

The usage of digital twins for data-based irrigation management

Decision Support Systems can help to minimize water inputs while enhancing productivity.
The DIGIREG case study in Catalonia, Spain.



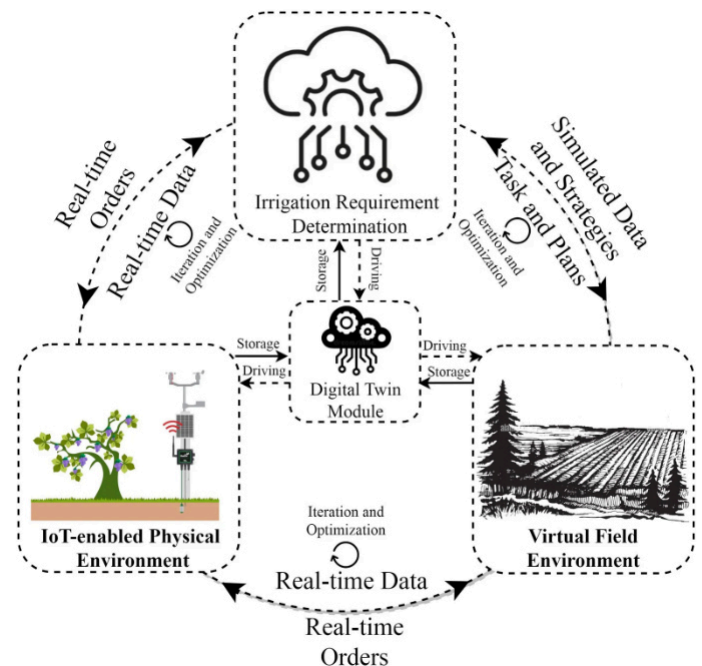
Water is becoming scarce not only in arid and drought areas.
Author: Institute of Agrifood Research and Technology (IRTA).
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/// Context ///

In the actual context, water is becoming scarce not only in arid and drought areas, but also in regions where rainfall used to be abundant. Although approximately 70% of freshwater resources are used for food production, less than 60% of the irrigation water is effectively incorporated by crops. One way to address this issue is to reduce inefficiencies in irrigation management. Key issues in this regard include how to deal with spatial variability and the adoption of deficit irrigation strategies at the field scale.

To achieve this goal, smart technologies related to Decision Support Systems (DSS) such as Digital Twins (DT) are being increasingly utilized for its capability to allow real-time interactions and modifications between the irrigation system and its digital representation. Thus, supporting a precise and low labor management of irrigation. This solution enables to create a virtual replica of the physical irrigation systems, providing a dynamic, data-driven platform to monitor, predict, and enhance irrigation practices. The DT technology's core benefit lies in its ability to provide precise, real-time insights into the irrigation process. By leveraging data from various sources such as soil moisture sensors, weather forecasts, and crop growth models, the DT continuously updates to reflect current conditions. This continuous feedback loop allows for the precise application of water, ensuring that crops receive the optimal amount needed at the right time. The main outcomes include increased water use efficiency, improved crop yields, and sustainable water resource management.

How Decision Support Systems (DSS) can minimize water inputs while enhancing productivity.



Conceptual architecture of an irrigation determination framework.
Author: Manocha, A., Sood, S. K., & Bhatia, M. (2024).
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Digital Twins allow real-time interactions and modifications between the irrigation system and its digital representation.

Farmers can integrate DT technologies into their existing irrigation infrastructure. This can be achieved through the installation of Internet of Things (IoT) sensors and connectivity tools that feed data into the DT model. By doing so, farmers can gain a comprehensive understanding of their irrigation systems, identifying inefficiencies and areas for improvement. For instance, the DT can simulate different irrigation scenarios, helping farmers make informed decisions about scheduling and quantity of water application. This proactive approach ensures that water is used judiciously, conserving resources while maintaining crop health.

By leveraging data from various sources such as soil moisture sensors, weather forecasts, and crop growth models, the Digital Twins continuously updates to reflect current conditions.



Grapevine with a sensor to measure its hydric status in the form of water potential.
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/// Solution for a Resilient Future ///

Digital twin technology involves the creation of a virtual model that accurately replicates a physical irrigation system. This model is continuously fed with real-time data from various sources:

- Weather Forecasts (e.g. temperature, relative humidity, solar radiation)
- Sensors installed on the ground or on plants (e.g. soil humidity)
- Remote sensing (e.g. crop vigor, evapotranspiration)
- Information provided by the farmer

The DT uses this data to simulate various irrigation scenarios, allowing farmers to make informed decisions about water application. It continuously learns and adapts, improving its accuracy and effectiveness over time.

Implementation Process

- Assessment and planning: Evaluate the existing irrigation infrastructure and identify the specific needs and goals of the farm. Plan the integration of DT technology, including the types of sensors and data sources required.
- Installation of sensors and data collection tools: Install soil moisture sensors, weather stations, and other relevant devices throughout the farm. Ensure these devices are connected to a central data collection system.
- Development of the digital twin model: Create a virtual model of the irrigation system using software that can assimilate the installed sensors and other external sources into soil-crop models.
- Integration and testing: Connect the digital twin model to the data collection system and test its accuracy. Make necessary adjustments to ensure the model accurately reflects the physical irrigation system.
- Training and capacity building: Train farm personnel on how to use effectively the prescription tools powered by the digital twin technology. This includes understanding

Digital twin technology involves the creation of a virtual model that accurately replicates a physical irrigation system.

how to interpret the data and make informed decisions based on the model's predictions.

- Continuous monitoring and optimization: Regularly monitor the performance of the digital twin and the physical irrigation system. Use the insights gained to continuously optimize irrigation practices.

Equipment Needed

Depending on the complexity and scope, the architecture of a DT can be very different. In general, creating and maintaining a DT involves a combination of various machine-to-machine technologies that collaborate to replicate, monitor, and analyze physical objects or systems in a digital environment.

- Soil moisture sensors: These sensors measure the moisture content in the soil at different depths and locations across the farm.
- Weather stations: Comprehensive weather stations that monitor temperature, humidity, wind speed, solar radiation, and rainfall are crucial, providing real-time weather data that impacts irrigation needs. There are different sources available:

1. Weather stations installed in the farm. May be expensive and require some maintenance. In practice they are only recommend in large farms and where is no other alternative weather station around.
2. Public weather network accessible online through an API, such as XEMA (Catalonia) or SIAR (Spain). It is a good option if the farm is nearby.
3. Virtual weather station, offered by several companies, which provide weather data at any point in the planet. It is a good option where is no public network around.



Moisture probes installed in the soil of a productive orchard.
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Advancing agricultural irrigation through Digital Twin Technology: Implementation strategies and practical insights.

The DT uses this data to simulate various irrigation scenarios, allowing farmers to make informed decisions about water application.



DataLogger.

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Depending on the complexity and scope, the architecture of a digital twin can be very different.

- **Software for DT modeling:** Specialized software that can create and manage the digital twin model. This software should integrate data from various sources into sol-plant models, run simulations, and provide actionable insights.
- **Irrigation Control Systems:** Automated control systems that can adjust irrigation schedules and amounts based on the insights provided by the DT. If the users have an irrigation controller accessible online through an API, the whole prescription process can be automated. If not, then the user would have to type manually the prescription into the irrigation controller.

Results from Practical Applications

One example of demonstrative approach toward implementing DT technologies in commercial farming systems is the DIGIREG (<https://digireg.cat/>) project. The demonstration integrates everything from installing sensors, using remote sensing and interpreting all these types of data to optimize and precisely control irrigation, to automatically adjusting the programs in the irrigation controllers. It has different case studies on commercial vineyards and on pistachios, almonds, peaches and horticulture orchards.

- **IoT Connectivity tools:** The devices should be connected to the cloud of a sensing company and then accessed through the API of their servers.
- **Central Data Collection System:** This system, often cloud-based, collects, stores, and processes data from all sensors and external sources. It should have robust data management capabilities and provide interfaces for data visualization and analysis.

/// Always Moving Forward ///

While the advantages of digital twin technology are numerous, there are also a number of challenges that must be addressed in order to successfully implement it. The initial investment required to procure the necessary sensors, data collection tools, and software can be considerable. Complementation of local sensors with remote sensing sources allows to optimize the number of sensors and, hence, to alleviate the initial investments. Another potential solution to this issue is to seek funding opportunities or to implement the technology in phases, thereby spreading the costs over time. In addition, it is recommended that a pilot project be initiated on a limited portion of the farm to evaluate and enhance the digital twin technology before its implementation on a larger scale. Furthermore, the complexity of integrating data from disparate sources that comprise the digital twin necessitates the presence of an overall compatibility and a robust data management system. It is crucial to collaborate with technology providers and to invest in training programs to ensure that individuals involved in farm management are able to utilize and maintain the DT system effectively. It is essential that all relevant stakeholders, including farm managers, workers, and technology providers, are involved in the planning and implementation process. Continuous contact with the technology provider is necessary to ensure that the latest data and technological improvements are incorporated into the DT, thereby maintaining and enhancing its accuracy and

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effectiveness. Additionally, the DT requires a period of adaptation to the specific farm conditions, needing regular monitoring and adjustments during this phase.

The utilization of the Internet of Things (IoT) in agriculture has witnessed a notable surge in recent years, while the deployment of digital technologies (DT) in this sector remains in its nascent stages. Furthermore, a number of additional factors, including performance measurements,



Researcher working with the DT.

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Exploring the challenges and potential of Digital Twin Technology in agriculture: Investment strategies, pilot projects.



Technician checking measures in the field.
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access to data, operations planning, operations control, and farm characteristics, have been identified as influencing the adoption of technologies in agriculture. Farmers have reservations about allowing a system to operate automatically, given the potential risks to their crops in the event of system malfunction. Consequently, the system must facilitate an evaluation of its performance in a virtual environment prior to undertaking the automated irrigation control of a farm. Once the IoT platform is deployed, farmers may opt for automated control or just to decide for each received prescription whether to transfer them to the controller or decide another irrigation scheduling. When the system is operational, farmers are able to visualize the past, current, and potential future states of their farms by accessing the personalized dashboard and the data stored in the IoT platform. The integration of soil, weather, crop, and irrigation system data enables farmers to receive personalized prescriptions, which can either be applied automatically or be used by farmers to make their own informed decisions, thus enhancing operational efficiency, and reduce water usage in irrigation. As a general guideline, the main role of these systems is to undertake day-to-day

The additional value of DT has yet to be fully realized in commercial farmlands.

The integration of soil, weather, crop, and irrigation system data enables farmers to make more informed decisions, enhance operational efficiency, and reduce water usage in irrigation.

routine decisions (automatically) and let farmers or agronomist concentrate their effort in tactical and strategic decisions (one or few times per year).

The additional value of DT has yet to be fully realized in agricultural applications; however, projects such as DIGIREG are making progress in this area. The potential for DT to be used pervasively, on different spatial and temporal scales, and with varying levels of complexity is dependent on the specific components involved and the desired functionality. The future of DT may evolve from simpler cases, exhibiting fewer components, to more sophisticated ones. As the technology develops, these applications can be enhanced by gradually adding components and functionality, thus showing the full potential of DT.



Efficient water management is essential to overcome desertification and future problems to irrigated crops.
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Further information

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