

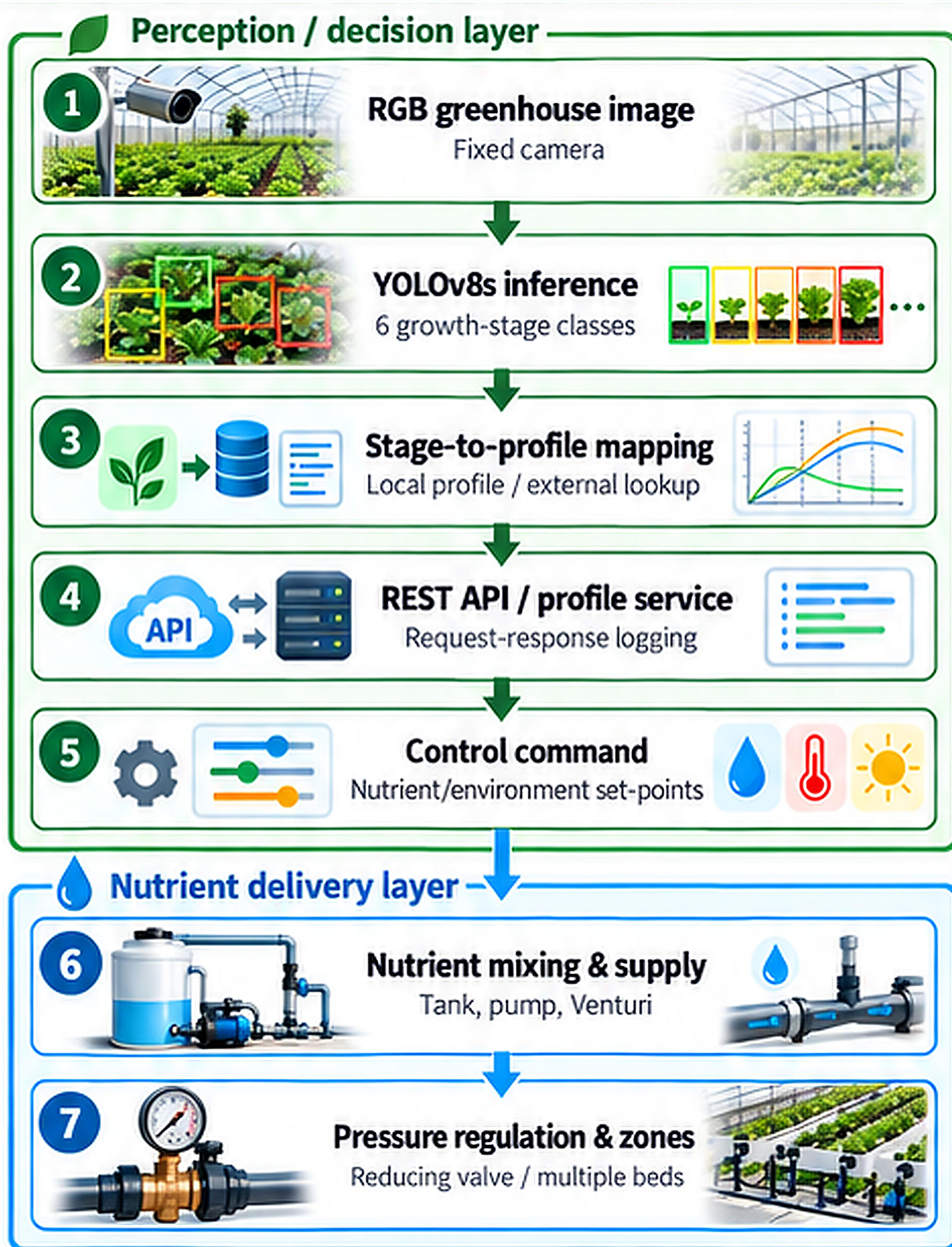
Background & Objective

- 1**  **Need for stage-aware management**
Water and nutrient requirements change across strawberry growth stages.
- 2**  **Study objective**
Build an integrated prototype linking image-based stage recognition to nutrient control.
- 3**  **Evaluation scope**
Evaluate six-stage recognition, API communication, profile application, and command generation.

Key Contributions

- 1**  **Six-stage recognition**
YOLOv8s classified six operational growth stages from real greenhouse RGB images.
- 2**  **Perception-to-control linkage**
Predicted stages were mapped to profiles and converted into control commands.
- 3**  **Quantified integrated evaluation**
Accuracy, latency, profile success, and command reflection were measured together.

System Overview: From Perception to Nutrient Control



Dataset & Training

1,800

Greenhouse RGB images

6

Growth-stage classes

70 : 20 : 10

Train / Val / Test

70%

20%

10%

Six operational growth stages



Nursery



Post-trans.



Vegetative



Flowering



Fruit set



Harvest

Model

YOLOv8s (pretrained)

Input

640 × 640

Epochs

100

Batch

16

Optimizer

AdamW (initial LR 0.001)

GPU

NVIDIA RTX 3060 12 GB

 Dataset note

- Greenhouse RGB images were collected across different positions and times.
- Six operational stages were annotated and split 70:20:10 for training, validation, and testing.
- The best checkpoint was selected using validation performance.

Detection Results (Test Set)

0.918 Precision	0.885 Recall	0.901 F1-score	Per-stage F1-score		
			Nursery		0.88
			Post-transplant		0.89
			Vegetative		0.90
			Flowering		0.93
			Fruit development		0.90
			Harvest		0.91
0.936 mAP@0.5					
0.694 mAP@0.5:0.95					
Result interpretation					
- Flowering achieved the highest class-level F1-score (0.93); most confusion occurred between visually adjacent early stages. - High mAP@0.5 (0.936) indicates reliable stage detection, while the lower mAP@0.5:0.95 (0.694) reflects stricter localization criteria.					

Integrated Prototype Evaluation

18.7 ms/image Mean inference time	26.4 ms/image Inference p95	142 ms API round trip median
231 ms API p95	99.2% Profile application success 992 / 1,000	96.8% Command reflection (±5%) 250 bench trials
258 ms Image-to-command end-to-end p95		
Sub-second command generation supports the technical feasibility of the perception-to-control workflow.		

Future Cultivation Validation

Objective: Separate the benefit of stage-aware nutrient management from the additional benefit of automated visual recognition.		
T1 - Fixed Schedule Conventional time-based nutrient management Operational baseline	T2 - Human Stage Judgment Stage-specific profiles selected by an experienced operator Isolates the benefit of stage-aware management	T3 - YOLOv8 Stage Output Profiles automatically selected from predicted growth stages Evaluates the added value of automated perception-to-control
Measured outcomes		
Yield - Marketable yield - Fruit count - Mean fruit weight	Quality °Brix - Defect rate	Nutrient / Water - Irrigation volume - EC / pH - Nutrient-use efficiency
Control performance - Override frequency - Pressure/flow uniformity		
Experimental control: Same cultivar, planting date, substrate, greenhouse zone, and profile library across treatments; replicated beds as experimental units.		

The prototype achieved accurate six-stage recognition and fast command generation, supporting the feasibility of stage-aware smart-farm nutrient control.