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Published in:
Ambient Intelligence – Software and Applications

DOI:
10.1007/978-3-030-58356-9_34

Publication date:
2021

Document version:
Accepted manuscript

Citation for pulished version (APA):
Howard, D. A., Ma, Z., & Jørgensen, B. N. (2021). Digital Twin Framework for Energy Efficient Greenhouse Industry 4.0. In P. Novais, G. Vercelli, J. L. Larriba-Pey, F. Herrera, & P. Chamoso (Eds.), *Ambient Intelligence – Software and Applications: 11th International Symposium on Ambient Intelligence* (pp. 293-297). Springer. Advances in Intelligent Systems and Computing Vol. 1239 https://doi.org/10.1007/978-3-030-58356-9_34

Digital Twin Framework for Energy Efficient Greenhouse Industry 4.0

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Abstract. This paper introduces the ongoing research conducted on enabling industrial greenhouse growers to optimize production using multi-agent systems and digital twin technology. The project seeks to develop a production process framework for greenhouses, based on several case studies, that can be applied to different greenhouse facilities to enable a broad implementation in the industrial horticulture sector. The research will incorporate AI technology to support the production process agent in forecasting and learning optimal operating conditions within set parameters that will be feedback to the grower through a common information model. Furthermore, the production agent will communicate with other process agents to co-optimize the essential aspects of production. In turn, this allows the growers to optimize the production cost with minimal risk to product quality while aiding in upholding grid stability. The findings in this research project may be beneficial for developing industry-specific energy flexibility solutions incorporating product and process constraints.

Keywords: Industry 4.0, Greenhouse, Multi-agent System, Digital Twin.

1 Problem Statement

The greenhouse sector has been identified as a sector with significant unexploited process flexibility and as discussed by Ma et al. there is also a potential for monetary gain for the participating growers [1]. Several projects have already studied the planning and control of the lighting used for production within greenhouses [2-4]. However, to understand the flexibility constraints regarding product quality further research is required.

1.1 Greenhouse Industry 4.0

This research is part of the Greenhouse Industry 4.0 funded by the Danish Energy Technology Development and Demonstration Program (EUDP). The project takes a holistic approach by optimizing the operation based on inputs from three developed digital twins. The digital twins will cover the energy system, the climate compartment and the research presented here will develop a digital twin for the production process flow.

1.2 Research Aim and Objectives

This research aims to develop a digital twin of the greenhouse production flow, to create an artificial intelligence (AI) based simulation model of the greenhouse production flow for investigating the effects of co-optimizing production schedule, plant growth, energy consumption, and cost, by considering influential factors including production deadlines, quality assessment, (district) heating demand, gas and electricity prices, and weather forecasts. To achieve the project aim, the following objectives will be conducted:

- Development of multi-agent simulation model for greenhouse production flow
- Identification of Common Information Model interface
- Investigating the effects of co-optimizing factors influencing the production flow
- Simulation of energy efficiency and demand response potentials

The research will be conducted as a part of the Greenhouse Industry 4.0 project between September 2019 and October 2023.

2 Related Work

2.1 Brewery Fermentation Process Optimization

Applying multi-agent-based simulation on a production process, a case study was conducted on a Danish brewery. The goal was to establish a baseline consumption model for the fermentation tanks within the brewery and subsequently investigate any potential for the process to deliver energy flexibility based on market conditions. Brewing is a quality-oriented process and this was emphasized by developing a process agent logic using the product agents (beer) constraints, primarily temperature zones for the yeast.

2.2 Greenhouse Flexibility Potential

Before the co-optimization using the information provided by the other digital twins in the system, a baseline flexibility potential for the process should be established as a line of reference. In order to determine the flexibility potential, a multi-agent system representing the current greenhouse production process was developed. Using the multi-agent system and data provided by the growers it was possible to estimate the current power consumption and flow of the processes. Furthermore, a product agent representing the process product (plant) could be developed in order to account for variations in growth depending on the environment.

2.3 Integration of Simulation Software with Optimization Platform

The simulation software used to represent the digital twin for the production process is required to interact with an optimization platform through data exchange it is important to establish the integration possibility between said platforms. As the digital twins developed in the project will run on different platforms it is beneficial to connect them using a horizontal integration approach to minimize the connections for each subsystem. Using an in-memory data grid (Hazelcast) it was possible to establish a connection between the simulation platform (AnyLogic) and the optimization platform.

3 Hypothesis

> Will the potential energy flexibility for implicit demand response in industrial greenhouses using a process framework incorporating production deadlines be more effective than traditional estimation of energy flexibility potential to prevent overrunning delivery deadlines?

To aid in answering the research question a set of hypotheses were constructed:

- **H1**: If the frequency of unmet product deadlines is related to energy flexibility then greenhouses utilizing energy flexibility will have a higher frequency of unmet production deadlines.
- **H2**: If the product growth is related to light/CO_2/humidity exposure then forecasting the parameters (light/CO_2/humidity) will yield the estimated completion time.
- **H3**: If the production price is dependent on multiple compartments then co-optimizing with the other compartments will result in the cheapest production price.

4 Proposal

The research proposes the development of a digital twin that utilizes AI technology within the production process agent and considering inputs from the surrounding agents the research proposes a method for optimizing the production while incorporating product deadlines. The novelty of the research hence lies in incorporating the product deadline and estimating the best-practice production schedule (if possible) to minimize production cost.

5 Preliminary Results

The conducted research thus far has focused on establishing a base-line for product process modeling. From the established model it has been possible to estimate the energy consumption from the production process in accordance with the first point of the research aim and objectives. An overview of the production process flow can be seen in **Fig. 1**.

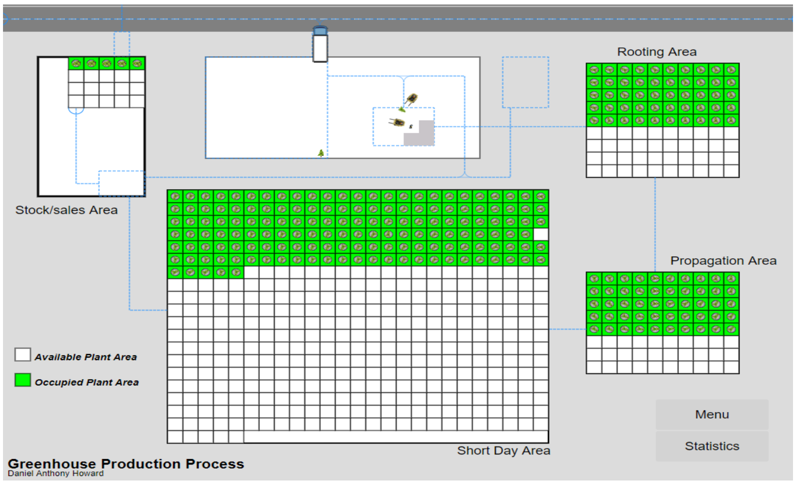

Fig. 1. Greenhouse production process model overview

6 Reflections

The research project is still in the initial phase of development it is imperative for successful completion to establish the correct system architecture for data handling. Moving forward with the research the goal will be to incorporate AI technology into the agent logic allowing to train the model based on inputs. Inputs will be supplied by other digital twins to which the communication flow will also need to be established. As the project relies on multiple parties to incorporate their work an initial estimation of input parameters has been set that can be exchanged for real-data input once available.

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