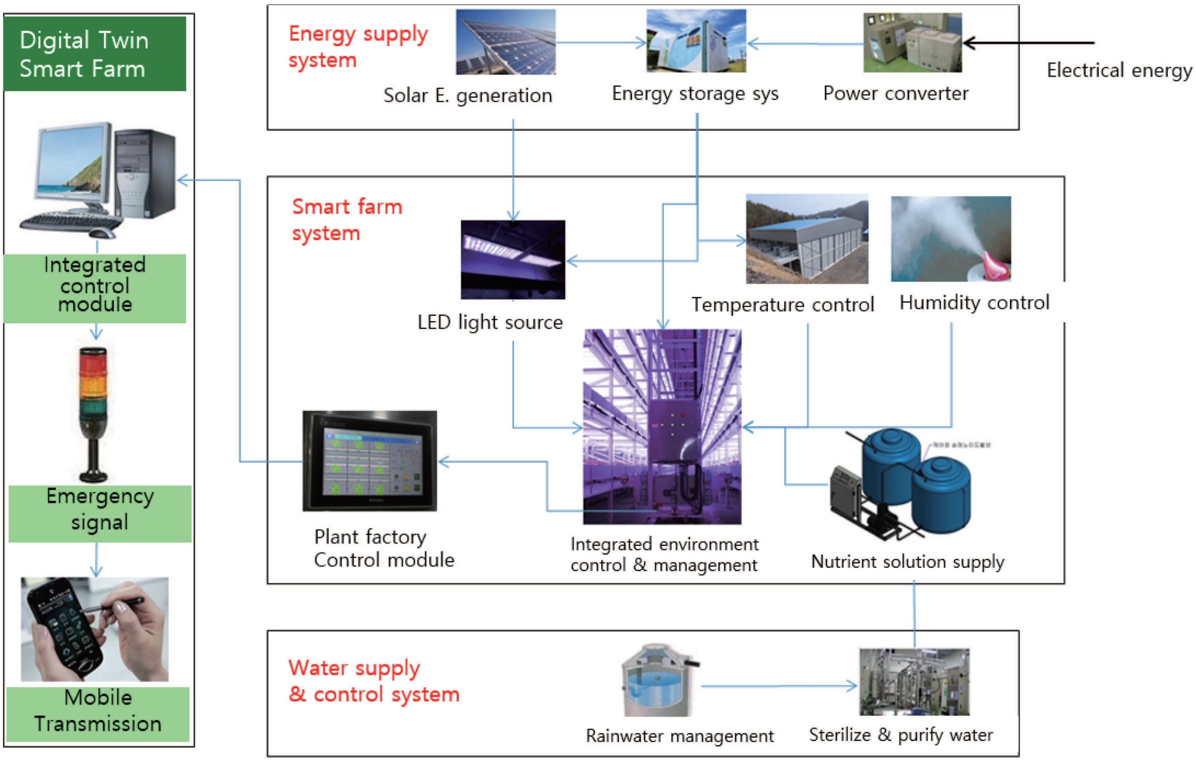
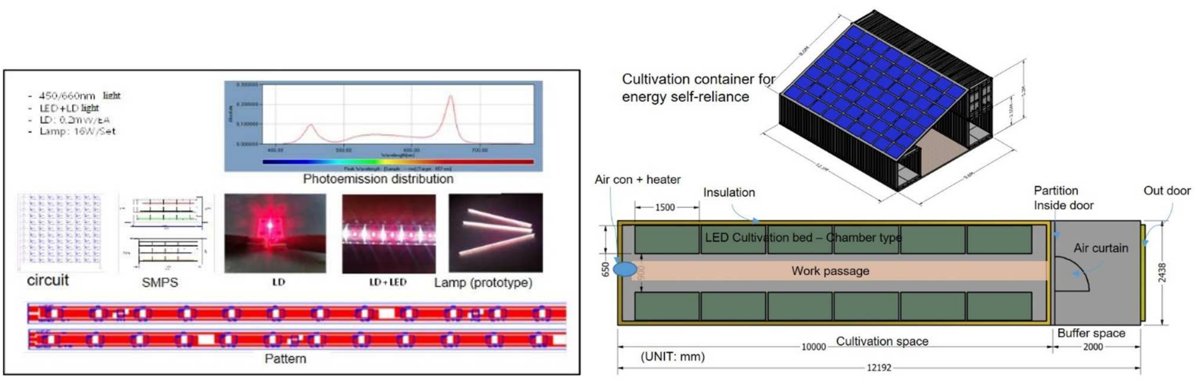


FIGURE 2. Architecture of digital twin smart farm

Multi sensors are attached in the plant factory control module which monitors the nutrient and growing status of the plant. Outside weather condition is also monitored from the sensors which are installed in the roof of the laboratory. According to the weather condition, electrical energy is supported or stopped automatically. The self-monitoring and control system plays the role of digital twin in the DTSF system.

Figure 3 shows the artificial light source and container-type cultivation system. We have designed LED and LD (Laser Diode) wavelength controlled vegetable cultivation system which optimizes the elements of plant growth. It is fully controlled and monitored based on digital twin and IoT. Real growing system is designed using container in the laboratory level as shown in Figure 3(b).



(a) Artificial light source design (b) Container-type plant cultivation system

FIGURE 3. Artificial light source and container-type cultivation system

Figure 4 represents digital twin-based smart farm implemented in the laboratory and venture firm. Soil is essential element in agriculture. However, in the smart farm system, soilless hydroponics cultivation is possible with the control of nutrient solution and

(a) Smart farm prototype in the laboratory (b) Commercial smart farm in the venture firm

Figure 4. Digital twin-based smart farm implemented in the laboratory and venture firm

pesticide-free. The water usage can be minimized by simulating the spray system of nutrient solution. Thus, the water contamination through excess usage can be lowered. The autonomous control system of smart farm can be realized through the unmanned 24-hour monitoring system, temperature/humidity precision control, sterilization, nutrient solution supply and mixing, filtering, etc.

5. **Conclusions.** Digital twins have been adopted in smart farming in wide areas in the past decade. Digital twins can play central means for farm management which enables the decoupling of physical flow from its cyber control system. In the smart farm environment, farmers can be free from soil or farm land. Rather, they can control and monitor the status of farming in the building room as they play games in the monitor. This transforms the farming activities into different dimensions compared to the past.

The model of digital twin smart farm has been suggested and implementation is presented in the laboratory level and field level which is in the commercial stage. The plant of ginseng berry has been adopted and tested in the DTSF. The result from the laboratory has been implemented in the real field with the same smart farm equipment.

Further research is required in the modeling of DTSF for different areas. The possible extensible area can be horticulture, greenhouse, special-purpose farming, and animal farm management. For the extension to dairy farming and animal farm, special cooperation is needed from dairy scientist and veterinary specialist.

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