Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 1, 247-251

Digital Twin: Orchard Management using UAV

Imants Zarembo
Institute of Engineering
Rezekne Academy of Technologies
Rezekne, Latvia
imants.zarembo@rta.lv

Sergejs Kodors
Institute of Engineering
Rezekne Academy of Technologies
Rezekne, Latvia
sergejs.kodors@rta.lv

Ilmārs Apeināns
Institute of Engineering
Rezekne Academy of Technologies
Rezekne, Latvia
ilmars.apeinans@rta.lv

Gunārs Lācis
Institute of Horticulture (LatHort)
Dobele, Latvia
gunars.lacis@llu.lv

Daina Feldmane
Institute of Horticulture (LatHort)
Dobele, Latvia
daina.feldmane@llu.lv

Edgars Rubauskis
Institute of Horticulture (LatHort)
Dobele, Latvia
edgars.rubauskis@llu.lv

***Abstract*. Orchard management can benefit greatly from the use of modern technology to reach higher yields, decrease costs and achieve more sustainable farming. Implementation or such a smart farming approach into orchard management can be realised via application of unmanned aerial vehicles (UAV) for data collection and artificial intelligence (AI) for yield estimation and forecasting. On top of that, a digital twin of the orchard can be implemented to represent the physical system of the orchard in the digital format allowing implement modern data-driven decision-making based on fruit-growing automation.**

The aim of this study is to present a digital twin based on application of UAV and AI for orchard management that is being developed as part of a research project lzp-2021/1-0134. At this moment, we are developing a user-centred design which is oriented to satisfy horticulture specialists' needs for an autonomous monitoring system and to help them in decision-making. Within the framework of this study an enterprise model of orchard management is designed, which supports the digital twin concept and provides autonomous orchard monitoring. The study is scoped with subjects: apples, pears and cherries, and yield management based on orchard monitoring using UAV.

Keywords: cyber-physical system, digital twin, data-based decision-making, smart horticulture.

I. INTRODUCTION

Due to the impact of artificial intelligence and robotization development, the modern fruit-growing industry overcomes business process transformations to continue with the new technologies and improve production workflows. Therefore, it is a problem to model new agribusiness processes, which new technologies like digital twins and artificial intelligence will support. The artificial intelligence is already well known, but the digital twin concept requires some introduction. The digital twin is a virtual representation of a physical object or process capable of collecting information from the real environment to represent, validate and simulate the physical twin's present and future behaviour [1]. The digital twin is a modern approach to design management systems based on cyber-physical system application. Cyber-physical systems integrate sensing, computation, control and networking into one infrastructure, which must be human- and business-centred. As a result, new approaches to analyse and design modern management systems must be developed to overcome their complexity and multidisciplinary nature. It is a key technology of modern data-driven decision-making for complex system management based on industry robotization. It can be considered a type of gamification paradigm evolution resulting from boundary blur between real and virtual worlds due to the development of IoT and BigData technologies, which digitise our world. Digital twin based recommendation system triggers activities, which must be accomplished to achieve a set of business goals.

Pylianidis et al. (2021) identified 28 use cases of the digital twin application in agriculture developing their comprehensive literature review [2]. From the similar projects, the "Digital-Twin Orchard" can be mentioned [3]. Its authors created a system that can create a digital twin for every tree in an orchard by using spinning 3D cameras. This digital-twin enables the improvement of production and dynamic prediction of disease, stress and yield gaps using an end-to-end AI platform. Another related project is OliFLY application, by using it,

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol1.7290

accompanied by real-time imaging of pest traps in the orchard, olive growers are able to monitor olive fly occurrence in the orchards from their homes or offices [4].

Smart horticulture leverages modern information and communication technology to advance high yield, cost-effective and sustainable agriculture through collection of data on environmental parameters, smart processing of the data and other activities that support data-driven decision making. Such smart horticulture services can be achieved via application of UAV for data collection activities and AI for data processing. However, the new technologies change the agribusiness processes and request overthink the old-school of fruit-growing processes, asking for new competence and decision-making workflows. The previous models of commercial orchards must be upgraded and new enterprise models must be developed.

Nowadays, we look at entrepreneurship from an engineering point of view proposing the enterprise engineering discipline (Fig.1) - the triangle, which joins three cornerstones: enterprise modelling, business modelling and cyber-physical system modelling. Enterprise modelling is a discipline, which designs the structure of enterprise to provide service for a specific domain, segment or niche. Business modelling describes processes and logistics which support the designed structure of the enterprise. Meanwhile, cyber-physical system modelling is infrastructure which supports developed business models. At the same time, the spiral model (Fig.1) shows validation and improvement of each discipline's milestones to harmonise them and to obtain stronger synergy for enterprise goal achievement.

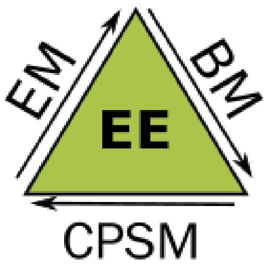

Fig. 1. Enterprise engineering (EE) triangle: EM - enterprise modelling, BM - business modelling, CPSM - cyber-physical system modelling.

Capability Driven-Development (CDD) is one of the enterprise modelling methodologies, which proposes effective business process organisation through enterprise capabilities [5]. ARTSS methodology is developed as an extension of the CDD considering the digital twin paradigm [6]. ARTSS is more compatible with eco-cyber-physical system development, because ARTSS provides a meta-class "Service", which is more suitable for the description of digital tools like image classification or autonomous systems like data collection using UAV.

The management of business goals can be achieved through the application of key performance indicators (KPIs) and measurement properties. KPIs motivate workers to achieve better results while displaying enterprise scores of success. Meanwhile, the measurement properties describe the current environment, - they must help to make correct decisions to achieve better results considering KPIs. If KPIs and measurable properties can be measured and expressed in the quantified form, then it is possible to provide a decision-making solution, which is based on the artificial intelligence application. These relations can be defined using some modelling methodologies and provided to users through a management program based on the digital twin paradigm.

Our project lzp-2021/1-0134 is directed to develop a digital twin for orchard management, which is based on application of UAV and AI. At the end of the project, we plan to achieve a technology readiness level "TRL7", which considers a prototype validated using the LivingLab approach. At this moment, we are developing a user-centred design which is oriented to satisfy horticulture specialists' need for an autonomous monitoring system for orchard management, which can support their decision-making.

The aim of the study is to present a digital twin based on application of UAV and AI for orchard management that is being developed as part of a research project lzp-2021/1-0134.

We applied an enterprise modelling methodology called ARTSS to model a smart orchard management system and structured expert knowledge to measure the environment using artificial intelligence and UAV with the objective to providing advantageous adjustments for fruit-growers.

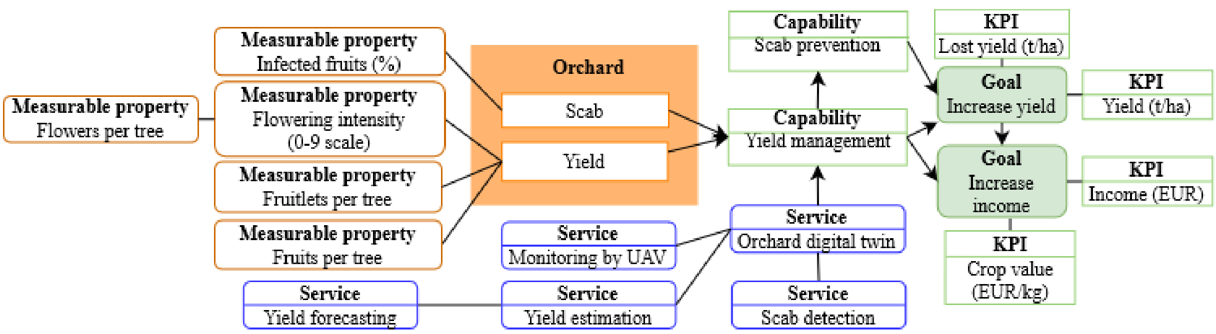

Fig. 2. Capability model of digital shadow for orchard management.

II. Materials and Methods

The scope of project lzp-2021/1-0134 was developed using a brainstorming approach based on the review of modern studies. We selected two use cases for the orchard digital twin: 1) scab detection; 2) yield estimation and forecasting. The scab detection was selected, because we had AI technology for scab detection developed in project lzp2019/1-0094 [7]. Meanwhile, the decision to include yield estimation was mainly impacted by the comprehensive analysis made by the Chinese Academy of Agriculture Science [8].

Capability Driven Development is an enterprise modelling methodology which represents enterprise capabilities, where a capability is an ability and capacity that enable an enterprise to achieve a business goal in a certain context. A focus area of the methodology is making the designs of management systems more accessible to business stakeholders to articulate their business needs more efficiently [9]. To achieve the aim of the study, we applied ARTSS notation to design a capability model of the orchard digital twin. ARTSS is a branch of CDD [6]. ARTSS provides a meta-class "Service", which is more suitable for the description of digital tools like image classification or autonomous systems like data collection using UAV.

The stages of plant phenology used in the model development were described according to BBCH scale [10][11]. The flowering intensity was estimated on a scale from 0 (no flowers) to 9 (all fruiting branches are abundantly flowering).

III. Results and Discussion

The digital twin created recommendation could be used as a decision support system tool. It could be useful in several directions: yield amount predictions, harvest time estimation, production management according forecast, modelled amount of fruits influencing fruit quality, growth and yielding regularity, as well as pest influence on the outcome of sales possibilities (dessert, processing etc.).

The developed capability model presents the orchard digital shadow, which provides a functionality to monitor orchard remotely using UAV, where yield estimation and scab detection is achieved using AI. Speaking about modern solutions of AI, measurable properties like flowers, fruitlets, fruits, leaves and scab caused damages on leaves and fruits can be detected using convolution neural networks with architecture like YoLoV5 or YoLoX. The application of convolution neural networks (CNNs) is a data-hungry approach, which requires a large collection of labelled data, images or video records, which are applied for their training.

However, the industrial progress has introduced plenty of tools like LabelStudio, Roboflow or MakeSense, which simplify image annotation process providing a user-friendly environment including automatic classification by using pre-trained CNN models. In addition, AI experts and data scientists are working on methodologies, which are intended to overcome data collection expenses.

Table 1. Examples of adjustment to environment changes for apples and pear

Measurable properties	Capability	Adjustment (recommendation)	Impact on KPI
Apples & flowering intensity > 5	Yield management	Thinning of flowers and protecting flowers from spring frosts by active protection measures.	Provides stable yields year by year & adequate fruit quality. Increases crop value.
Apples, Pears & flowering intensity < 5	Yield management	Reduce nutrient supply, reduce moisture level and irrigation rates down to 70% of optimal moisture level, introduce growth regulation media and technologies.	Reduce growth and promote induction of the flower buds, their development for the next cycle at the low yield condition.
Apple, Pears & fruitlets of off year	Yield management	Reduce nutrient supply, reduce moisture level and irrigation rates down to 70% of optimal moisture level, introduce growth regulation media and technologies.	Reduce growth and promote induction of the flower buds, their development for the next cycle at the low yield condition.
Apples & infected fruits > 0%	Yield management	Plan harvest strategy: for storage (sorting after storage, partly for storage sorting during harvest, only for juice) and sales.	Decrease of lost yield during storage & increase of income.
Apples & infected fruits > 0%	Scab prevention	Decide and perform plant protection measures against scab.	Decreases lost yield & increases productivity in next year.
Apples & fruits per tree	Yield management	Timing of harvest including planning of workers.	Decreases lost yield during harvest and storage.

Flowers/ fruitlets/ fruits per tree	Yield management	Prognosing harvest organisation, fruit sale and orchard management for next season.	More stable and predictable productivity, increased crop value and income.

TABLE 2. EXAMPLES OF ADJUSTMENT TO ENVIRONMENT CHANGES FOR CHERRIES

Measurable properties	Capability	Adjustment (recommendation)	Impact on KPI
Cherries & flowering intensity > 5	Yield management	Protect flowers from spring frosts (when forecasted) by active protection measures (heating, watering, spraying, covering etc.).	Decreases lost yield & increases yield.
Cherrie**s &** fruitlet density ≥ 6 fruitlets per 10 cm of branch & BBCH = 72 (sepals beginning to fall)	Yield management	Provide the nutrients and water for the trees near the optimum level by additional irrigation and leaf fertilising until the harvest.	Decrease of lost yield (dropped fruits) & increase of high-quality yield. Increases crop value.
Cherries & BBCH = 75 (fruit about half of final size)	Yield management	Assess the expected yield, plan harvest organisation and fruit sale.	Decreases lost yield (over ripened, rotted fruit) & increases income.
Cherries & BBCH = 81 (beginning of fruit colouring)	Yield management	Protect yield from bird (covers, bird repellent devices)	Decreases lost yield (bird damaged fruit) & increases income.
Cherries & BBCH = 87 (fruit fully coloured)	Yield management	Test the fruit taste and firmness, and start to harvest.	Decreases lost yield (over ripened, rotted fruit) & increases income.
Flowers/ fruitlets/ fruits per tree	Yield management	Prognosing harvest organisation, fruit sale and orchard management for next season.	More stable and predictable productivity, increased crop value and income.

Some examples of such methodologies include:

- augmentation algorithms, which automatically generate modified images and search for the best;
- policy for image transformation like AutoAugment;
- transfer-learning algorithms, which improve recognition quality retraining pattern-CNNs trained on adjacent domain datasets or extra huge datasets like ImageNet and COCO;
- Table 1. Examples of adjustment to environment changes for apples and pear, Table 2. – adjustments for cherries;
- active training, which focuses on optimization of human resources using spiral model for image annotation, requesting supervision only when it is required;
- weak supervision, which overviews methods related to the application of low-quality labelled data obtained using unsupervised methods or through crowdsourcing, or joining datasets with different classification hierarchy or annotation formats.

As the vertical development of the modelled system (see Fig. 2), the concept of trustworthy AI is the future challenge considering industrial evolution from Industry 4.0 to 5.0, which proposes cobots and social safety in cyber-physical space. This direction mainly depends on the scientific revolutions in the field of AI.

The horizontal development is more perspective speaking about the model development, if it is viewed from a trade-off point of view between awaiting research and existing solutions. The described digital shadow can be transformed to digital twin, that is really transition from precision agriculture to smart farming. Autonomous harvesting and spraying by using UAV can be mentioned as trending development vectors. However, cross-domain studies as human detection are interesting, because it is not only a use-case for orchard security, but it can be applied as a trustworthy AI element to fly around a human.

Regarding applicability in fruit production, the model has been developed for decision support in the adaptation of growing technology elements to the yield quantity and quality in the current year. So, the decisions for fruit thinning or supplementary fertilisation and irrigation could be supported by the assessment of fruitlet amount in the trees. Similarly, yield protection, harvest organisation and production sale could be supported by the detection of fruit ripeness stage and scab infection level.

The development of the capability model should continue in the further improvement of model accuracy and applicability for current fruit crops as well as in the adaptation for other ones. This can be achieved by expanding the range of indicators to be assessed – fruit rot infection level, incidents of insect damage, fruit size, level of chlorophyll degradation of fruits etc. and by keeping the involvement of cultivar-specific numeric values.

IV. Conclusions

Orchards are a complex system comprising a series of interdependent components: abiotic environment, biotic factors and crop management techniques. The only component that can be purposefully managed is the cultivation techniques and the selection of its parameters, which is not so simple due to the longevity of the orchards. The result of the decisions can be evaluated only with a deviation of several years. This problem can be solved by applying the digital twin concept. This study identified the main principles of creating a digital twin of apple, pear and cherry orchards, the application of inclusive assessments and their potential impact on orchard management decision-making.

The identified principles have been formally specified in form of orchard digital shadow capability model using ARTSS notation. The capability model lays groundwork for the development of digital shadow-based orchard management systems. The model can be expanded to develop digital twin-based orchard management systems. It can also be used as an example to expand upon or adapt to different subfields of horticulture.

The goal of the project lzp-2021/1-0134 is to develop and implement the autonomous apple, pear and sweet cherry orchard management system. Application of capability model to specify domain knowledge for the further development of digital twin orchard management system enabled straightforward collaboration between system developers and experts of the horticulture domain by providing an accessible notation and tools.

V. Acknowledgements

This research is funded by the Latvian Council of Science, project “Development of autonomous unmanned aerial vehicles based decision-making system for smart fruit growing”, project No. lzp-2021/1-0134.

VI. References

[1] D. M. Botín-Sanabria, A.-S. Mihaita, R. E. Peimbert-García, M. A. Ramírez-Moreno, R. A. Ramírez-Mendoza, and J. de J. Lozoya-Santos, “Digital Twin Technology Challenges and Applications: A Comprehensive Review,” *Remote Sensing*, vol. 14, no. 6, p. 1335, Mar. 2022, https://doi.org/10.3390/rs14061335

[2] Ch. Pylianidis, S. Osinga, I. N. Athanasiadis, “Introducing digital twins to agriculture”, *Computers and Electronics in Agriculture*, Volume 184, 2021. https://doi.org/10.1016/j.compag.2020.105942

[3] P. Moghadam, T. Lowe, E. J. Edwards, “Digital Twin for the Future of Orchard Production Systems”. *Proceedings* 2019, *36*, 92. https://doi.org/10.3390/proceedings2019036092

[4] C. N. Verdouw, J. W. Kruize, “Digital twins in farm management: illustrations from the FIWARE accelerators SmartAgriFood and Fractals.” *7th Asian-Australasian Conference on Precision Agriculture*, 2017, https://doi.org/10.5281/zenodo.893662 https://www.researchgate.net/publication/322886729.

[5] J. Grabis, J. Zdravkovic, J. Stirna, “Overview of Capability-Driven Development Methodology”. *Capability Management in Digital Enterprises.* Springer, Cham, 2018, https://doi.org/10.1007/978-3-319-90424-5_4

[6] J. Stirna, J. Grabis, I. Stefanisina, E. Roponenta, V. Minkevica, “ARTSS: Advanced Resilience Technologies for Secure Service” [Online], Oct 31 2020. Available: https://iti.rtu.lv/vitk/sites/default/files/file-upload/WP1_Metodes_apraksts_v5_0.pdf

[7] S. Kodors, G. Lacis, O. Sokolova, T. Bartulsons, and I. Apeinans, “Fruit-Grower Digital Tool for Apple Scab Detection.”, *International Symposium of Digital Horticulture*, Bulduri, Latvia, 2021.

[8] C. Zhang, J. Valente, L. Kooistra *et al.,* “Orchard management with small unmanned aerial vehicles: a survey of sensing and analysis approaches.” *Precision Agric* 22, 2021, pp. 2007–2052. https://doi.org/10.1007/s11119-021-09813-y

[9] S. Bērziša, G. Bravos, T. C. Gonzalez *et al.*, “Capability Driven Development: An Approach to Designing Digital Enterprises.”, *Bus Inf Syst Eng* 57, 2015, pp. 15–25. https://doi.org/10.1007/s12599-014-0362-0

[10] U. Meier, “Growth stages of mono- and dicotyledonous plants: BBCH Monograph.” *Open Agrar Repositorium, Quedlinburg*, 2018. https://doi.org/10.5073/20180906-074619

[11] U. Meier, “BBCH – Monographie.”, Entwicklungsstadien von Pflanzen. Berlin und Wien, Blackwell, 1997. (in German)