Chapter 5
Enhancing IoT-Based Smart Farming With Digital Twin and XR:
A LoRaWAN-Powered System for Soil Monitoring and Automated Irrigation Control

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ABSTRACT

The convergence of Internet of Things (IoT), LoRaWAN, Digital Twin (DT), and Extended Reality (XR) is transforming smart farming, especially in resource-constrained regions. This chapter proposes an integrated system that combines LoRaWAN-based soil sensors, edge gateways, a cloud-synchronized Digital Twin, and an XR interface for immersive monitoring and control. Real-time environmental data is visualized through an interactive digital twin, enabling farmers to simulate and automate irrigation decisions effectively. The pilot implementation in Indonesia demonstrated improved soil moisture consistency and a 22% reduction in water usage (Abdulrazzaq et al., 2021). Key challenges such as connectivity, cost, and XR accessibility are discussed, alongside future integration of AI agents and predictive analytics to further enhance system intelligence and scalability.

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1. INTRODUCTION

The agricultural sector is facing unprecedented challenges in the 21st century. Rapid population growth, climate variability, shrinking arable land, and the urgent need for sustainable food production systems have created a pressing demand for innovation. Traditional farming practices—often labor-intensive and inefficient—are proving inadequate in meeting global food security goals, especially in developing countries where resources are limited and environmental pressures are intensifying.

Smart farming technologies have emerged as a transformative solution to these issues. At the heart of this evolution is the convergence of the Internet of Things (IoT), automation, and digital visualization technologies such as Digital Twin (DT) and Extended Reality (XR). These technologies collectively enable precision agriculture by offering real-time monitoring, data-driven decision-making (Azzaz et al., 2022), and remote control of agricultural processes. By integrating these technologies, farms can move from reactive to predictive and prescriptive operations, dramatically enhancing productivity and sustainability.

Among these innovations, IoT plays a foundational role. Through the deployment of distributed sensor networks, IoT systems collect granular data on soil conditions, microclimate, and crop health. However, the challenge lies not only in data collection but also in the interpretation and application of that data in a user-friendly, actionable format. This is where Digital Twin and XR technologies come into play. A Digital Twin allows for the creation of a virtual replica of a physical farm (Batty, 2018), enabling real-time simulation and monitoring. Meanwhile, XR tools, including Augmented Reality (AR) and Virtual Reality (VR)—enable immersive interaction with these virtual environments, making complex data intuitive and accessible for users, including farmers and agricultural educators.

The integration of LoRaWAN (Long Range Wide Area Network) as the communication backbone for these systems is particularly advantageous in rural and remote farming locations. Its low power consumption and extended transmission range make it ideal for large-scale agricultural deployments with minimal infrastructure. Combined with cloud-based analytics and edge computing capabilities, LoRaWAN-enabled smart farms can function with high efficiency (Farraj & Abdallah, 2020), even in areas with limited internet access.

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