ABSTRACT

The effects of climate change continue to permeate through every section of human civilisation with food security being one of the most affected. Innovative approaches to sustainable farming are required to alleviate some sections of the problem with the integration of Digital Twin (DT) and Virtual Reality (VR) being a promising technology. However, currently, there is a lack of development on plant growth visualisations that is a foundational aspect of Digital Twins, particularly for some popularly-grown vegetables, such as Pak Choi (*Brassica rapa* subsp. *chinensis*). Despite advancements in environmental monitoring and control systems, plant growth visualisation development has stagnated which limits the potential for DT applications to improve efficiency and sustainability in farming systems. This research aims to address the aforementioned gap by developing a Pak Choi growth visualisation through a Lindenmayer System (L-System) approach for a Virtual Reality (VR) Digital Twin (DT) of a Plant Factory (PF). This tool aims to offer insights into crop development, optimise resource usage, and assist in decision-making for closed-environment agriculture (CEA), specifically PFs. To achieve this objective, a modular, deformable, physically-intractable, optimised (to support the low-computational power of the VR hardware), and well textured Pak Choi modelling system was developed to simulate plant growth stages up to 30 days (or during harvest period). The development followed an Agile workflow and incorporated a simplified growth algorithm based on an established GDD-based model alongside with the parallel-developed L-System approach to control real-time visual changes. Subsequently, an evaluation using the System Usability Scale (SUS) and Expert Review evaluation method was utilised to assess the subjective visual intuitiveness from the users' perspective and the biological accuracy according to a domain expert. Moreover, each feature implementation was assessed using a functional testing method, specifically the black box testing, to ensure functional usability, with a majority of the test cases being successful. With a SUS Score of 72, the visualisation has indicated that it has "Good" and "Acceptable" usability, with visual intuitiveness being acceptable. Additionally, feedback from the Expert Review indicated that the visualisation has good biological accuracy, but it requires some adjustments in certain areas to further improve it. These improvements include reworking the plant model system, reworking optimisation systems, implementing the model using a parametric modelling system, adjusting the premature petiole colour change, adding a root section with a hydroponic pot attached, and reworking the diegetic user interface (UI) system. Overall, this research developed a Pak Choi growth visualisation that has the potential to be a foundational aspect of a DT-VR of a PF.

Keywords: Plant Growth Visualisation, Plant Modelling, Digital Twin, Virtual Reality, Plant Factory, L-System, Pak Choi