Digital twins in farm management: illustrations from the FIWARE accelerators SmartAgriFood and Fractals

C.N. Verdouw[1, 2], J.W. Kruize[*1]
1 Wageningen Economic Research, Wageningen University and Research, NL
2 Information Technology Group, Wageningen University and Research, NL

Abstract

The Internet of Things (IoT) provides a vision of a world in which the Internet extends into the real world embracing everyday objects. In the IoT, physical objects are accompanied by Digital Twins: virtual, digital equivalents to physical objects. The interaction between real/physical and digital/virtual objects (digital twins) is an essential concept behind this vision. Digital twins can act as a central means to manage farms and has the potential to revolutionize agriculture. It removes fundamental constraints concerning place, time, and human observation. Farming operations would no longer require physical proximity, which allows for remote monitoring, control and coordination of farm operations. Moreover, Digital Twins can be enriched with information that cannot be observed (or not accurately) by the human senses, e.g. sensor and satellite data. A final interesting angle is that Digital Twins do not only represent actual states, but can also reproduce historical states and simulate future states. As a consequence, applications based on Digital Twins, if properly synchronized, enable farmers and other stakeholders to act immediately in case of (expected) deviations. This paper introduces the concept of Digital Twins and illustrate its application in agriculture by six cases of the SmartAgriFood and Fractals accelerator projects (2014-2016).

Introduction

Automation and mechatronics has enabled huge steps forward in production efficiency, quality improvements and sustainability. The improvements are mainly accomplished by non-internet technologies, such as mechanisation of field operations, breeding new varieties, and more environment-friendly cultivation techniques. Yet, the sector has to drastically increase productivity to feed the growing world population and to satisfy their changing food demands.

The Internet of Things (IoT) is a very promising approach for realizing new levels of control (Porter and Heppelmann, 2014; Sundmaeker et al., 2010; Verdouw, 2016). The IoT provides a vision of a world in which the Internet extends into the real world embracing everyday objects. The interaction between real/physical and digital/virtual objects is an essential concept behind this vision. In the IoT, physical objects are accompanied by Digital Twins: virtual, digital equivalents to physical objects (Grieves, 2014; Verdouw et al., 2015). Digital Twins are rich, globally accessible digital counterparts, which contain both current, historical and future information on that object's physical properties, origin, ownership, and sensory context (Sundmaeker et al., 2010).

This paper introduces the concept of Digital Twins and illustrates its application in agriculture by some cases of the SmartAgriFood and Fractals projects (2014-2016). As part of the FIWARE Accelerator Programme[1], these projects have promoted the uptake of Future Internet Technologies in the European farming industry with special focus on SMEs and start-ups.

[1] https://www.fiware.org/fiware-accelerator-programme/

The Concept of Digital Twins

Digital Twins are virtual, digital equivalents to physical objects (Grieves, 2014). They are real-time and remotely connected to the real objects and provide rich representations of the objects and its context. More specifically, a Digital Twin (also called virtual object) can be defined as 'a digital representation of an object, with a unique identification, that can be trusted, possesses the property of integrity, is timely available, and can be used for the intended purpose' (Verdouw et al. 2015).

The interaction between real/physical and digital/virtual objects is an essential concept behind the Internet of Things. In the IoT, physical entities have digital counterparts; things themselves become context-aware and they can sense, communicate, act, interact with their digital counterparts and others, exchange data, information and knowledge (Sundmaeker et al. 2010). These counterparts are twins of the physical objects and can be linked to and synchronized with the physical object throughout their lifecycle (Canedo, 2016; Grieves and Vickers, 2016; Verdouw et al. 2015). The Internet acts as a storage and communication infrastructure that holds a virtual representation of things linking relevant information with the object (Uckelmann et al. 2011). As such, Digital Twins serve as central hubs of object information, which combine and update data continuously from a wide range of sources.

The usage of Digital Twins removes fundamental constraints concerning place, time and human observation. Instead of control based on direct observation of physical objects, which requires physical proximity, Digital Twins enable remote control of farm operations (Figure 1). This allows for the decoupling of physical flows from information aspects of farm operations. Furthermore, Digital Twins can not only represent actual states, but can also reproduce historical states and simulate future states. Moreover, Digital Twins can be enriched with data about object properties that cannot be observed (or not accurately) by the human senses, e.g. sensor and satellite data. As such, Digital Twins allow for more 'sophisticated' control capabilities, including event-based monitoring, fine-mesh tracking and tracing, quality management and planning functionalities.

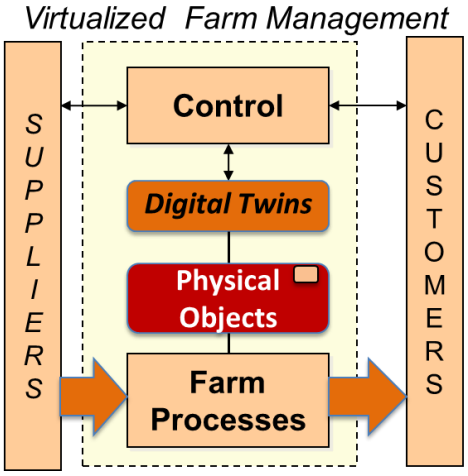

Figure 1. Role digital twins in farm management

The application of Digital Twins based on the Internet of Things (IoT) is very promising for realizing new levels of automated execution and control (Porter and Heppelmann, 2014; Sundmaeker et al., 2010). It is expected to be a powerful driver that will transform farming and the entire food production chain into smart webs of connected objects that are context-sensitive and can be identified, sensed and controlled remotely (Verdouw et al. 2016). As such, we believe that the usage of Digital Twins will be a real game changer in agricultural production.

Results

Application of digital twins in agriculture

As part of the FIWARE Accelerator Programme, the SmartAgriFood and Fractals projects have promoted the uptake of FIWARE technology enablers in the European farming industry [www.fiware.org/accelerators/#agrifood]. The cases that are used to illustrate the application of Digital Twins in farm management are developed within these accelerators and listed in Table 1. We selected cases that include IoT technologies and that were highly instructive for the purpose of this paper. Furthermore, we tried to include different agricultural subdomains and topics.

Table 1. Illustrative cases based on IoT technologies in the Smart Agri Food and Fractals accelerators

Case	Accelerator	Topic	Objects
Dairy Monitor (Connecterra, NL)	SmartAgriFood	Heat detection, health analysis and location services	Dairy cattle
Open PD (Espiral Pixel, PT)	SmartAgriFood	Identification of plant pests and diseases	Crops
INSYLO (Ubikwa Systems, SP)	SmartAgriFood	Stock monitoring of feed silos of livestock farms and optimization of the replenishment	Feed Silos
FarmTelemetry (Lesprojekt, CZ)	Fractals	Fleet management, tracking machinery and energy monitoring	Farm equipment
OLIFLY (HarphaSea, SI)	Fractals	Monitoring of olive fly occurrence and expanding	Olive trees
BeeZon (GR)	Fractals	Apiary monitoring to identify diseases, pest infection, pesticide exposure and toxicity	Bee colonies

Below, the cases are introduced and the role of Digital Twins is described.

Dairy Monitor (Connecterra, Netherlands)

The Dairy Monitor solution of Connecterra (www.connecterra.io) uses high-tech pedometers mounted on cows to very accurately sense its movements (Pretz, 2016). The solution is scalable and directly connected to a cloud services platform with advanced algorithms for predictive analytics. Connecterra actually creates Digital Twins of cows that are used to remotely monitor cows and to detect when a cow is in estrus (in heat) and to monitor its health. The Dairy Activity Monitor is able to provide multiple behaviour detection and predictions including animal heat & estrus cycles, health analysis and also provide a forward looking prediction of the next cycle start dates. The devices learn and tune their behaviour based on the individual movements of cattle. Furthermore, Connecterra provides location services that track and trace the movements of dairy cows giving you an accurate measurement of the free-grazing time per animal.

Open PD (Espirial Pixel, Portugal

Plant pest and disease identification is critical and normally a slow process. OpenPD (http://www.openpd.eu) is a mobile app that provides an on-the-field and on-the-fly system for fast identification of plant pests and diseases. It is easy to use, based on open community and peer learning platform. Starting point is a photo of the plant part affected by the pest or disease. Coloured, clean and good resolution photos work better in this context. The user describes the problem he's facing based on the photos taken and his own observation of the local conditions. The picture and the problem description form the Digital Twin of the affected plant. Based on this Digital Twin, a community of experts then provides help to the user in order to identify the pest or disease, including discussion, asking for more details or inviting other users to join in.

INSYLO (Ubikwa Systems, Spain)

INSYLO (www.insylo.com) is a solution to remotely monitor the stocks of the silos of the livestock farms and optimize the replenishment routes. It is composed of a new generation device, installed on top of the silos, and a collaborative cloud platform that provides the apps and services needed by farmers and feed suppliers. Currently, most of the farmers control the amount of feed available in the silos of the farm in a manual and risky way. In a periodic basis, they have to climb on top of the silos to make visual estimations of the stocks. On the other hand, feed suppliers have to process the replenishment orders mostly by phone calls and lack the necessary data to optimize the delivery routes and the production plans. With INSYLO, a Digital Twin of a silo is available for the farmer and other authorised users. When the stocks reach a critical level, farmers receive an alarm in his mobile phones and send the replenishment orders by a simple click. Feed suppliers process the orders in an automatic way and have access to the stocks of his customers to optimize in advance the production plans and replenishment routes.

FarmTelemetry (Lesprojekt, Czech Republic)

The effectiveness of farm operation is determined by the ratio of production output and input value. FarmTelemetry focuses on optimization of farm inputs, such as energy needed to power agricultural machinery on the fields, energy for the transport of inputs and outputs of production. It supports online visualization of current position of any machinery and also history of movement in the selected period. The analysis are focused on monitoring activities and utilization of individual tractors. Farm Telemetry also provides an overview for individual farmer's fields. As such it creates Digital Twins for machinery and its relations to fields. Based on these Digital Twins, FarmTelemetry enables to track the machinery fleet in real time, to monitor the energy consumption of the crops on individual fields, to evaluate economic efficiency of the crop management treatments within the fields and to evaluate machinery passes on the soil environment, including detailed analysis of the tractor trajectories within the fields considering the site specific conditions.

OLIFLY (HarphaSea, Slovenia)

Olive fly is the single most important pest damaging up to 100% of table olive production and severely reducing the quality and yield of olive oil. By using the OLIFLY application, accompanied by real-time imaging of pest traps in the orchard, olive growers will be able to monitor olive fly occurrence in the orchards from their homes or offices[2]. This will enable them to react on time to save their crop and product quality, reduce the cost for pesticides and labour.

OliFLY automated imaging system enables farmers to monitor olive fly population growth and dynamics on their farm on their phone or on the webpage. The cameras image the pest trap and transfer information in real-time through Web in a Digital Twin of the trap. The images are of sufficient quality to enable olive fly identification and distinction from other species. This will enable prompt reaction to the olive fly population growth, resulting in optimal and effective pesticide use to minimize the damage and preserve the fruit quality as well as save farmers' time and money.

BeeZon (Greece)

Climate change, including high temperatures, over winter periods and intense rainfalls, has affected the entire ecosystem and especially beekeeping. The timing of nectar-flows is unstable, and the natural resources are scarce. The bees are starving, or dying, and the professional beekeepers loose populations and production. Most professionals, in order to sustain their business, are forced to practice migratory beekeeping, hunting nectar flows across large geographical areas based on nothing but past experiences. But this choice comes with much cost in terms of manpower, transportations, poor supervision ability, and losses of colonies. For this, BeeZon (www.beezon.gr) provides a real-time continuous apiary monitoring system that enables beekeepers to remotely control their apiaries and make smart management decisions interacting with the bees as little as possible. This solution, called a Virtual Bee Consultant, creates Digital Twins of bee colonies based on a GPS-based tracking system and real-time data from various sensors including humidity, exterior & interior temperature, brood temperature and weight. This allows beekeepers remote monitoring and control over the following aspects:

[2] http://www.harphasea.com/index.php/en/international-projects/fractals

Time management of nectar flows;

- Identifying the presence of diseases, pest infection, pesticide exposure and toxicity;
- Insight of colony status, colony dynamics and colony hygiene;
- Inspection of queenless and swarming states;
- Food storage reserves' management;
- Antitheft mechanism and tracking system;
- Notification system tailor made by the user.

Conclusion and discussion

This paper has introduced the concept of Digital Twins from the perspective of the Internet of Things and illustrated its application in agriculture by some cases of the SmartAgriFood and Fractals accelerators. Digital Twins are real-time and remotely connected to the real objects and provide rich representations of the objects and its context. Applications based on these Digital Twins enable farmers and other stakeholders to act immediately in case of (expected) deviations. The cases introduced show that Digital Twins are already used in innovative internet-based applications. The main contribution of this paper is that it has explicitly addressed the concept and the underlying mechanisms of how Digital Twins impact farm management.

It should be noticed that the application of Digital Twins as addressed in this paper, is still at an early stage of development in farm management. Existing applications mostly focus on basic monitoring capabilities or they virtualize objects at a high granularity level. Management at lower granularity levels is often still too expensive and integrated software solutions are lacking. Using generic technologies and SaaS-approaches can provide broadly affordable solutions, especially for SMEs. These developments establish a basis for the next level of virtual control: optimization, simulation and decision support based on on-line Digital Twins. Ultimately farms can become autonomous, self-adaptive systems in which smart Digital Twins can operate, decide and even learn without on-site or remote intervention by humans.

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