# Digital Twin Platform Architecture Design to Support Smart Aeroponic Potato Cultivation in Indonesia

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**Abstract.** Potato (*Solanum tuberosum L.*) is one of the essential crops consumed in Indonesia. Currently, smart aeroponic potato cultivation practices in a greenhouse environment provide precision treatment to the crops, including watering and fertilizer, for more efficient cultivation and better yield and potato grade. The next step of the digital innovation for potato cultivation is to provide a smart monitoring system usable by farmers to get an accurate representation of the crop condition based on various sensors available in the greenhouse. In this research, we provide an architecture design for a digital twin platform for potato cultivation to support smart aeroponic potato cultivation in Indonesia. The architecture design consists of the in-farm sensor networks (smart farm), a back-end database system in the cloud, and a front-end module to monitor and visualize the cultivated potato's actual condition based on sensor data. We also provided a strategy to implement the proposed design based on the hierarchy, integration, and maturity levels of the digital twin platform. We hope the proposed architecture can be integrated into the current smart aeroponic potato cultivation, and encourage further adoption of a digital twin for crop monitoring in other products, most prominently the high-value product, to increase the value of Indonesia's agriculture productions.

**Keywords:** digital twin · smart aeroponic · potato · crops monitoring · smart farming · system architecture

## 1 Introduction

Potato (*Solanum tuberosum L.*) is one of the essential crops consumed in Indonesia. Aeroponic cultivation [1] is an emerging choice for potato cultivation because of the minimal use of soil and water [2, 3], in which plant roots are suspended in the open air under controlled circumstances to replace the soil. Currently, smart aeroponic cultivation practices [4] in a greenhouse environment provide precision crop treatment, including watering and fertilizer, for more efficient cultivation and better yield and grade.

The next step of the digital innovation for potato cultivation is to provide a smart monitoring system [5] usable by farmers to accurately represent the crop condition based on various sensors available in the greenhouse through various means (preferably


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mobile applications). The smart monitoring system also includes control systems to enable farmers to conduct cultivation actions based on the data provided [6].

The most recent innovation in agriculture monitoring systems involved the creation of digital twins. Digital twins (DT) [7] provide a virtual representation of a farm, providing an easy understanding of the complex, dynamic, and requires sophisticated management systems of smart agriculture systems [8, 9]. In their most mature form [7], DT allows them to experiment with cultivation techniques, eventually enabling farmers to experiment and develop new techniques without risking real-world crops. DT also supports the hierarchical structure [10], from unit level (e.g., plants, pot, or other individual units on agriculture site), system-level (e.g., greenhouse or farm level), and system-on-system (or process) levels (e.g., multisite enterprises, provincial, or national level) which parallels to agricultural context, including in Indonesia.

In this research, we provide an architecture design for a DT platform for potato cultivation to support smart aeroponic potato cultivation in Indonesia. The architecture design consists of the in-farm sensor networks, a back-end database system, and a DT module to visualize the cultivated potato's actual condition based on sensor data. The produced architecture design will serve as our next experiment to build both the physical and virtual system of potato digital twins in the Internet of Things for Smart Urban Farming Laboratory (I-Surf Lab) at IPB University [11].

In this paper, we provide three things: (1) the design of the smart aeroponic system for potato cultivations, (2) the DT architecture design, and (3) the strategy to develop the DT platform based on the proposed DT architecture design, by considers the maturity of the DT [12].

## 2 Onsite Smart Aeroponic System for Potato Cultivation

The DT platform will only work if the onsite smart aeroponic system data is available and sent to the servers. We proposed the modifications to the smart aeroponic system suggested by [13] and [2] and added more sensors to facilitate the DT platform. Figure 1 depicts the improved design, with extra sensors (light intensity, total dissolved solids (TDS), ultrasonic, water temperature, and stereo cameras). We also connect the control system with connectivity to cloud infrastructure used in the DT platform. In our research, the smart aeroponic system for potato cultivation will be built in the I-Surf Lab (Fig. 2) at IPB University, Bogor, Indonesia, which provides a controlled space and wireless sensor networks underlying infrastructure. The lab previously has been used in other research such as [11] and [14].

## 3 Methods

In this paper, we proposed the architecture design of the digital twin platform to support smart aeroponic cultivation and the strategy to develop the platform. This paper focuses on the analysis and design phase of the software development lifecycle, with emphasis on the design phase. The analysis is mainly done through literature studies from previous related research such as [8, 9, 15, 16], and [17] while considering the situation in the I-Surf Lab. We will use the output of this paper in the subsequent research about implementing the digital twin platform in the I-Surf Lab, IPB University.

**Fig. 1.** Proposed design of the Smart Aeroponic Potato Cultivation equipments (adopted and modified from [13] and [2]).

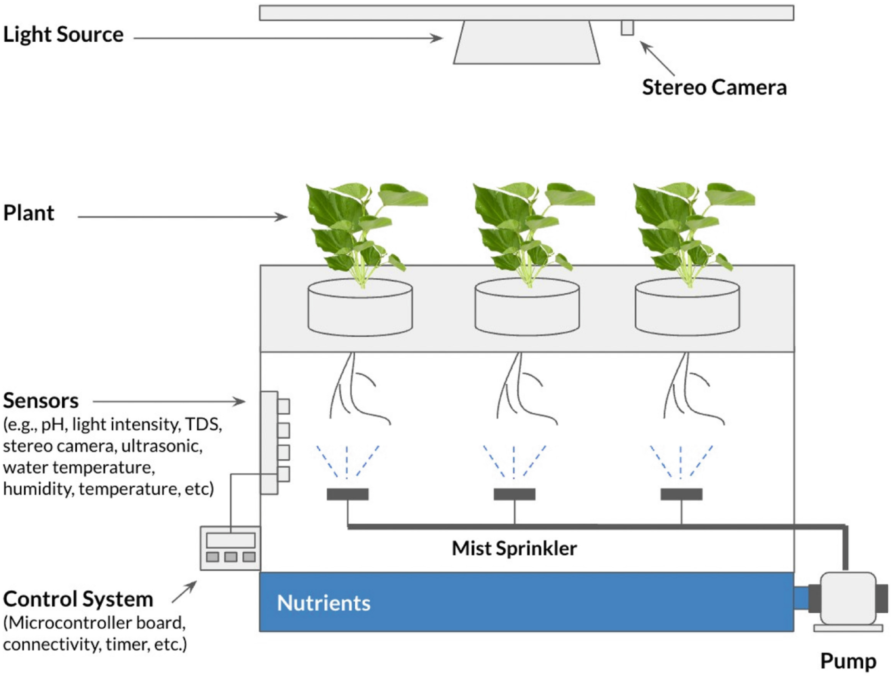


**Fig. 2.** Aerial and inside photo of the Internet of Things for Smart Urban Farming Laboratory (I-Surf Lab), Department of Computer Science, IPB University where the smart aeroponic will be implemented.

## 4 Digital Twin Architecture Design to Support Smart Aeroponic Potato Cultivation

Previous research such as [8, 9, 15, 16], and [17] has attempted to formulate the general architecture for DT in an agricultural context. A DT platform will generally consist of the smart farm with its sensors capabilities, a cloud platform that stores and processes the sensor data, and a front-end system that interacts with users and delivers DT services to them. Based on the architecture above, we then designed the architecture for the potato

DT platform, depicted in Figure 3. In the following subsections, we will discuss each architecture component in detail.

### 4.1 Smart Farm

The smart farm represents an infrastructure housing equipment explained in Sect. 2. **Underlying physical farm infrastructure**: the smart will have space and infrastructure to house and run the smart agriculture equipment. **Actuators**: the actuators act and interact with plants, usually doing actions based on the data reading from sensors, pre-scheduled actions, or commands from farmers. **Wireless sensor networks**: the wireless sensor networks provide a mesh of sensors connected using wireless technologies and protocols [18]. **Sensors Databases**: sensor database stores the data from the wireless sensor networks locally in the smart farm, which then synchronizes to the server for long-term storage and further processing. The strategies for implementing sensor databases are available in [19].

**Edge Computation**: a local data storage and processing on-farm to process data that need a real-time computation or is sensitive to security or privacy issues [20]. **Microcontrollers**: a compact integrated circuit designed to govern a specific operation in an embedded system. It is responsible for various computing tasks in the smart farm, such as managing the wireless sensor networks, running edge computation tasks, and connecting the smart farm to the cloud.

### 4.2 Cloud Infrastructure

The cloud infrastructure served as a back-end infrastructure for storing and analyzing the sensor data. It has a larger capacity than a sensor database on the farm and a more powerful processing capability than edge computing, but it is more exposed to cyberattacks because it facilitates communications with other parts of the systems. **The secured API endpoints** enable communication and data transfer to and from the server. The REST API protocol is a popular choice for its ability to secure the communication using transport layer security encryption, lightweight, and scalable [21, 22]. **The repository database** stores the data in the long term and, depending on the scale of the usage of the DT platform, will be the backbone of the big data platform for sensor data. These data then can be processed by the **data analytics module**, which is responsible for processing the data using techniques such as data analytics, machine learning, and simulations. The module provides services to various front-end applications interacting with farmers and other stakeholders.

### 4.3 Front-End Systems

The front-end systems utilize the data and processing capabilities of the cloud infrastructure and deliver them to end-users. The most common front-end systems are provided through **mobile monitoring applications** [23], allowing end-users to access it flexibly even outside the farm. Meanwhile, **web monitoring applications** are used to navigate and explore more complex data, otherwise too complicated to be shown on mobile

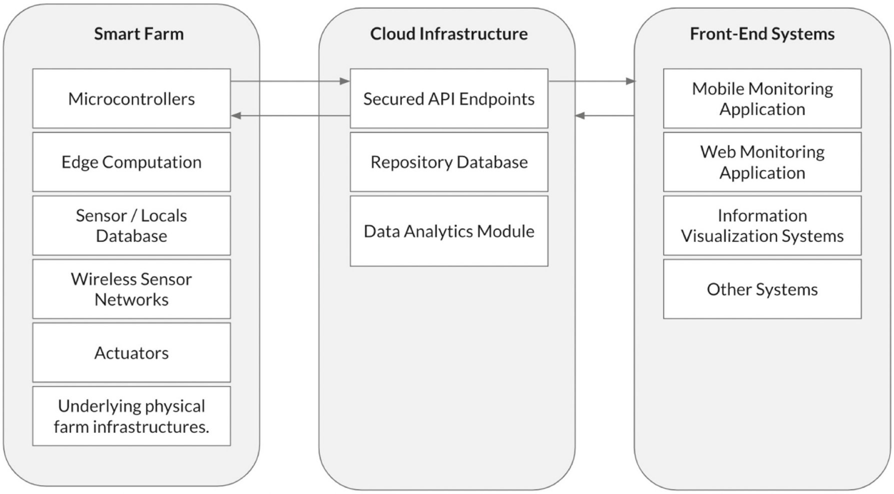


**Fig. 3.** Proposed architecture for potato DT platform in the I-Surf Lab.

phones' small screens. The **information visualization system** is a broad term for visualization, from two-dimensional to immersive visualization, depending on the level of integration of the DT platform. The simplest example might only utilize the information in the form of digital models, while the most sophisticated example allows the user to interact directly with the digital twins and simulate them. **Other systems** might benefit from the services provided by the DT platform, which might includes knowledge management systems such as [21] and supply chain monitoring system.

## 5 Strategy to Develops the Digital Twin Platform for Smart Aeroponic Potato Cultivation

Developing a fully capable DT platform might be difficult and expensive. Hence, the most common approach to developing complex software is by adding functionality iteratively to achieve the desired complexity. This approach, through software engineering life cycle such as prototyping and iterative development, enables end-users to perceive the value of the systems while gathering feedback to ensure sustainability and the market fit of the future results. A similar strategy can be adopted in developing the DT platform by delivering the minimum viable products first and iteratively achieving the highest level of maturity. [12] formulate three levels of the DT platform, which can serve as guidance for DT platform developments: level of hierarchy, level of the integration, and the level of maturity. The proposed strategy is to gradually develop the DT platform from the lowest level until it reaches a higher level. Aiming for high-level implementation initially has significant risks in the development process.

### 5.1 Level of Hierarchy

The hierarchy level refers to the scope of physical objects that will be digitized in the DT platform. In potato cultivation, the 'physical objects' could refer to a potato, a plant, a plantation kit, a greenhouse, a farm, or even the entire potato supply chain. Generally, there are three levels of hierarchy in the DT platform: unit level, system level, and system of system (SoS) levels [12]. The unit level is the smallest unit in the platform and might refer to a single piece of equipment, single potato, single plantation, or environmental factors. System levels involved several unit level DT and form the digital twins of cultivation systems such as a complex cultivation kit or an entire greenhouse. The SOS hierarchy can represent the farm, consisting of several greenhouses or even entire potato supply chains. As smaller units will aggregate into larger units in the hierarchy, the proposed strategy is bottom-up development, where the DT platform is created from unit levels first, then improved to a higher hierarchy.

Depending on the scope of the area, the proposed architecture presented in Figure 3 might also involve integration with broader monitoring means, such as drone or satellite imaging. The proposed architecture is adjusted for potato aeroponics cultivation, primarily done in a greenhouse or enclosed area. However, if the DT platform is developed for more extensive open plantations, such a monitoring method must be considered in the architecture.

### 5.2 Level of Integration

Integration in DT represents how strongly the coupling between the real-world objects is. It is separated into a digital model, digital shadow, and digital twin [12]. In digital models, the data between physical and digital objects are exchanged manually; consequently, the digital object does not reflect the physical object's state. Meanwhile, the digital shadow flows the data from the physical object to the digital automatically, but the digital object changes will not affect the physical object. Finally, the digital twin automatically delivers the data between objects, and changes on one will reflect the other.

### 5.3 Level of Maturity

The level of maturity represents the possible utilization of the DT platform: pre-digital twin (level 1), digital twin (level 2), adaptive digital twin (level 3), and intelligent digital twin (level 4) [12]. On level 1, the DT was created before the physical assets to reduce technical risk and issues before the tangible assets were built. On level 2, the DT platform utilizes the data from physical assets to assist decision-making in the design and development of the asset. On level 3, the DT platform has a machine learning capability to learn from the preferences and priorities of the end-users. This capability can be used for real-time planning and decision-making. On level 4, the DT platform has unsupervised machine learning capability, allowing them to recognize patterns and take action with more degree of autonomy. It also utilized the reinforced learning methods for a more precise and efficient analysis of the environments.

## 6 Conclusions

In this paper, we have provided the architecture design of the digital twin platform to support smart aeroponic potato cultivation in Indonesia. The architecture design consists of the in-farm sensor networks (smart farm), a back-end database system in the cloud, and a front-end module to monitor and visualize the cultivated potato's actual condition based on sensor data. We also provided a strategy to implement the proposed design based on the hierarchy, integration, and maturity levels of the digital twin platform. Future research will focus on implementing this strategy starting from a small scale in the I-Surf lab at IPB University. We hope the proposed architecture can be integrated into the current smart aeroponic potato cultivation, and encourage further adoption of a DT for crop monitoring in other products, most prominently the high-value product, to increase the value of Indonesia's agriculture productions.

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