{Plant Inoculation} System

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Problem Statement

Root System Analysis

Accurately extracting root traits like growth patterns and architecture is crucial for understanding plant health but is challenging due to complex root systems and traditional imaging limitations.

Inoculation Precision

Accurate microbial inoculation is critical for studying plant-microbe interactions, yet variability in root growth demands advanced automation.

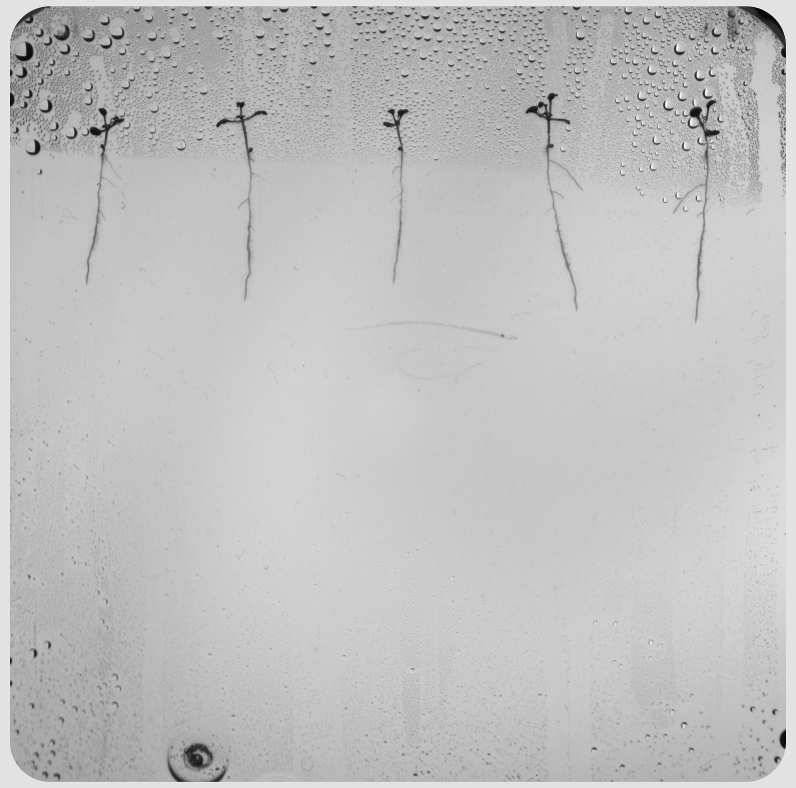
Scalability and Automation

High-throughput root phenotyping is vital for large-scale studies but requires a fully automated system to replace inefficient manual methods.

Solution Overview

Computer Vision Pipeline

Automated detection and measurement of root systems using deep learning models



Input iImage

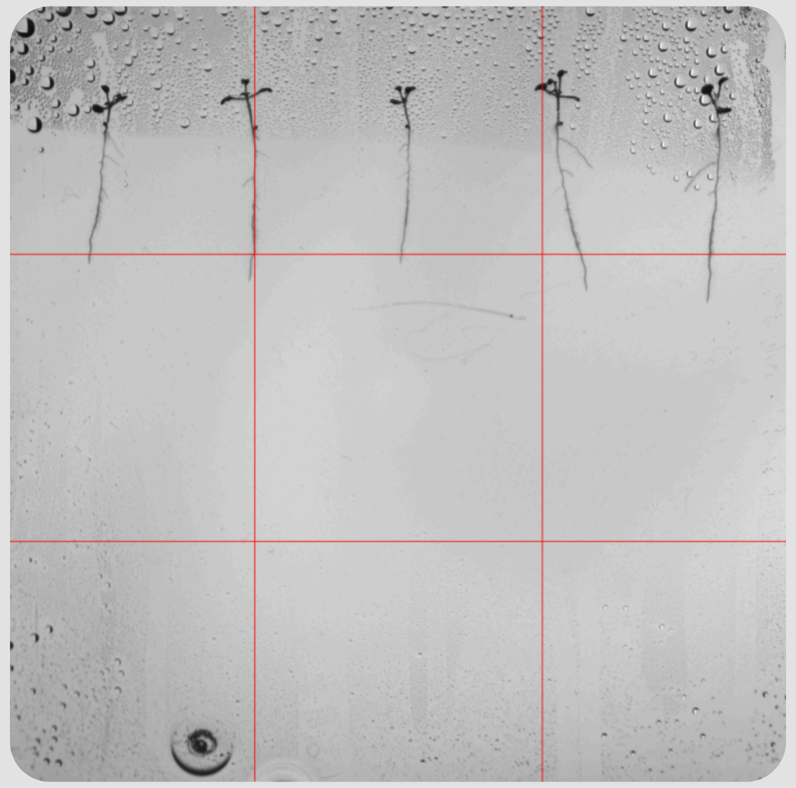
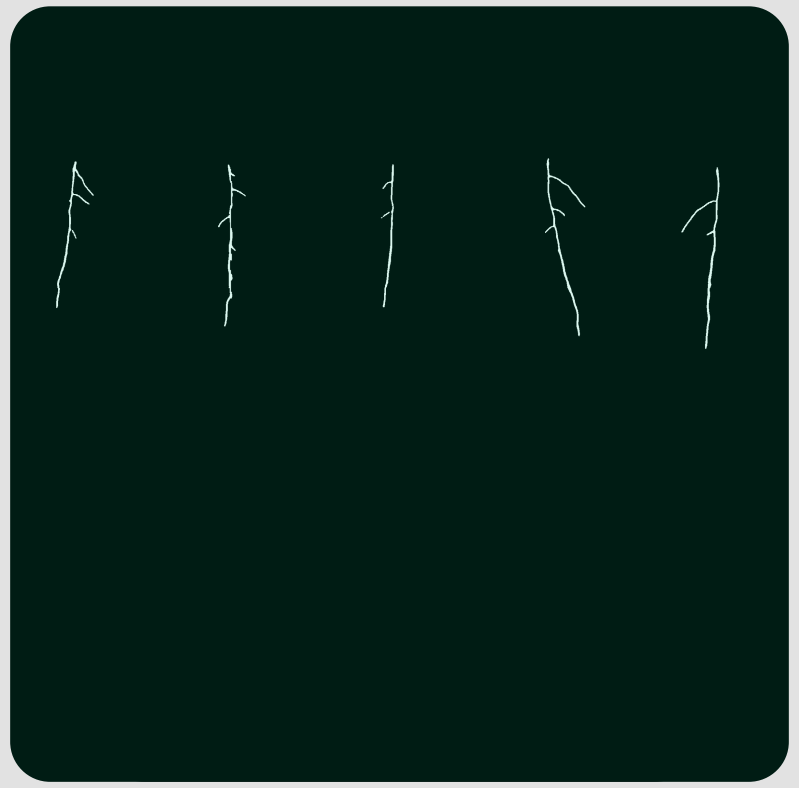
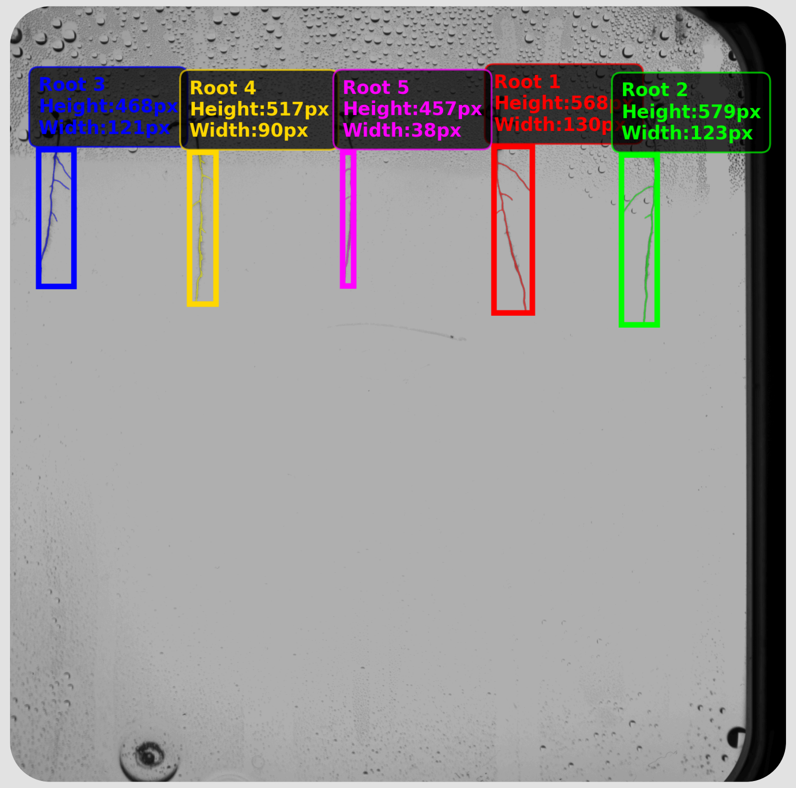


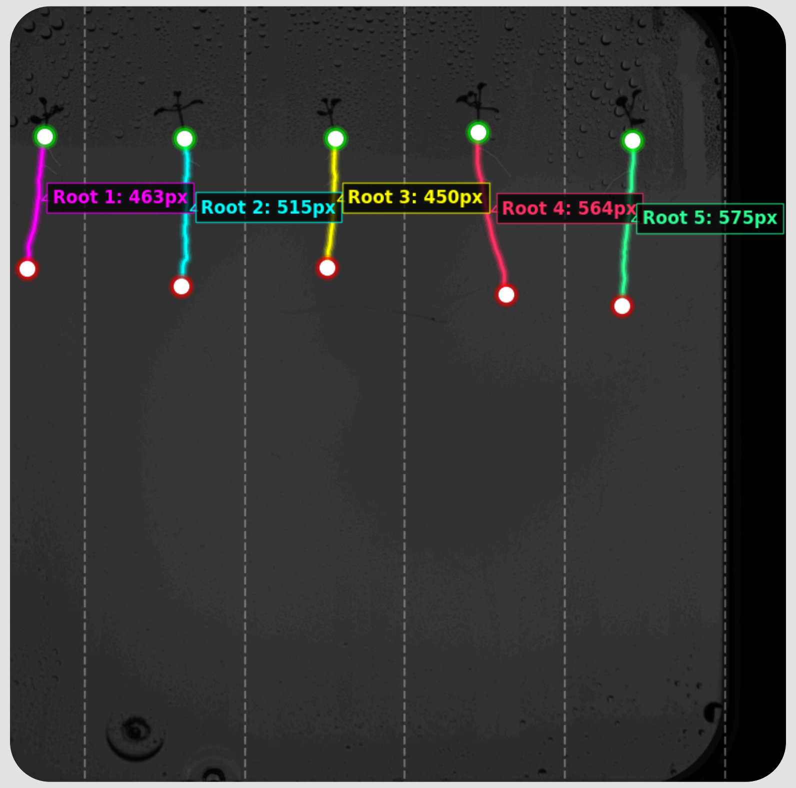
Image Pre-processing



Root Segmentation



Individual Root Instances

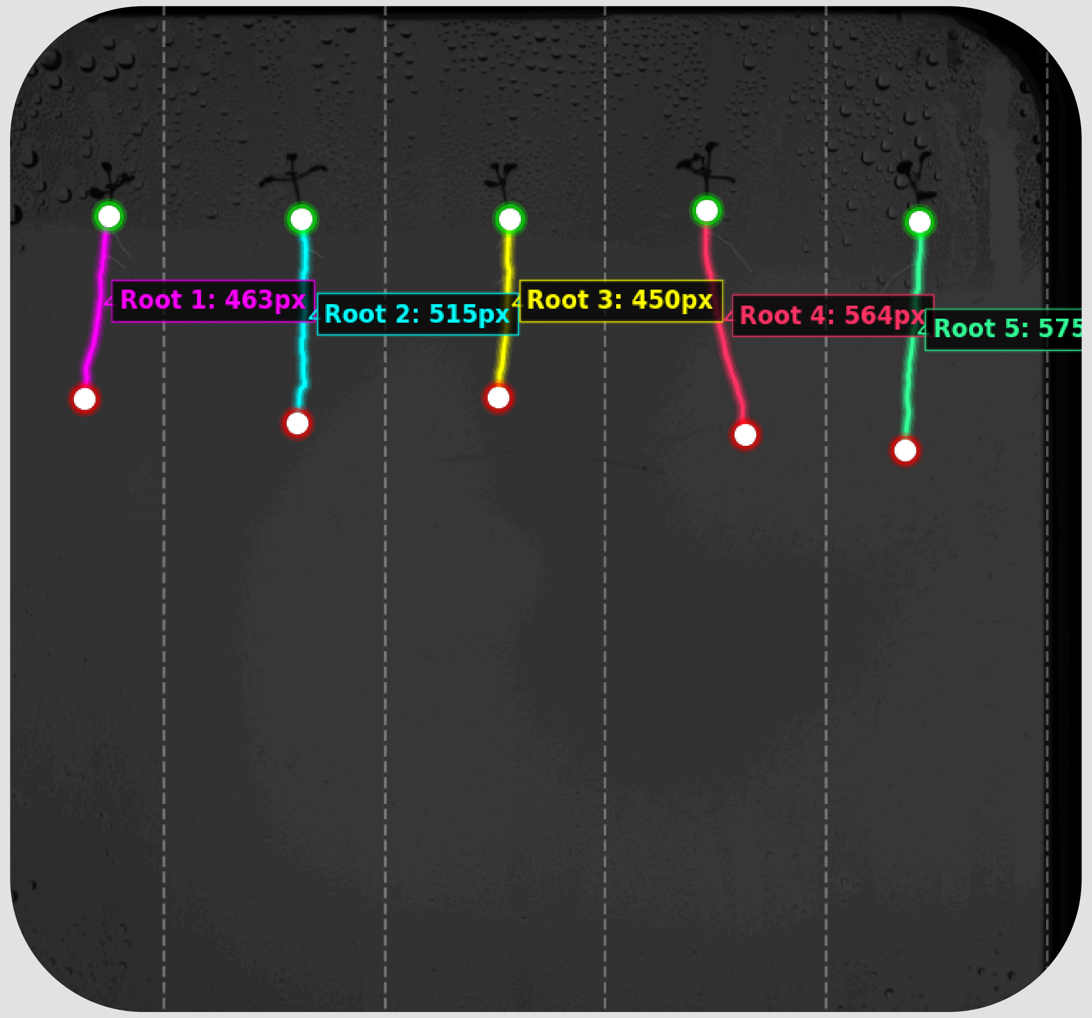


Root System Architecture (RSA)

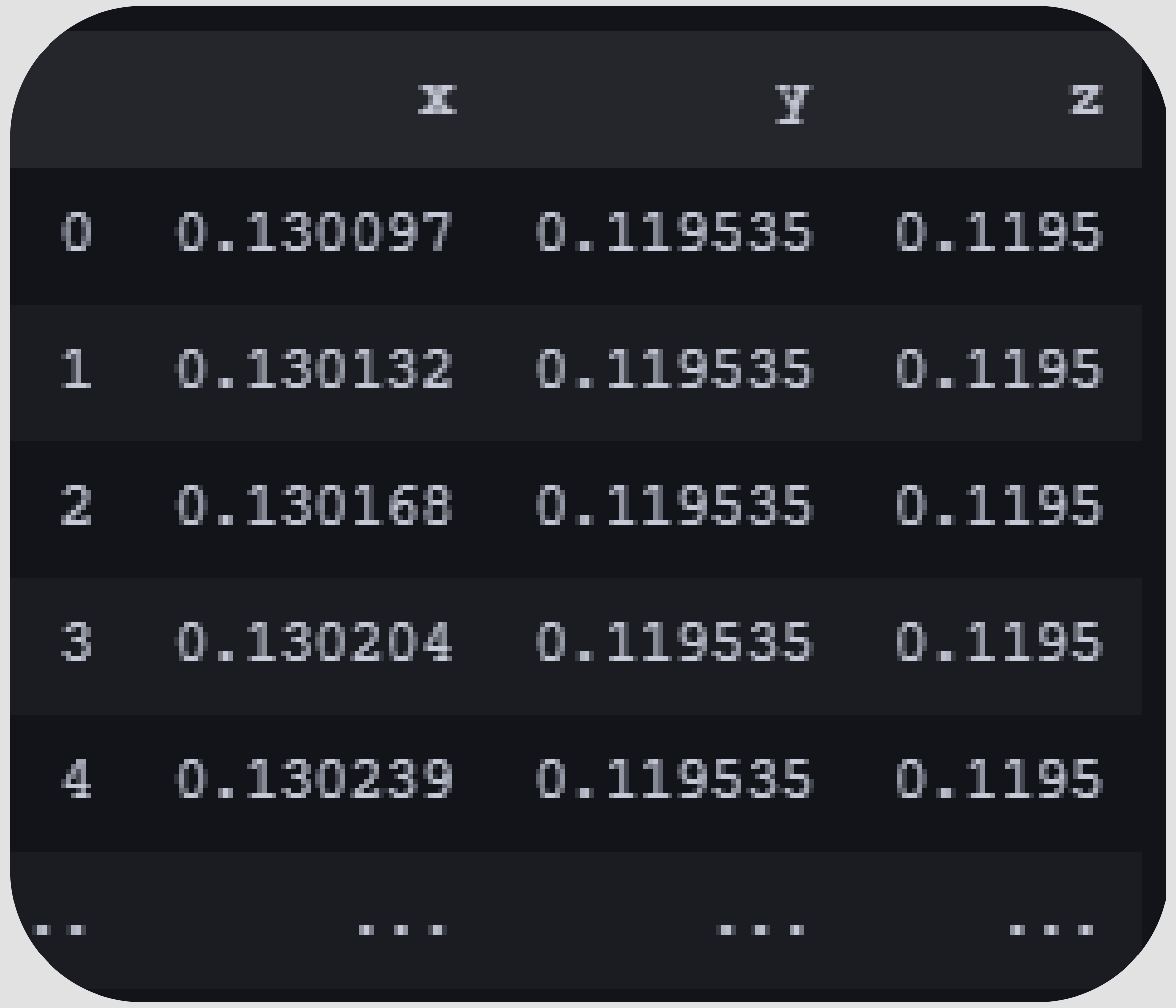
Solution Overview

Reinforcement Learning and Robotics Pipeline

Precise inoculation using dual-control approach (PID & RL) with OT-2 robot

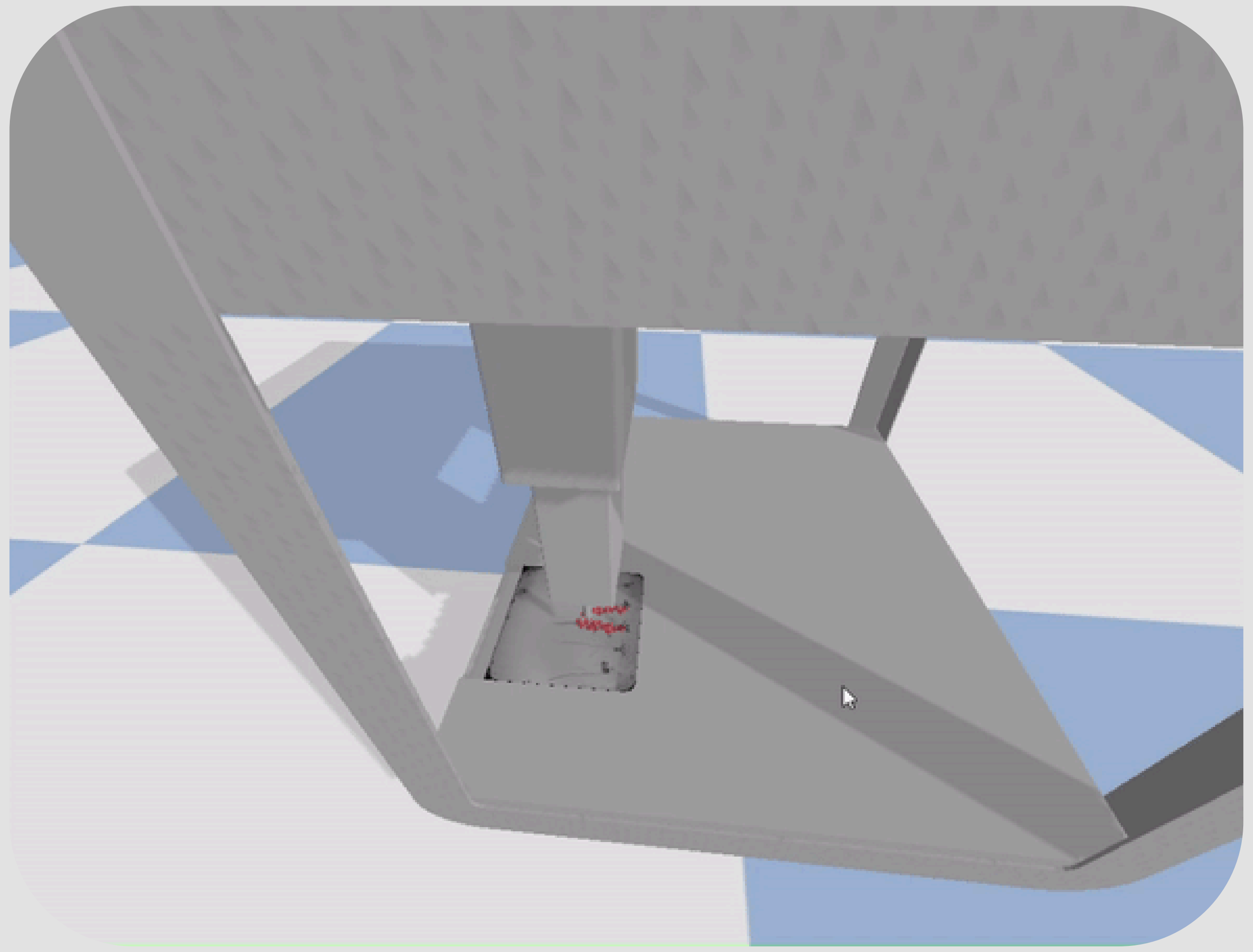


Input RSA Coordinates



	x	y	z
0	0.130097	0.119535	0.1195
1	0.130132	0.119535	0.1195
2	0.130168	0.119535	0.1195
3	0.130204	0.119535	0.1195
4	0.130239	0.119535	0.1195
..	...	...	...

Coordinate Transformation



RL/PID Controller

How This Helps

Automate Root Phenotyping

Streamlines data collection on root traits, shifting focus from manual labor to research.

Analyze Root System Architecture (RSA)

Creates detailed RSA models to quantify traits for breeding resilient crops.

High-Throughput Screening

Accelerates root trait analysis to identify stress-resistant or high-yield genotypes.

Optimizing Rhizosphere Management

Evaluates beneficial microbes to enhance plant growth and resilience.

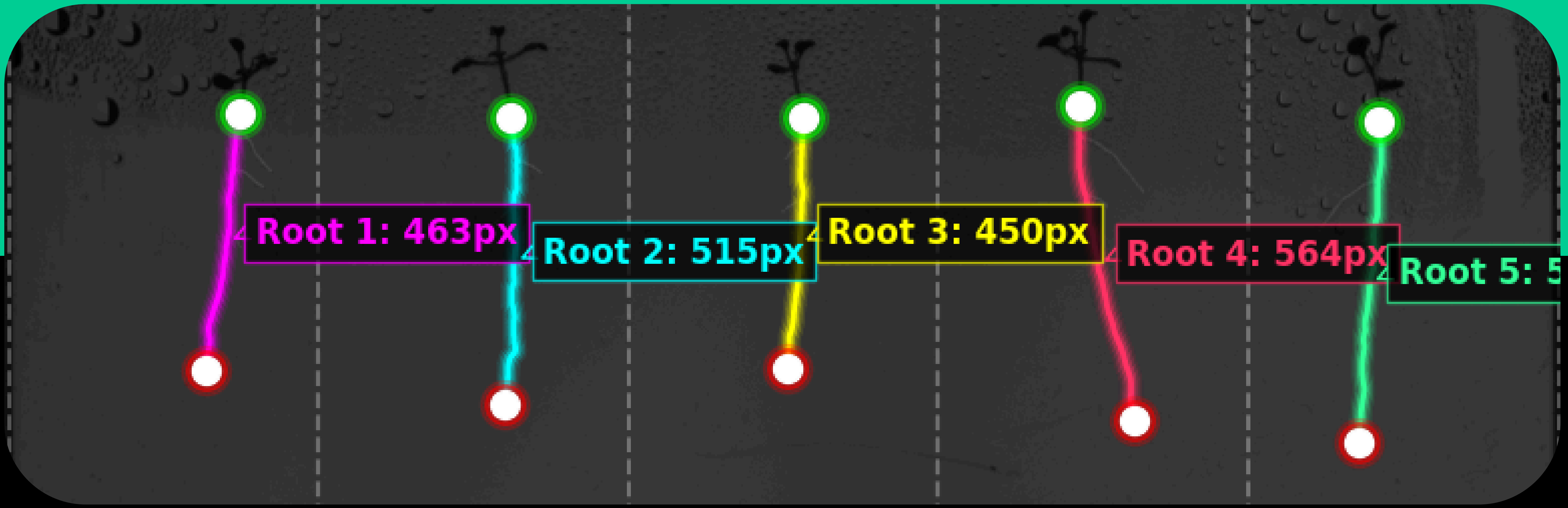
Precision Inoculation

Ensures accurate and uniform treatment delivery to roots for consistent experiments.

Assumptions

Max 5 plants/dish

If we divided the petri dish width to 5 columns, each column must contain maximum of 1 plants.

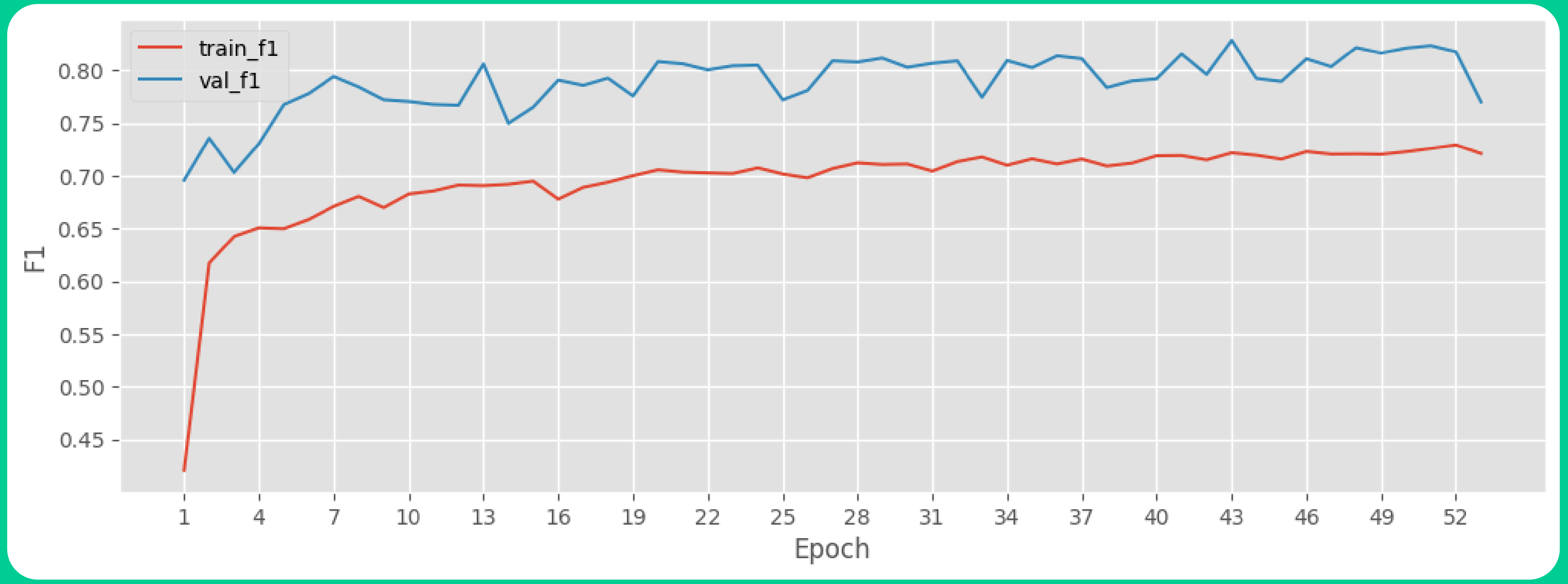


Computer Vision

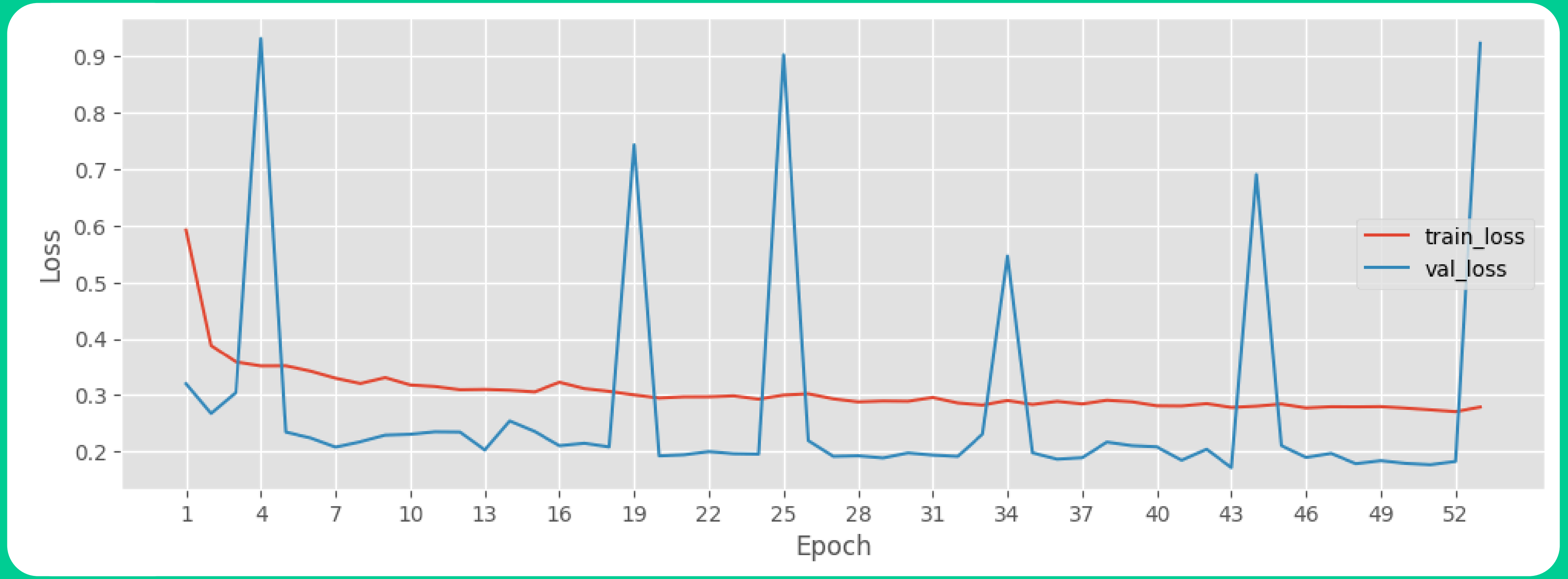
F1 Validation **82,86**

Loss Value Validation (Dice) **17,17**

F1 Score Across Epochs



(Dice) Loss Value Across Epochs

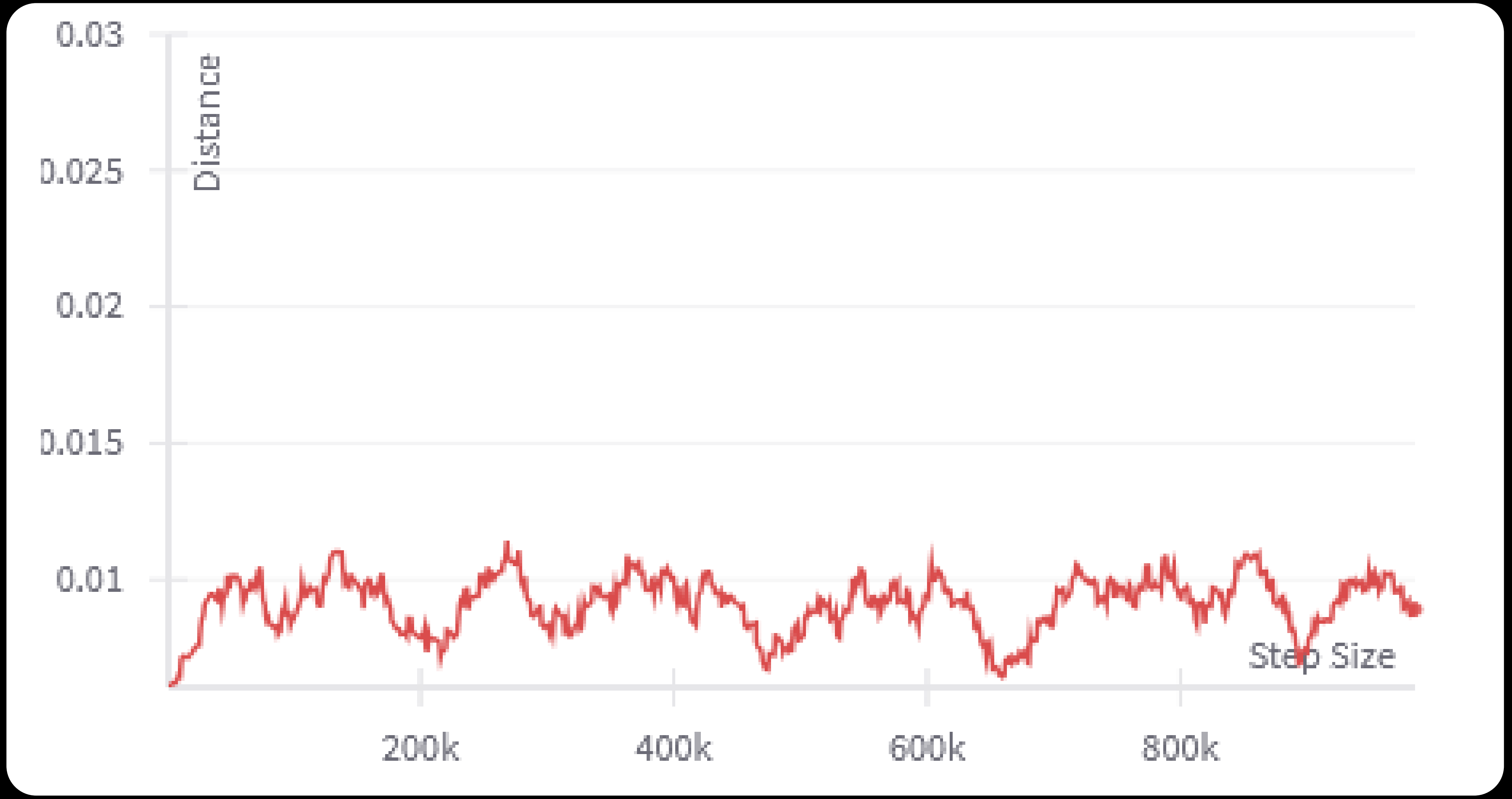


RL/Robotics Pipeline

Average Final Distance **9 mm**

Min Final Distance **0,7 mm**

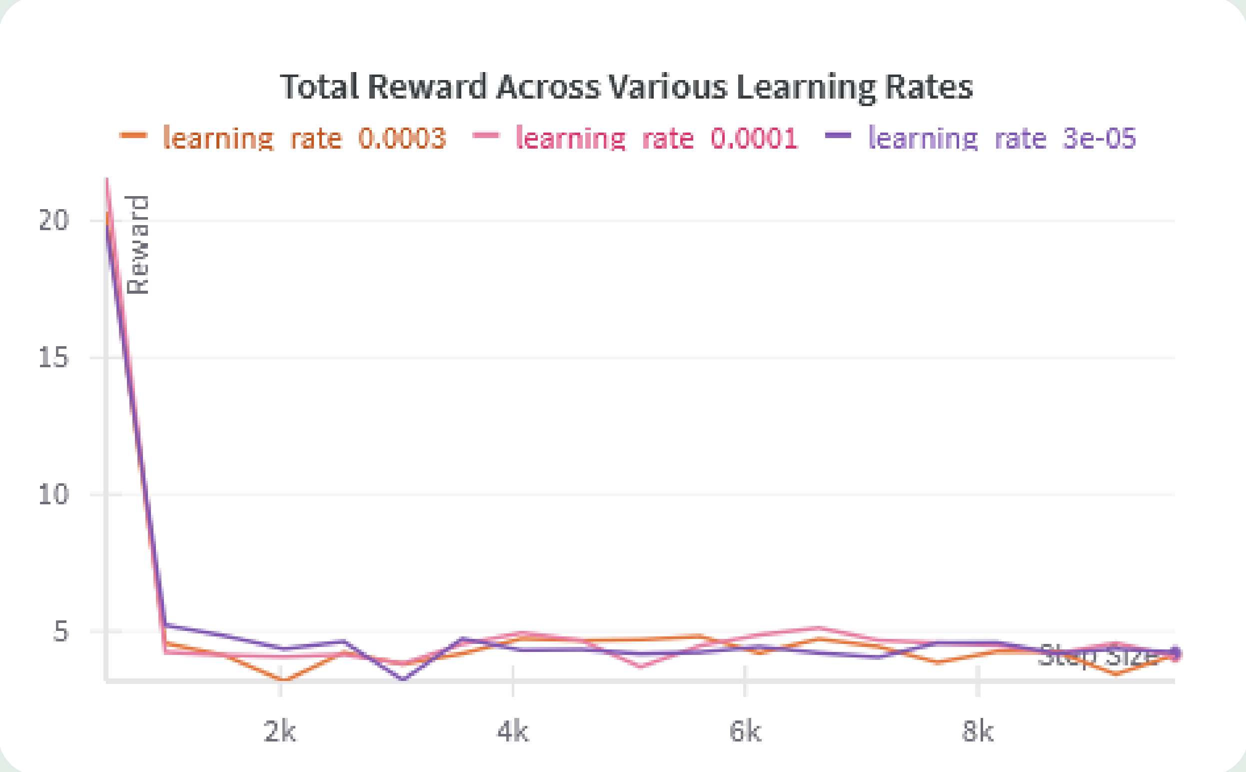
Final Distance Target Coordinate

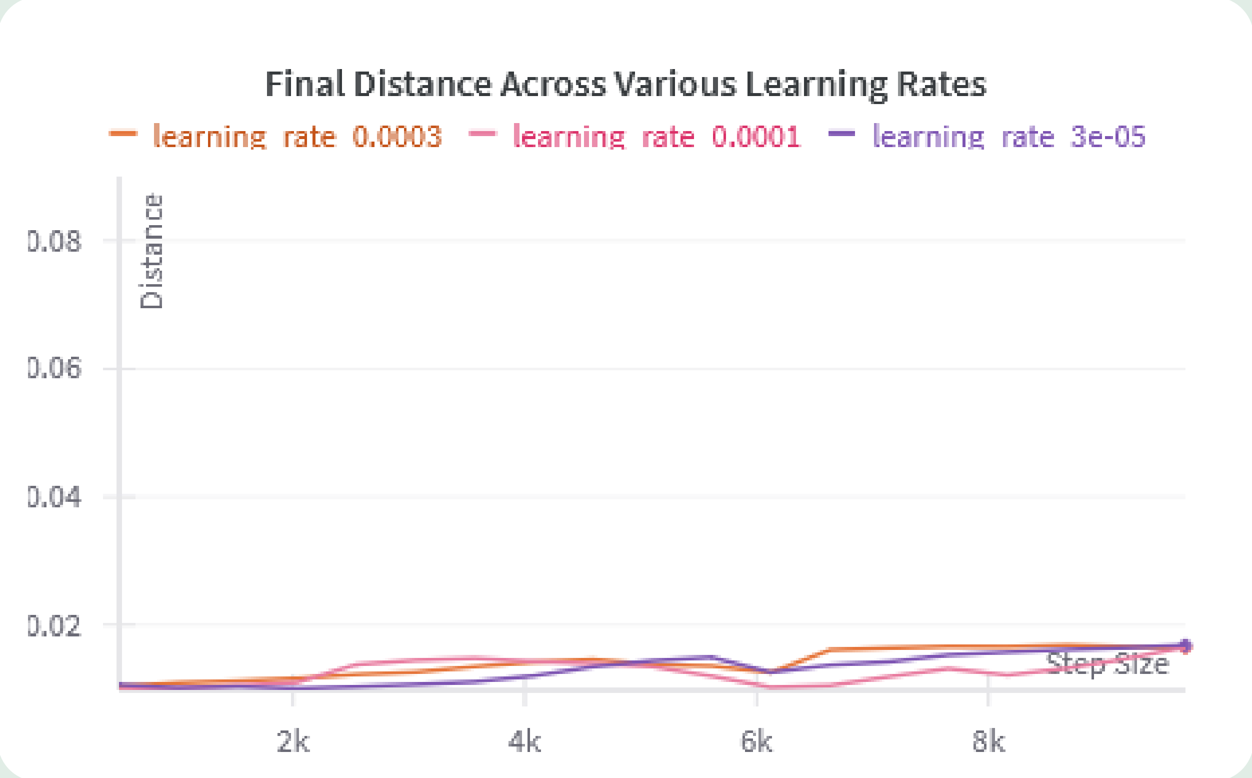


Best Solution

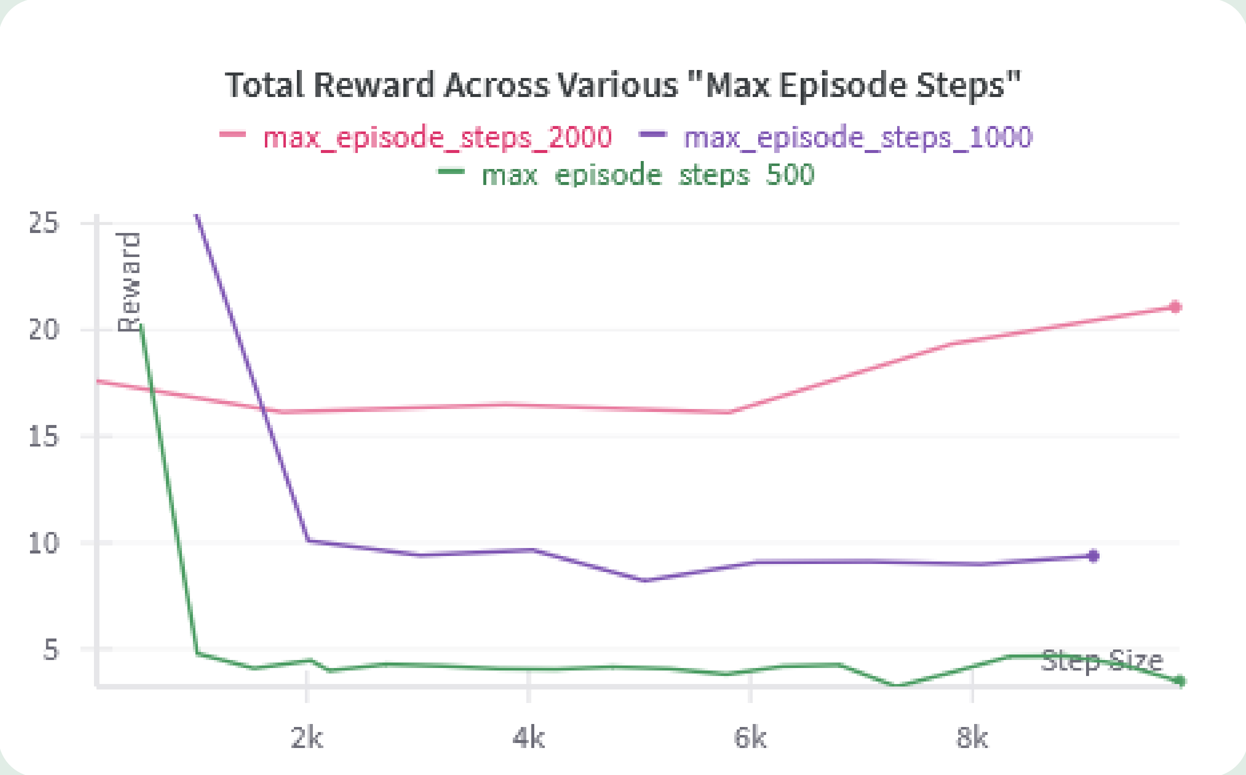
Hyperparameter Search

Learning Rate: Not much Difference

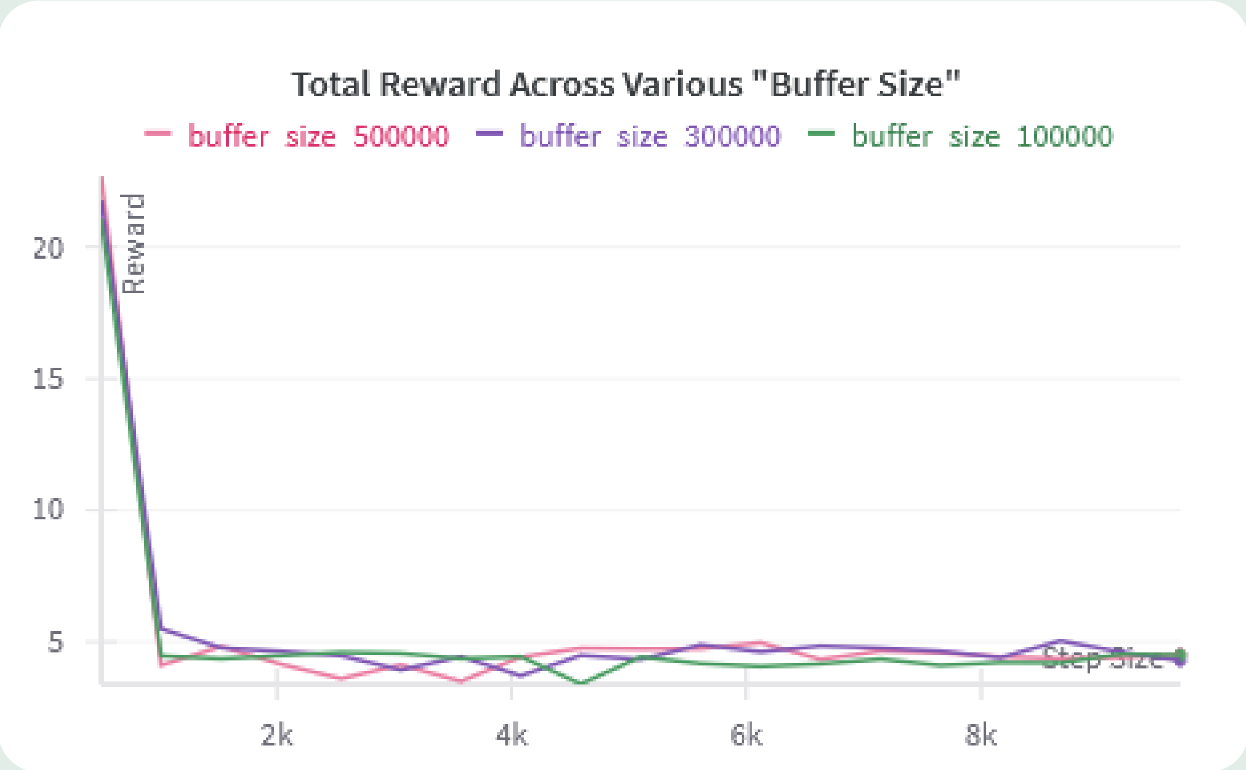


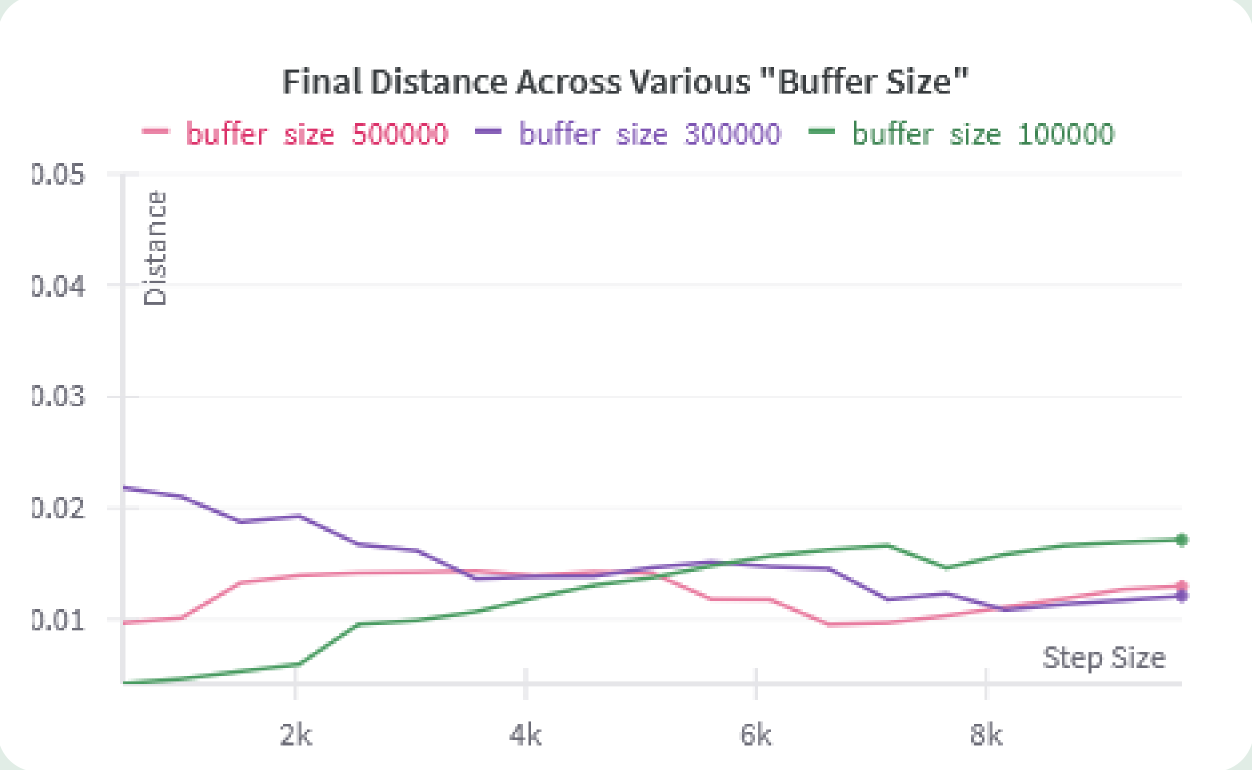


Max Episode Steps: Higher the better



Buffer Size: No much Difference





Benchmark

Soheil

Minimum Final Distance: 0.7mm

Average Final Distance: 9mm

Noah

Minimum Final Distance: 7mm

Average Final Distance: 50mm

Error Analysis & Iteration

Task 11 Hybrid Learning

I've noticed RL takes time to improve, so I used PID-guided learning initially, then phased it out, achieving strong early results.

Task 12 Systematic Tuning

Instead of manually tuning the PID gains (Kp, Ki, Kd), I've found it more effective to automate the process by testing various values programmatically.

Task 13 Injection Control

Identified a limitation in the action space, which lacked water injection control (defaulted to 0). Modified the environment to include water injection as an additional action, addressing this oversight to improve task accuracy.

Limitations

One limitation of the model is its difficulty in accurately segmenting occluded roots in the presence of smudges, bubbles, or fungal growth.

Further Steps

- Model Refinement: Improve root segmentation accuracy in challenging scenarios.
- Integration Testing: Test end-to-end coordination of vision and robotics pipelines.
- Scalability: Optimize for high-throughput phenotyping and cloud-based processing.
- Deployment: Create user-friendly interfaces and finalize deployment documentation.

Summary

This project enhanced plant inoculation by using computer vision and robotics to precisely deliver nutrients and identify stress-resilient plants early. Initially, PID-guided reinforcement learning was used to speed up training, with automated tuning for optimal performance. Improvements in the system, such as adding water injection control, have increased accuracy in root trait analysis for breeding and microbial research.

Thank You For Your Attention!