POPULAR SCIENTIFIC ABSTRACT

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A Digital Twin Framework for Commercial Greenhouse Climate Control System

The horticultural industry in Nordic countries is highly dependent on greenhouse systems due to the limitation of the natural environment and the strict planting requirements of particular plant types. Commercial growers in these regions are encountering significant challenges in guaranteeing the quality of plants while minimizing production costs. On the one hand, a greenhouse system needs to consume a large amount of energy to provide a satisfactory climate for plant growth. On the other hand, in recent years, the energy price soaring in Europe has led to an increase in the production cost of greenhouses, making energy saving and optimization imperative. However, it is challenging for growers to handle this dilemma because greenhouse climate control is a highly dynamic and highly coupled complex system. By analyzing the features of nonlinearity and dynamism of the greenhouse climate, the existing solutions cannot properly satisfy the practical requirements of the horticultural industry.

To address these problems, a Digital Twin of Greenhouse Climate Control (DT-GCC) framework is proposed in this research to optimize the actuator operation schedule for minimizing energy consumption and production cost without compromising production quality. The architecture of the DT-GCC framework and the utilized methods are elaborated modularly, including Physical Twin of Greenhouse Climate Control (PT-GCC) system understanding, design of DT-GCC system, interconnection of DT-GCC and PT-GCC, and integration with other Digital Twins (DTs).

DT-GCC comprises a Virtual Greenhouse (VGH) and a Multi-objective Optimization based Climate Control (MOCC) platform. VGH is the digital representation of the physical greenhouse through modeling the factors that can significantly influence the greenhouse climate and the actuator operation strategies. MOCC is responsible for defining the greenhouse climate control as a Multi-Objective Optimization (MOO) problem, and optimizing the operation schedule of artificial light (Light Plan) and heating system (Heat Plan). Besides, a hierarchical structure of DT-GCC is designed according to the functions and responsibilities of individual layers, which benefits the practical realization of DT-GCC with an organized architecture of design and management.

The functionalities of DT-GCC are developed in a greenhouse climate control platform named by DynaLight, which is combined with a Genetic Algorithm (GA) framework called Controleum. DynaLight defines a MOO problem to abstract the greenhouse climate control system with multiple objective functions, and the costs are calculated based on the modeling results from VGH. Controleum is responsible for the implementation of GA to generate a Pareto Frontier (PF) and final solution selection for Light Plan and Heat Plan.

Various scenarios and corresponding experiments are designed to evaluate the performance of DT-GCC from individual perspectives, including VGH, MOCC and DT integration. The experiments on VGH verify the prediction performance of Artificial Neural Network (ANN) methods on indoor temperature, heating consumption and Net Photosynthesis (Pn). Concerning the two standalone experiments, the results guarantee the ability of DT-GCC to map growers' decision-making on Light Plan and Heat Plan and verify the MOCC performance to fulfil growing requirements while reducing energy consumption and cost. Finally, in the DT integration experiments with Digital Twin of Production Twin (DT-PF) and Digital Twin of Energy System (DT-ES), DT-GCC completes the corresponding response to prediction and optimization requests.