

Classification Framework for Autonomous Greenhouses

Introduction

The increasing demand for healthy food and shortage of skilled labourers for greenhouse crop growing puts pressure on the horticulture sector. This drives the sector towards the automation of different operations in greenhouses. This three-pager presents a framework that classifies the level of automation of crop growing activities in greenhouses and which can be used as a taxonomy to stimulate the development towards autonomous greenhouses. The framework is divided into four **Operational Phases** in which each phase is classified into one of the five **Levels of Automation**, ranging from *Level 0 = No Automation* to *Level 4 = High Automation* (see page 1 and 2). Together, these levels determine the level of automation of the greenhouse (see page 3, **Greenhouse Automation Levels**), ranging from a *Basic greenhouse (Level 0)* to a *Fully autonomous greenhouse (Level 5)*.

Operational Phases

1. **Logistics:** Moving products; sorting according to quality and size and packaging.
2. **Crop Manipulation:** Physical actions at crop level; harvesting; pruning and trellising.
3. **Crop Growing:** Assessing plant state; creating climate setpoints and controlling the climate inside the greenhouse.
4. **Greenhouse Strategy:** High level management decisions; scheduling phases.

Levels of Automation

0. **No Automation:** The grower does all operations.
1. **Grower Assistance:** The system assists the human.
2. **Partial Automation:** Grower supervises ("Hands Off").
3. **Conditional Automation:** Grower is fallback ("Eyes Off").
4. **High Automation:** Grower sets goals ("Brains Off").
5. **Full Automation:** All operational phases at Level 4 and integrated together.

Levels of Automation for the Operational Phases

The following tables show the Levels of Automation for the different Operational Phases. At each level the responsibilities for Execution (Sense, Plan, Act: SPA), Monitoring and Fallback of the control system are divided differently. Going up a level also involves new advantages and challenges, shown on the right-hand side of the tables.

Logistics

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	Human operators are responsible for all the logistics: Displacement, Sorting, Packaging, ...	Human	Human	Human		
1	Grower Assistance	Human operators carry out dexterous tasks, displacement and sorting are automated. Human operators always provide logical inputs for decision tasks.	Human and System	Human and System	Human and System	Reduced Physical Work	Infrastructure Investment
2	Partial Automation	Logistics for isolated sets of tasks are automated.	System	Human and System	Human and System	Logistics Operating 24/7 [Hands Off]	Sofisticated Control
3	Conditional Automation	The logistics are end-to-end automated but require supervision and human fallback strategy.	System	System	Human and System	No Active Supervision [Eyes Off]	Human Fallback
4	High Automation	The logistics are end-to-end automated with a robust fallback strategy.	System	System	System	No Human Risk Optimized Infrastructure Minimum Expense on Workforce [Brain Off]	Perfect Fallback System

Crop Manipulation

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	Human operators do all crop manipulation tasks with rudimentary tools.	Human	Human	Human		
1	Grower Assistance	Human operators do the crop manipulation and the system helps monitoring the tasks.	Human	Human and System	Human	Reduced Complexity for Operators	Installation of Sensors Solving Occlusion
2	Partial Automation	Human operators do the crop manipulation while robot/AI assists with sub-tasks within the activity.	Human and System	Human and System	Human		Software Complexity
3	Conditional Automation	The system is capable of handling all operations. Human operators still partly monitor the process.	System	Human and System	Human and System	No Teaching Phase Operating 24/7 [Hands Off]	High Investment
4	High Automation	Crop Manipulation is automated automated with a robust fallback strategy.	System	System	System	No Human Operators Required [Eyes Off] [Brain Off]	High Jump on Software Reliability

Crop Growing

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	The grower assess the state of crop through manual inspection, decides on the climate set-points and commands the climate control modules (like HVA, Illumination, etc)	Human	Human	Human		
1	Grower Assistance	The grower makes decisions on the climate set-points, AI will assist them through suggestions.	Human and System	Human and System	Human	Set Points for Optimality No Anomaly Problems Remote Climate Control	Determining Model Factors
2	Partial Automation	AI determines the climate set-points based on crop preferences set by high level planner(s). Humans need to actively monitor crop for response to corrective actions.	System	Human and System	Human	Optimal Climate Control [Hands Off]	Huge Datasets Advanced Sensing
3	Conditional Automation	AI is capable of steering crop towards specific range of preferences. The grower still takes over in fallback situations.	System	System	Human	No Physical Presence [Eyes Off]	Advanced Anomaly Detection
4	High Automation	AI is capable of ensuring optimal crop growth based on preferences commanded by a higher planner.	System	System	System	No Human Involvement [Brain Off]	Perfect Fallback System Not Intuitive for Humans Highly Theoretical

Greenhouse Strategy

Level of Automation	Name	Narrative Definition	SPA	Monitoring	Fallback	Advantages	Challenges
0	No Automation	The grower overlooks all the stages of growing and takes necessary decisions/actions for plant and greenhouse operations relying on observations of market, weather, available supply, crop health etc.	Human	Human	Human		
1	Grower Assistance	The grower schedules for plant and greenhouse operations (growing, harvesting and selling), assisted by prediction models.	Human and System	Human and System	Human	Reduced Physical Presence	Decision Making Factors
2	Partial Automation	The system takes over isolated decision tasks for which the grower don't actively takes but reviews and is able to overrule. Decisions outside of the scope are taken by the grower.	System	Human and System	Human	Only Monitoring Required [Hands Off]	Huge Datasets Keep Track of Process
3	Conditional Automation	All greenhouse decisions (growing, harvesting, crop preference) are taken by an AI. The grower is responsible for the fallback, but doesn't have to constantly monitor the system.	System	System	Human	No Physical Presence [Eyes Off]	Human Fallback Not Intuitive Situations
4	High Automation	All greenhouse decisions (growing, harvesting, crop preference) are made by an AI.	System	System	System	Grower Only if Physical Failure [Brain Off]	Perfect Fallback System Not Intuitive for Humans Highly Theoretical

Greenhouse Automation Levels

After successfully assessing the Levels of Automation for all Operational Phases, the greenhouse can now be categorised from a holistic perspective into different categories based on these determined levels. For a greenhouse to be classified as level 'X' automated, at least two operational phases should be level 'X' and others should be level 'X-1', as shown in the table below.

Automation Level	Level Name	Level Narrative	Crop Growing	Logistics	Crop Manipulation	Greenhouse Strategy
0	Basic Greenhouse	Rudimentary	All phases Level 0			
1	Technology Assisted Greenhouse	Grower receives assistance from AI/Robots but is involved in operations all the time	At least 2 phases are Level 1			
2	Partially Automated Greenhouse	Grower can take "hands off" of operations in a specific (set of) greenhouse phase(s)	At least 2 phases are Level 2, others are Level 1			
3	Conditionally Automated Greenhouse	Grower can take "eyes off" i.e; need not actively monitor over a (set of) phase(s)	At least 2 phases are Level 3, others are Level 2			
4	Highly Autonomous Greenhouse	Grower can take "brains off" i.e; expect AI to take over a (set of) phase(s)	At least 2 phases are Level 4, others are Level 3			
5	Fully Autonomous Greenhouse	Grower is only involved in target setting and AI takes over the greenhouse operations	All phases are automated to Level 4			

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