APPLICATION OF DIGITAL TECHNOLOGY IN AGRICULTURE: POTENTIAL SUPPORT FOR WINEGROWERS

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Abstract
In agriculture, disease and pest infestation are normal phenomenon, but they reduce the quality of the crop. Likewise, wrong irrigation or fertilization may damage the yield or lead to inefficient use of resources. Lack of adequate decision support tools and user-friendly interaction with advanced technologies are the most critical barriers that prevent the adaption of Precision Agriculture by farmers. In this article, we review the state-of-the art of digital technology in agriculture and present requirements for an ecosystem that goes even further than Precision Agriculture and reaches up to Digital Agriculture. Given the wide coverage of the agricultural sectors, the authors focus on grapevine in this article.

Key words: *digital agriculture; IoT sensors; sensor system; digital twin, grapevine.*

INTRODUCTION

Modern agricultural production is not possible without reliable and up-to-date information about farm operations (*Verdouw et al., 2021*). IoT sensors are increasingly used to collect information about farm operations and the situation in the fields. The collection of data from sensors creates new opportunities for innovation in the field of prediction systems in the vineyard (*European Commission, 2017*). Using IoT sensors leads to large-scale big data that provides valuable information (*Muangprathub et al., 2019*). Big data-driven agriculture offers opportunities to transform traditional decision-making into data-based decision-making (*Sarker et al., 2020*). Traditional agriculture with manual labour and low productivity is being transformed into sustainable, intelligent, efficient, and eco-friendly agriculture by using technologies (*Mitra et al., 2022*). Thanks to modern analysis systems and deep learning techniques, for example, it is possible to identify the changes of a plant being infected and thus notify the farmer in advance (*Udutalapally et al., 2021*). In addition, controlled usage of pesticides and fertilizers helps to increase the crop quality as well as minimizing farming costs (*Nabi et al., 2022*).

The modernization of agriculture is reflected in the application of digital technologies and the development of new agricultural concepts such as Precision Agriculture, Smart Farming and Digital Agriculture. Although these concepts may seem to be similar, there are significant differences between them.

Precision Agriculture is a modern farming management concept using digital technologies to monitor and optimize agricultural production processes (*Schrijver et al., 2016*).

Smart Farming is the use of information and communication technologies for optimization of complex farming/agriculture systems (*Udutalapally et al., 2021*). Smart Farming goes beyond the concept of Precision Agriculture by basing management tasks not only on location but also on data, enhanced by context and simulation awareness, triggered by real-time events (*Sundmaeker et al., 2016*).

In the agricultural sector, digitization is considered as a function of four components, including: Smart Agriculture, Smart Technology, Smart Design and Smart Business (*Elijah et al., 2018*). As a holistic approach, Digital Agriculture uses the knowledge of information science, environmental science, computer and software engineering, system science, GIS (Geographical Information System), GPS (Global Position System), remote sensing technology, and virtual satellite imaging for better integration of soil, climate and environment information with agriculture (*Sarker et al., 2020*).

With proper resource management, technology may be sound, feasible, relevant and quite useful to measure factors like climatic changes, undefined rainfall and high temperature and humidity, therefore helping the farmers to save the cost and time spent upon dangerous fungicide sprays (*Nabi et al., 2022*).

This article aims to identify the needs of winegrowers in particular and reviews the state-of-the-art for addressing these needs through the use of a combination of digital tools and technologies, which includes the identification of technological capabilities. In conclusion, we offer a – work-in-progress – concept for an extensible Digital Agriculture ecosystem for farm monitoring using a Digital Twin and Mixed Reality for data representation and interaction with a simulation model to test different farm management scenarios.

MATERIALS AND METHODS

During the Living Labs of the Erasmus+ project "Engaged and Entrepreneurial European University as Driver for European Smart and Sustainable Regions (E³UDRES²)" in Spring 2021, a group of researchers focused on developing a Digital Agriculture solution for winegrowers. The idea of the Living Labs was to bring researchers from the six universities of E³UDRES² initiative together with regional stakeholders. During the Living Labs a research group called "Human Contribution to Artificial Intelligence" was formed, comprising researchers with background in simulation modelling, IoT, machine learning, statistics and big data management. From the challenges and needs submitted by stakeholders it became clear that in each of the six countries (Austria, Belgium, Hungary, Latvia, Portugal, and Romania) grapevine is one of the agricultural sectors and all countries are facing similar problems (e.g., lack of tools and methods to deal with pests and diseases).

In order to examine in detail what has previously been done in the field of applying of digital technology in grapevine, the Scopus and Web of Science databases, and the World Wide Web were used to search for articles containing keywords, such as, Precision Agriculture, Smart Farming, Digital Farming, IoT sensors, sensor system, grapevine, Digital Twin.

Furthermore, in order to specify the requirements of the winegrowers from the perspective of the user, in-depth interviews and workshops were held. The questions were focusing on problems, challenges and needs regarding the cultivation processes that can be addressed by technological solutions. During a structured interview the following work processes were reviewed: canopy, soil, water, nutrient management; weed, disease, pest, insect, fungus and wild life management; weather forecast and frost protection; grapevine management, crop estimation and harvesting. Besides challenges and needs questions were also included to clarify what traditional, Precision Agriculture, Smart Farming and Digital Farming tools have already been used, what are the experiences of the utilization, what is not working and needs to be improved. The survey was carried out through highly different regions of Europe, we got answers from Austria, Hungary, Latvia and Portugal. For instance, in Portugal two interviews were conducted with representatives and members of Association of Wine Growers of the Municipality of Palmela (AVIPE), in Austria with the Federal Office of Viticulture and Pomology (Wein und Obst Klosterneuburg RTD).

RESULTS AND DISCUSSION

Results are divided into subsections where the authors conclude what is discovered from the literature review, what is discovered from in-depth interviews with winegrowers and what kind of Digital Agriculture ecosystem is proposed to make it easier for winegrowers to work using big data-driven disease detection and optimal resource-utilization tool.

Literature review

When considering Digital Agriculture, farmers' needs as well as their attitudes or perceptions towards these technologies play a crucial role. This can be done by drawing on published surveys and/or asking individual farmers.

In a survey by Kernecker et al. (*2020*), 287 farmers (from the arable, orchard, vegetable and vineyard sectors) from 7 EU countries and 22 experts from the agricultural knowledge and innovation system were asked about smart farming technologies (SFT). Winegrowers indicated that among the listed smart farming technologies (recording and mapping technologies, GPS based steering tools, apps and farm management information system (FMIS), and autonomous machines) apps and FMIS are most useful for their farm (*Kernecker et al., 2020*).

Also interesting are the findings that there is a large discrepancy between the daily work requirements and the ability of new technologies and their users to meet these requirements (*Kernecker et al., 2020*).

Users of SFT are frequently confronted with the challenge to interpret data and to assure devices' connectivity and preciseness. Farmers tend to support a positive assessment of SFT in general, but looking at impacts on economic profitability as well as on environmental performance of SFT, the level of conviction is clearly moderate (*Kernecker et al., 2020*).
Kaňovská (*2021*) conducted a survey of 22 small and medium winegrowers from the Czech Republic regarding the benefits and barriers of using of sensors and weather stations. Unfortunately, the needs of the winegrowers were not directly inquired there. The obstacles of using sensors were that it is not necessary to measure so much data or that the usefulness of this information is not clear (*Kaňovská, 2021*).
Methods made available to winegrowers should predict as far in advance as possible, must be as simple as possible, and work with as little data as possible, preferably with data that farmers can access quickly, easy, and cheaply and, if possible, without the need for intensive training. The best approach must consider the availability and/or possibility to have required inputs (required data is sometimes not available), the adequate spatial resolution (field level or regional level), the necessary granularity (information regarding the spatial variability in each area) and required precision (e.g., a simple smartphone camera, despite the loss in quality, can be in many cases a cost-effective alternative to hyper and multispectral cameras, LiDAR, ultrasonic and radar sensors) (*Barriguinha et al., 2021*).
Recently, several studies have looked at the problems of managing and effectively using large numbers of heterogenous devices, and have found a solution in the use of social networking principles and technologies. The guiding motivation is that a social-oriented approach is intended to aid in the discovery, collection, and composition of resources and knowledge offered by distributed objects and networks (*Delnevo et al., 2021*).

In-depth interviews

To understand what are the most urgent needs of the farmers, we conducted several informal in-depth interviews: with a technical adviser of AVIPE, with farmers associated to AVIPE, with a researcher for viticulture and orcharding of Wein und Obst Klosterneuburg RTD, and with a horticultural engineer of MATE Hungarian University of Agriculture and Life Sciences.
From the interviews was learned that the used technologies are well-known, well-adapted, but they are highly labour-demanding and require expertise. The main problem is the shortage of financial resources (high personnel costs) and manpower (unwillingness to work in the agriculture), which causes a critical overload of the present employees. Under these circumstances there is often no capacity for finding, learning and trying out the new technologies, even though it is highly needed and this need is identified. The knowledge base and expertise (and intention) are given even for research, development and innovation, but there is no free capacity for it. To summarize, new technologies are needed to reduce winegrowers' dependency on traditional labour-demanding agriculture management methods, but informative and financial support should be appropriate to implement them.
From the consumer's perspective, the required Digital Agriculture ecosystem:

- brings together different systems making them available to winegrowers,
- is user-friendly and easy to adapt,
- gives information on the management practices,
- suggests appropriate decisions or prevention measures to be taken,
- informs about when and where operations should be performed,
- conveys information on time,
- creates awareness among winegrowers so that only necessary plant protection is carried out,
- measures correctly so that it could give accurate information about, e.g., level of infection or possible emergence of a disease.
- is capable of identifying the situation in each row, individually for each plant,
- supports reliable means of communication with the farmer,
- allows networking (sharing experience and sensor data with other winegrowers),
- is cost effective, and
- reflects independently host, pathogen, and environmental interaction, etc.

A Digital Agriculture ecosystem

In view of the variety of crops, the group of researchers chose to create a Digital Agriculture ecosystem specifically for winegrowing purposes, with a potential to extending its use in future to other plant species that are grown in lines between which a self-driving drone can drive through. The principle of an on-surface-driving drone, to the contrary to a flying drone, was chosen (1) to allow it to move autonomously in closed areas, thereby (2) removing the need for a licensed drone pilot, while (3) complying with existing legislative requirements allowing the use of self-driving drones, such as lawn mowers and vacuum cleaners, in most countries.

To meet the demands arising from our literature review and in-depth interviews, the group of researchers propose a Digital Agriculture ecosystem using a Digital Twin concept and Mixed Reality applied to the grapevine field. A Digital Twin is a dynamic representation of a real-life object that mirrors its states and behaviours across its lifecycle and that can be used to monitor, analyse and simulate current and future states of and interventions on these objects, using data integration, artificial intelligence and machine learning (*Verdouw et al., 2021*). Basically, a Digital Twin 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 (*Grieves & Vickers, 2017; Redelinghuys et al., 2019; Verdouw et al., 2021*). The Digital Twin would allow observing, and ultimately simulation of the various internal and external influence factors with a focus on pest and disease detection (and ultimately prediction). Another ambition is to contribute to optimal resource-utilization, e.g., irrigation, fertilization. These solutions lead not only to reducing the costs and necessary resources such as water and chemical pesticides, but also to minimizing pressure on the environment (*Sarker et al., 2020*). Soil health is yet another application of the planned monitoring and prediction capabilities.

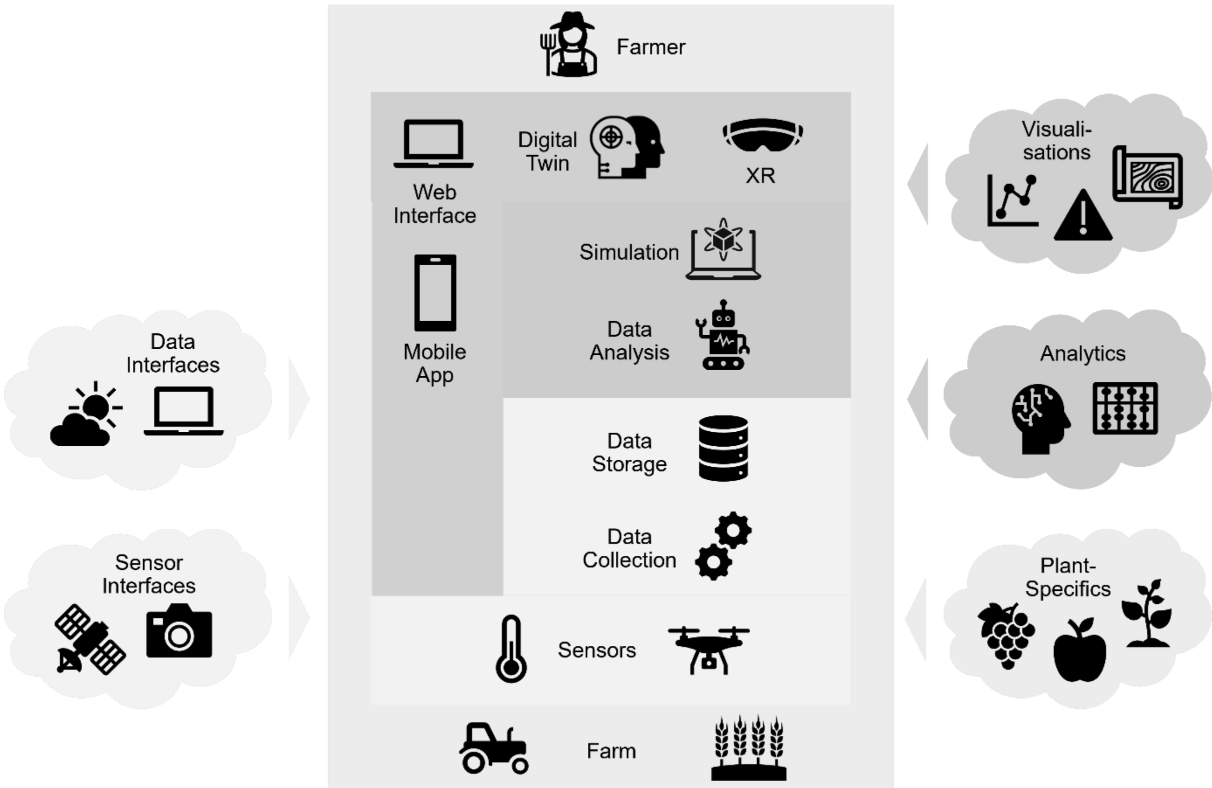

Fig. 1. Proposed Digital Agriculture ecosystem overview and extensibility

Figure 1 shows a high-level representation of the proposed Digital Agriculture ecosystem. It includes the following key solutions based on preliminary concepts (*Ojha et al., 2015*), which should be easily replaceable and extendable due to the modular nature of the proposed ecosystem:

- Wide range of sensors and other input data;
- Wide range of analytics tools and visualization outputs.

Given that not all farmers have applied SFT to manage their fields, it is intended to establish a three-level engagement where each subsequent one requires greater involvement of the farmer, while providing more detailed feedback:

- Smartphone mode. A user-friendly toll-free mobile app and only external data are used. The user receives rather general alerts and management recommendations from the data analysis service.
- Stationary sensor mode. A mobile or web app, external data and IoT sensor measurements from the field are used. More detailed data enables the data analysis service, thus providing the user with more detailed, tailor-made intervention proposals.
- Virtual twin mode. A mobile or web app, external data, IoT sensor measurements and a mobile sensor system are used. The mobile sensor system provides the possibility to generate a Digital Twin, thus the user can interact with the simulation service, test different management scenarios and consider strategic intervention proposals.

Various levels of the Digital Agriculture ecosystem are necessary at the first stage to enable productivity to be improved and environmental impacts to be reduced without financial contribution. After gaining trust in the system, acquiring additional IoT sensors enables productivity to be further improved and environmental impacts to be made even more neutral.

One impact of using the proposed system would be larger yields, since it will be possible to deal with pests and diseases in early stage, which leads to less pesticides and fungicides, which leads to clean and healthy food. It would also help to make more efficient use of resources such as water and fertilizer, thereby reducing the costs of winegrowers.

CONCLUSIONS

Literature review and in-depth interviews shows that the team of researchers is on the right track and that the job started on the Digital Agriculture ecosystem during the Living Labs is the right way to go. Considering the development of IoT sensors, data mining, machine learning etc., technological capabilities are available to establish an extensible ecosystem which helps winegrowers to deal with agricultural issues.

Farmers do not need general management advices, but a notification system that would warn of potential problems on their farm, explicitly providing their location and advising a possible solution.

A Digital Agriculture ecosystem consisting of sensitive and specific sensor devices allowing an automated non-stop monitoring of vineyards would (1) allow a temporally and spatially precise application of plant protection products and, in consequence, (2) allow a reduction of pesticides and thus their impact on the environment, as well as (3) reduce the winegrower's risk of economic losses due to plant diseases and pests, (4) it would also help to make more efficient use of resources such as water and fertilizers, thereby reducing the costs of winegrowers.

Next steps in further research are (1) to identify existing databases worldwide that collect information to be included in the Digital Agriculture ecosystem (e.g., meteorological data, disease and pest distribution, multispectral data, land surface data etc.), (2) to identify sensor capabilities to create a mobile sensor system for local information acquisition, (3) to adapt the Digital Twin approach to bog ecosystem management *(Cirulis et al., 2022)* for agricultural use, (4) to run first case studies to test the prototype and get feedback from winegrowers.

ACKNOWLEDGMENT

This study was supported by Erasmus+ project "Engaged and Entrepreneurial European University as Driver for European Smart and Sustainable Regions (E^3UDRES^2)" no 101004069.

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