Precision Targeting of a High-Power Diode Laser Using a Clavel-Based Delta Parallel Robot for Weed Elimination

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Introduction: The Weed Management Challenge

Weeds cause $138 Billion annual loss in the USA [1]

Weed management accounts for more than 30% of production costs in specialty crops [2]

Weeds harbor pests and diseases, increasing pesticide demand

Weeds in cotton field at J. Phil Campbell Sr. UGA Research Center, Watkinsville, GA

Introduction: Vidalia Onion Farming

"For South Georgia, the first Challenge is weed control"

- Aries Haygood, Vidalia Onion Grower [3]

Onions rank among the top three U.S. vegetable crops by volume and value, generating $1.7 - 1.8 billion annually. [4]

Nearly all commercial onions in Vidalia are transplanted

Vidalia growers spend $5000 - $7000 / per acre on transplantation [5]

Very limited post-emergence herbicide options exist for Vidalia onions.

Herbicide Resistance

Ecotoxic

Herbicide spraying in an onion field [6]

Introduction: Vidalia Onion Farming

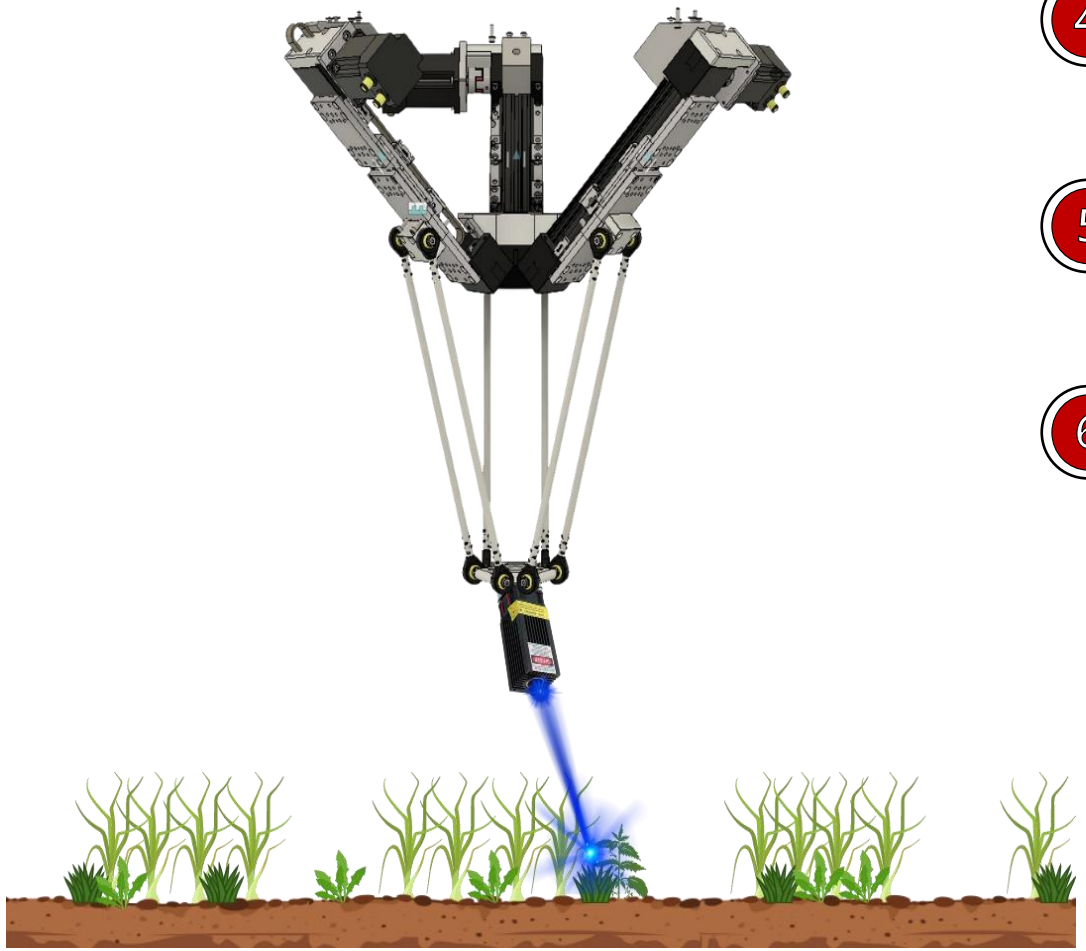
- Crop Injury Risk
- Soil Disturbance
- Field Limitations
- High Maintenance

Mechanical weeder in an onion field [8]

Manual weed removal [9]

Introduction: Robotic Laser Weeding

1. Organic Process
2. Minimized Crop Injury
3. Reduced Soil Disturbance
4. Precise Operation
5. Cost Effective
6. Automation & Labor Savings



Post Laser Weeding and Cultivation [10]

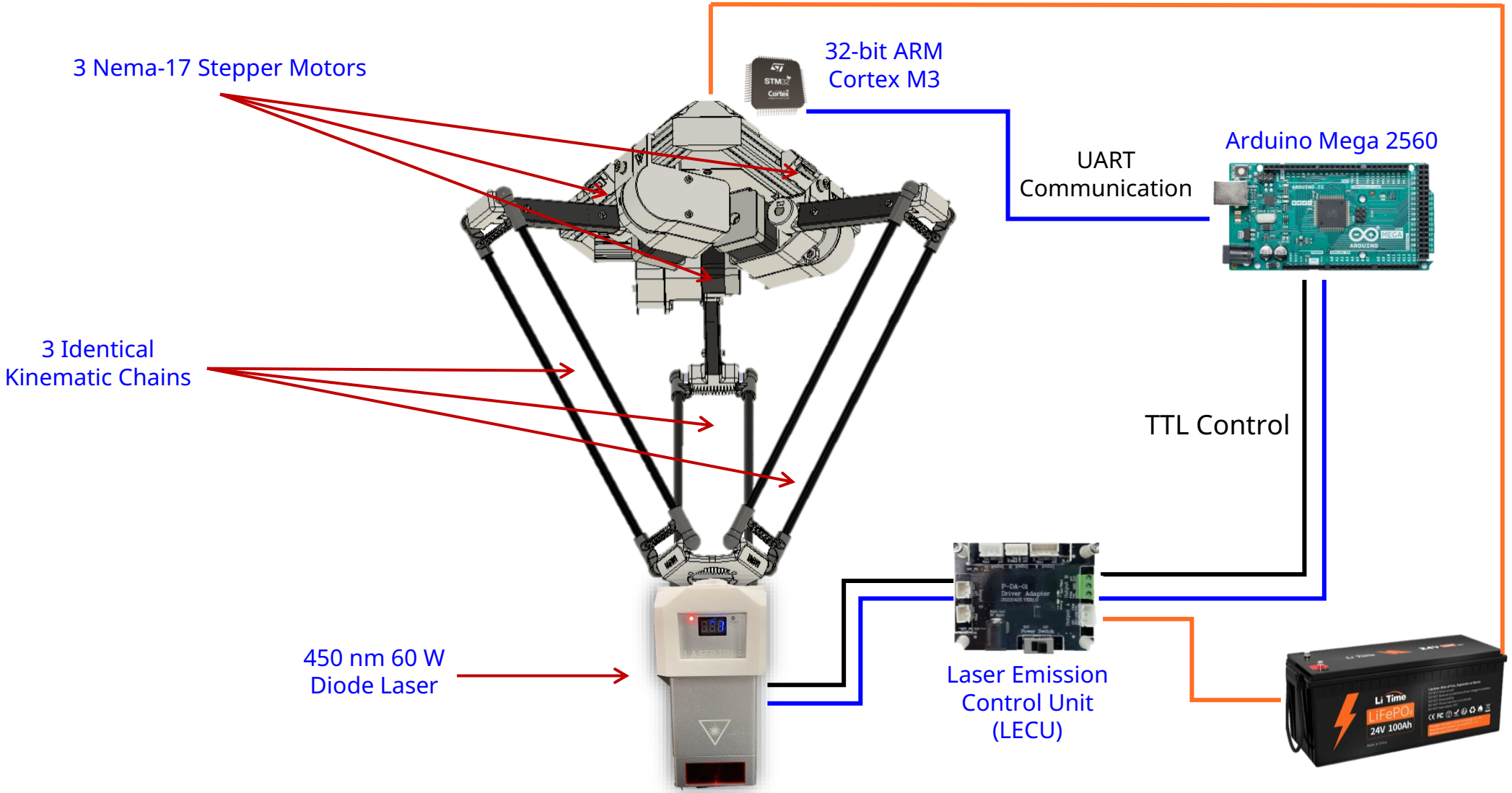
Laser Weeder under operation [10]

Goal & Objective

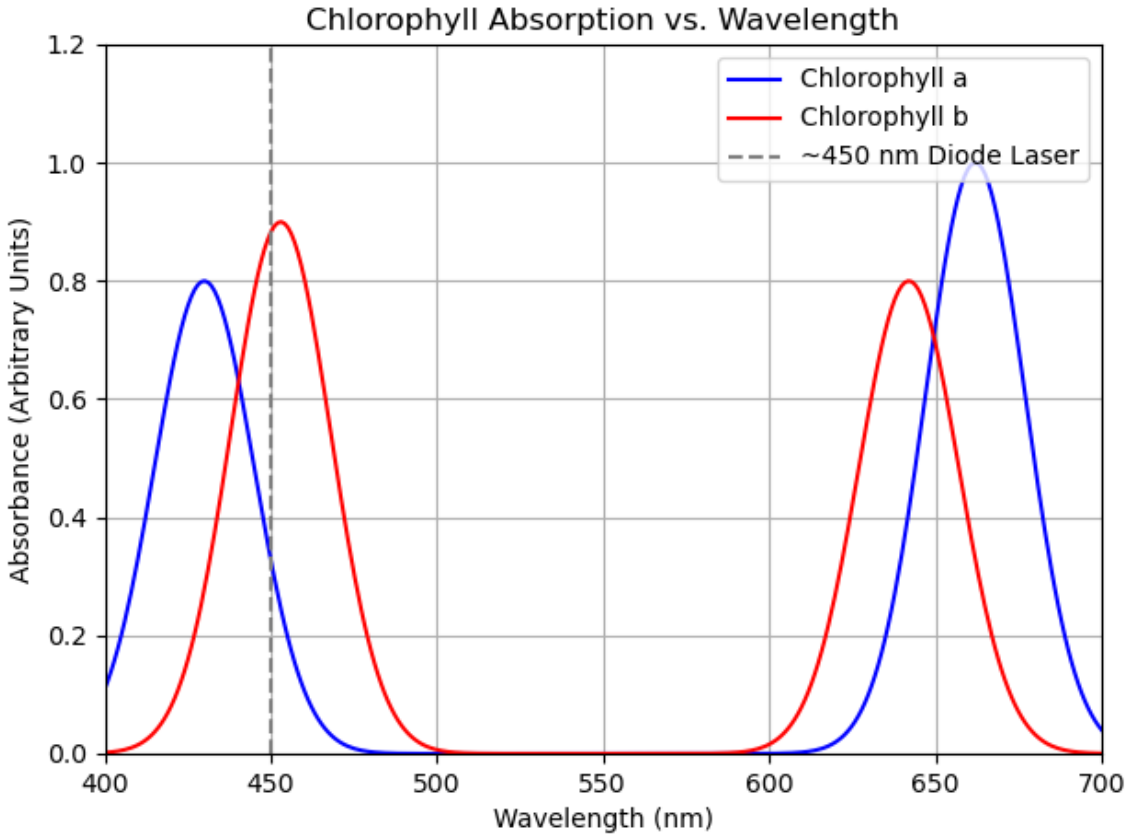
To achieve fully organic weed control in onion fields through laser-based weed elimination using a high-precision robotic system

To develop, test, and validate an automated laser weeding system through systematic assembly, greenhouse optimization, and comprehensive field trials

Methodology: System Architecture



Methodology: Optimal Laser Selection for Weed Control



Optimal Chlorophyll Absorption

Compact and Lightweight

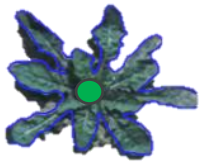
Efficient Thermal Management

Minimal thermal spread

High Electrical-to-Optical Efficiency

Chlorophyll a and b absorption spectra showing the 450 nm region where a blue diode laser aligns with peak absorption for efficient weed elimination.

Methodology: Control Logic & Signal Flow



Stem Emergence Point (X,Y,Z)

Task Execution Planner (TEP)

ATmega2560 MCU

32-bit Cortex-M3 MCU

Trajectory Planner (GRBL-Derived)

IK Solver

SmoothStepper Step Engine

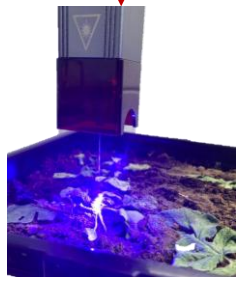
Positional Feedback

Encoder

Stepper Drive

Laser Emission Control Unit (LECU)

Laser Module (450 nm, 50 W)



Precise Laser Targeting

Methodology: Experimental Setup

Experimental Design

Randomized Complete Block Design (RCBD)

Target Specie: *Brassica rapa var. Twister*

T1	T2	T3	T4	Control
3000ms	2000ms	1000ms	500ms	No Laser
10	10	10	10	10

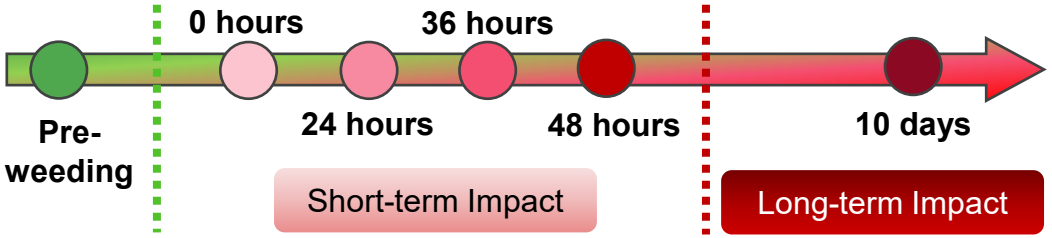
Standardized weed size (10 ± 1.5, 5 ± 1.5 cm)

Uniform growing conditions

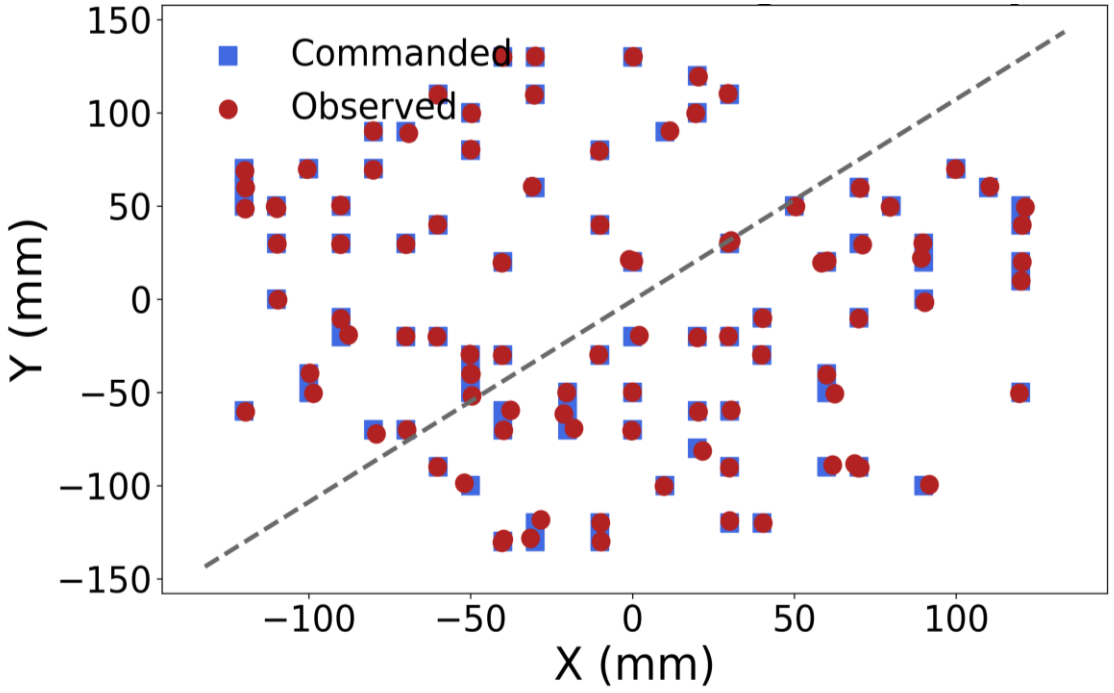
Response Variables

- Chlorophyll Content Index (CCI)
- Visual Necrosis Score (0–4)
- Half-Rossette Span Change
- Height Change

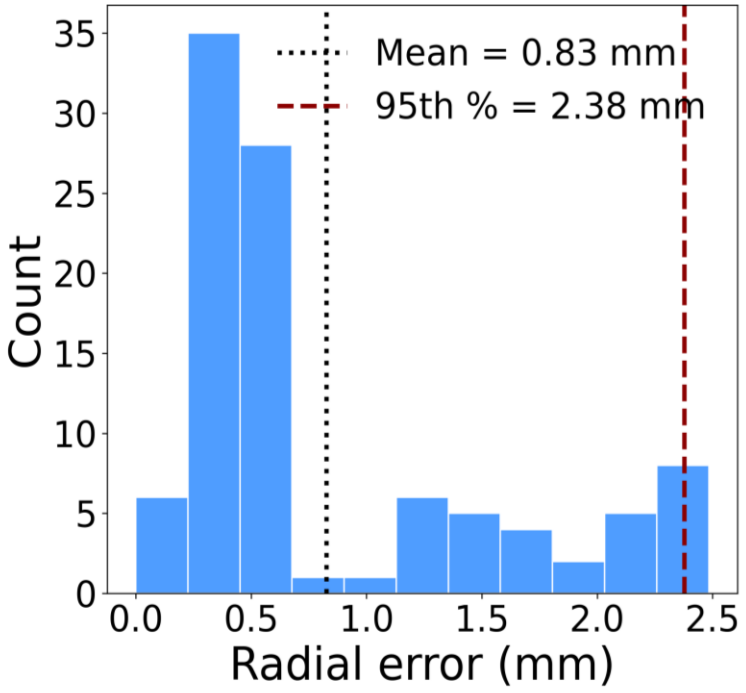
Temporal Monitoring Protocol



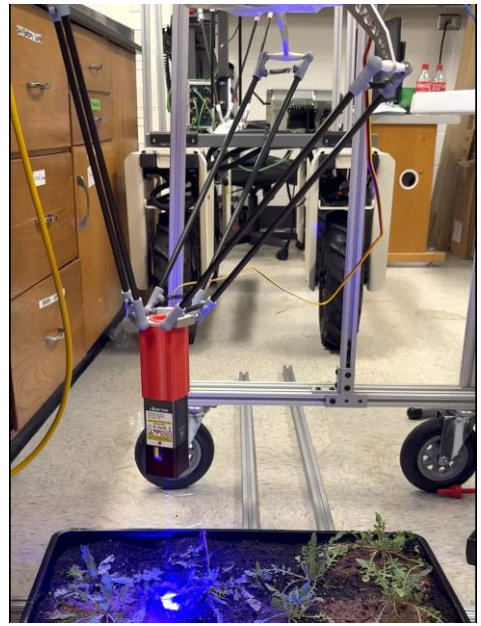
Results: Initial Controlled Environment Testing

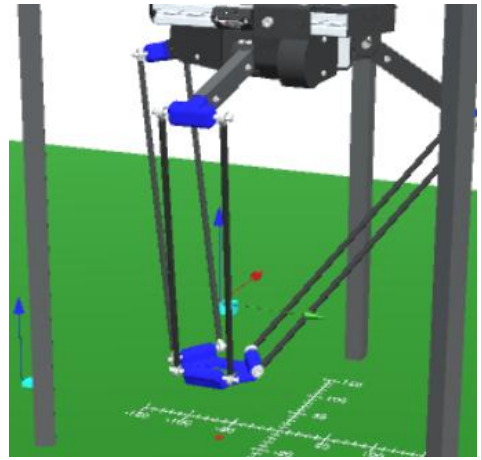


Commanded vs Observed Delta Robot Positions



Radial Error Distribution





Diode Laser:

5 mW Optical Power

532 nm wavelength

Results: Field Validation

Overdosing weeds by flashing laser for 3s, 2s and 1s

Results: Visual Assessment

3 s Laser Exposure

Baseline | 24 hrs Post Treatment | 36 hrs Post Treatment | 48 hrs Post Treatment | 10 days Post Treatment

2 s Laser Exposure

Baseline | 24 hrs Post Treatment | 36 hrs Post Treatment | 48 hrs Post Treatment | 10 days Post Treatment

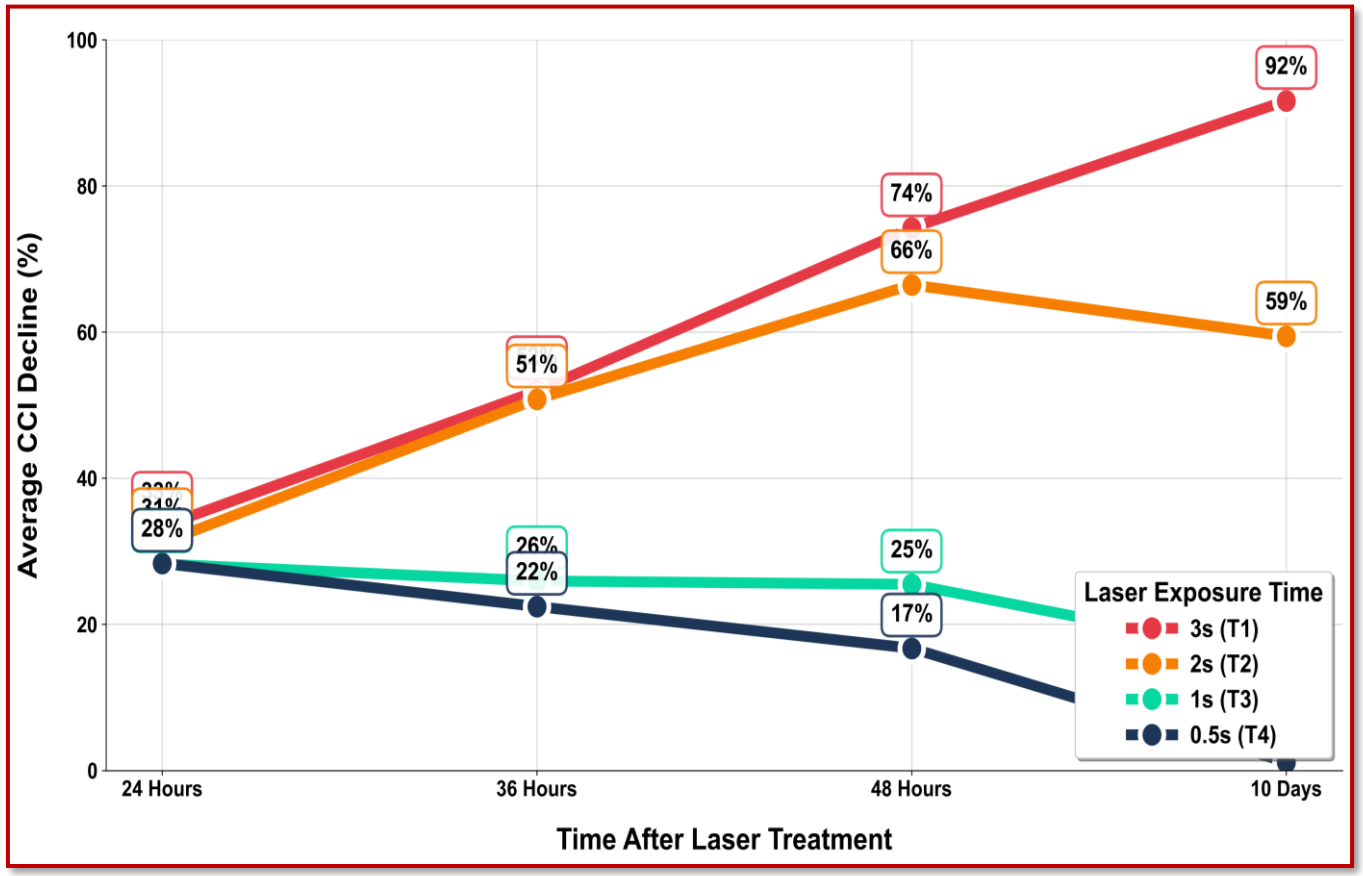
1 s Laser Exposure

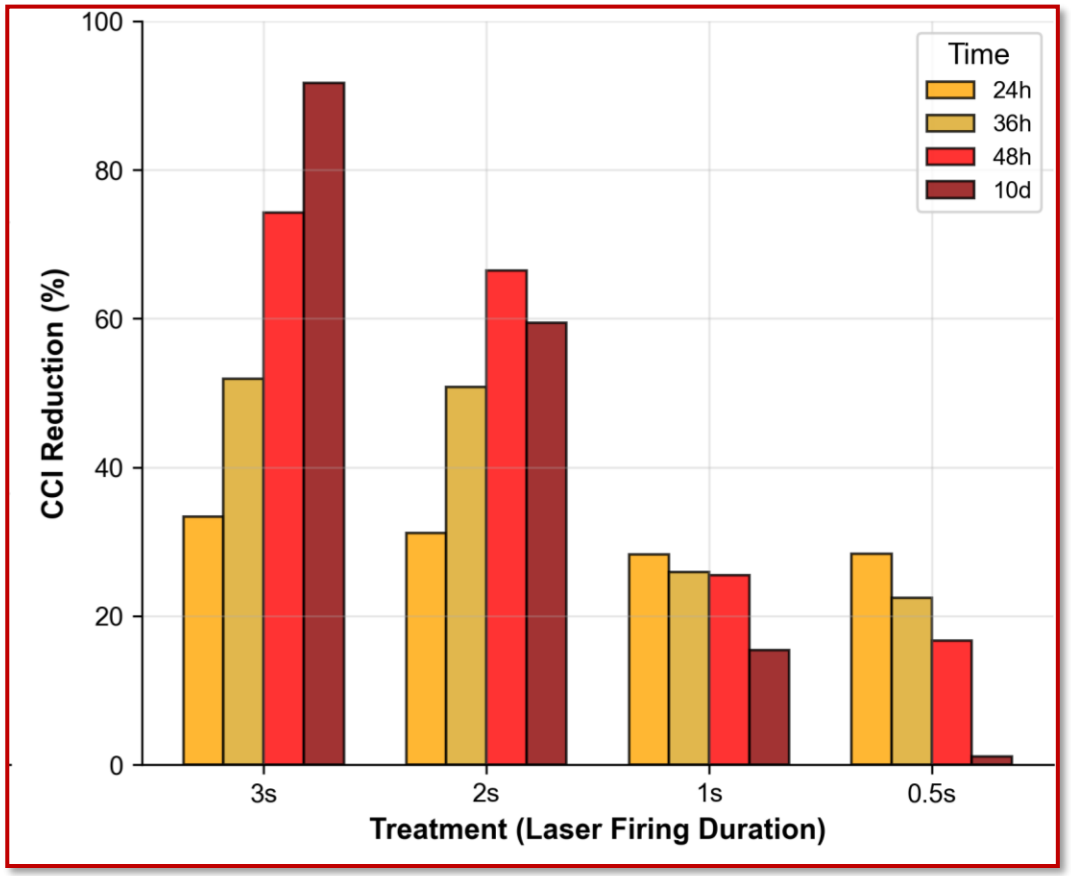
Baseline | 24 hrs Post Treatment | 36 hrs Post Treatment | 48 hrs Post Treatment | 10 days Post Treatment

0.5 s Laser Exposure

Baseline | 24 hrs Post Treatment | 36 hrs Post Treatment | 48 hrs Post Treatment | 10 days Post Treatment

Results: Chlorophyll Content Index (CCI)

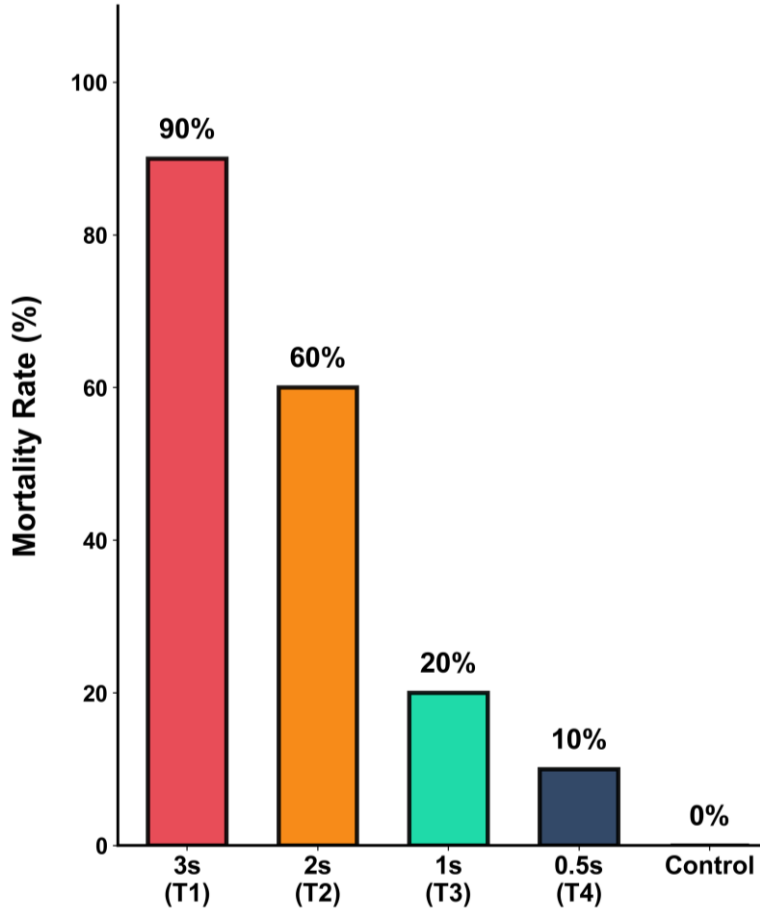




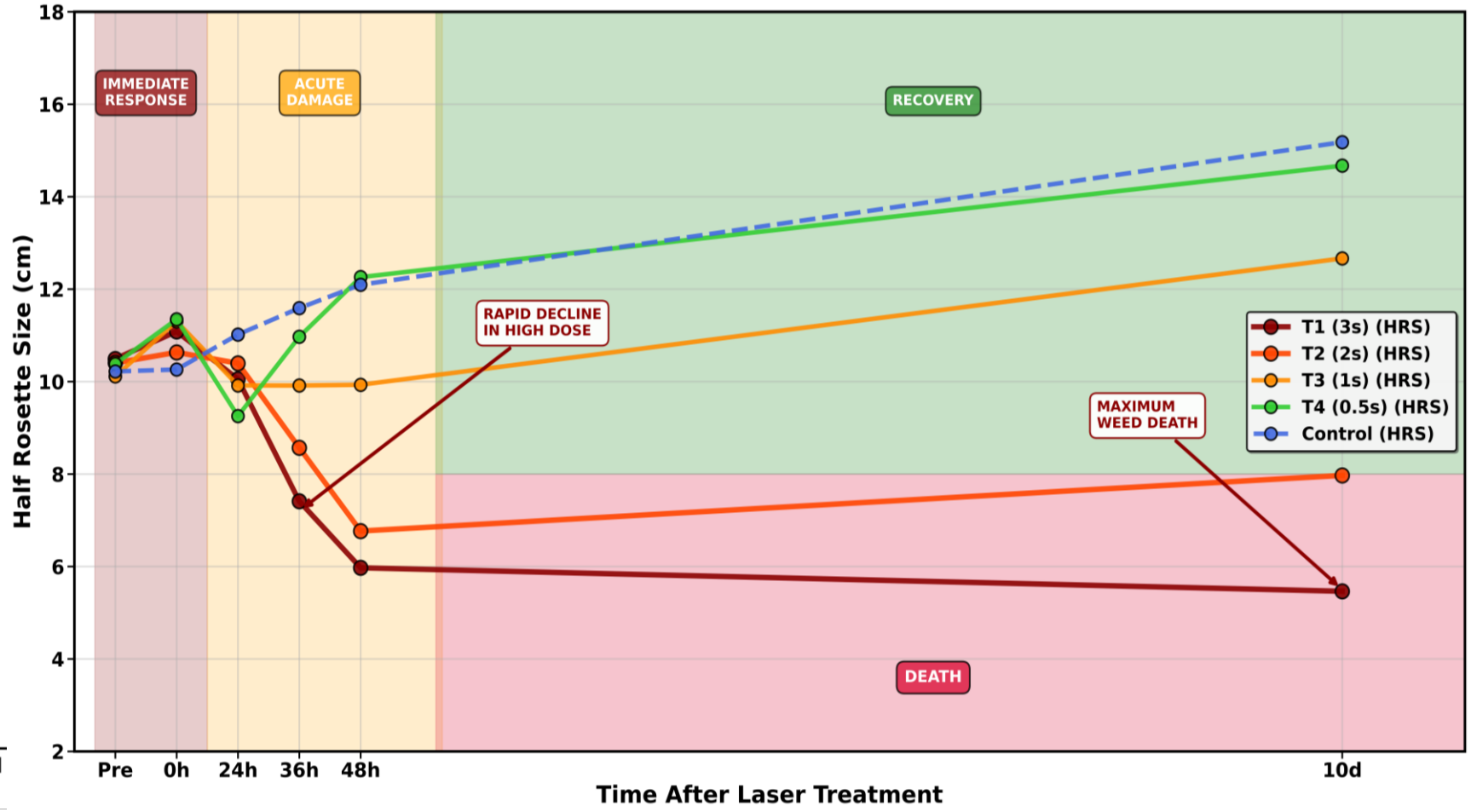
Average chlorophyll degradation over time

Chlorophyll decline rate of each treatment

Results: Morphological Response

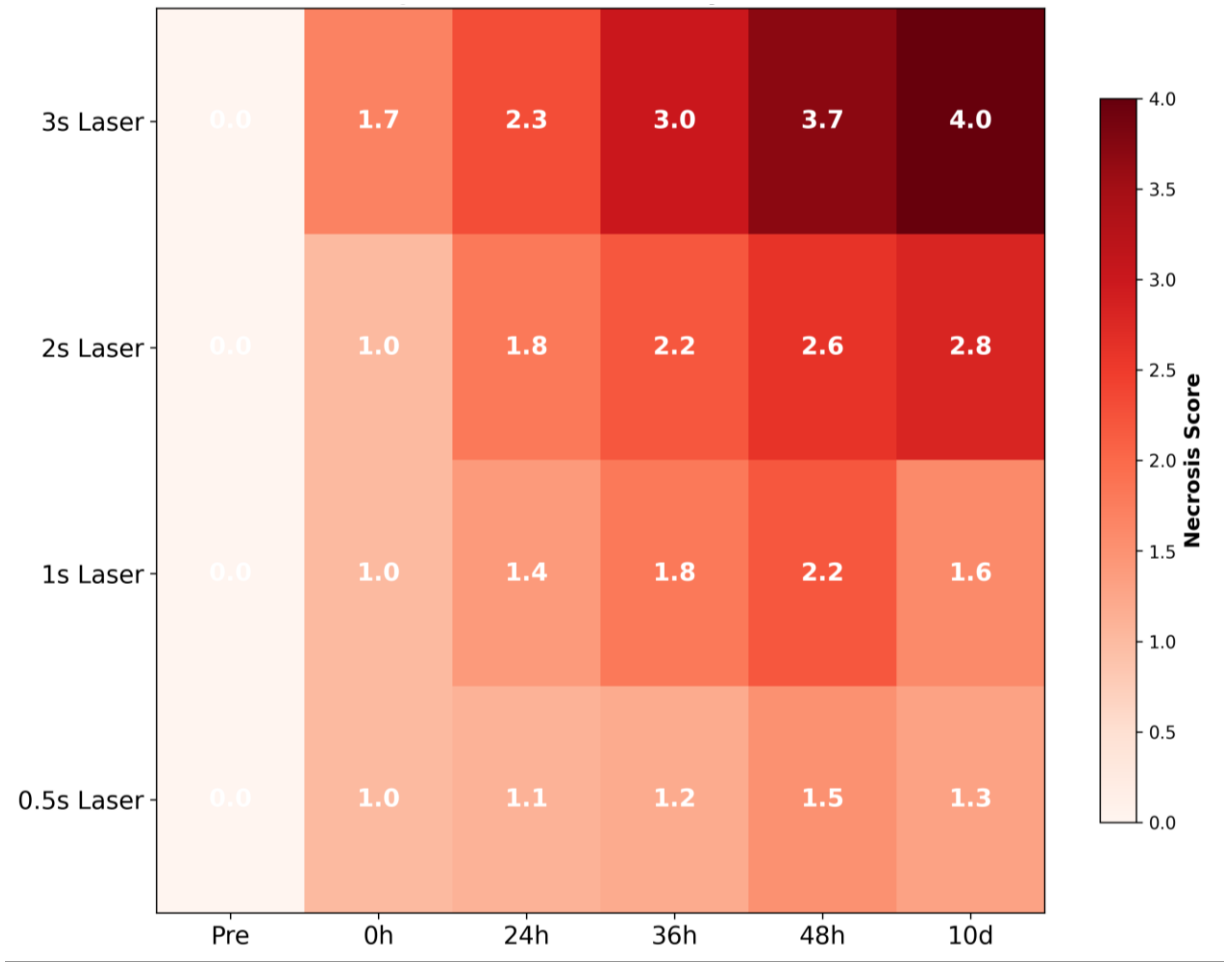


Weed Final Mortality Rate

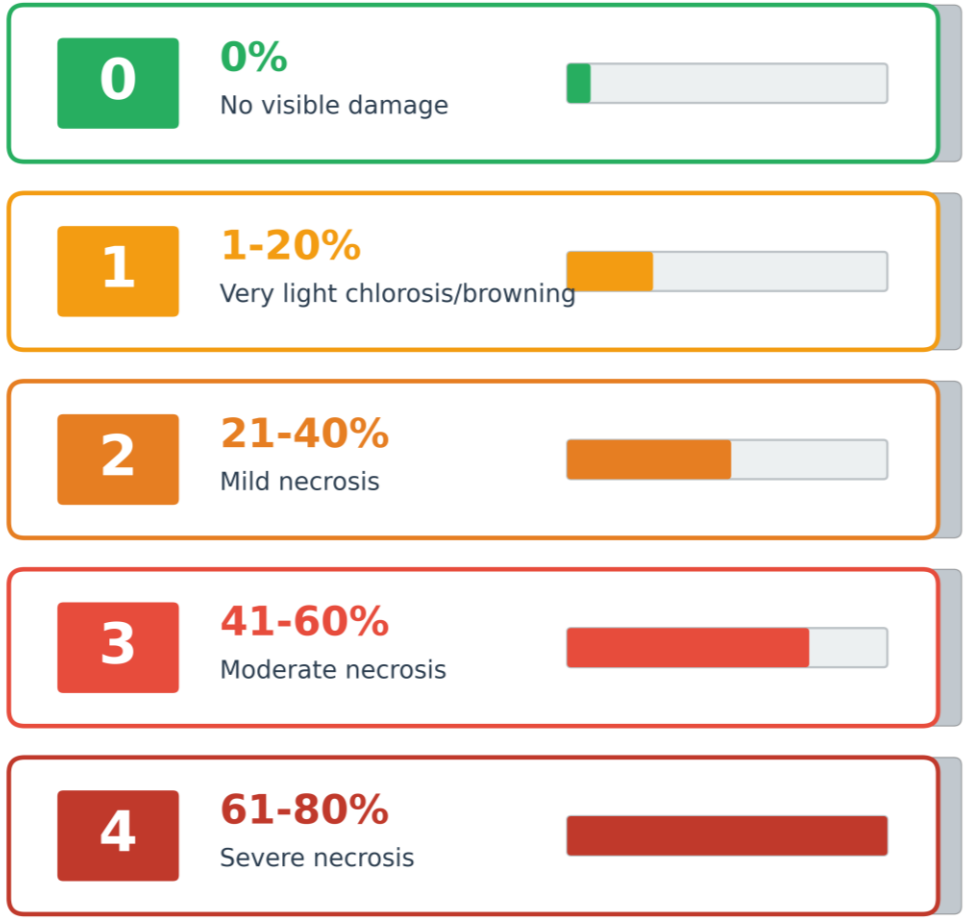


Temporal Decline in Weed Size showing Progressive Plant Death

Results: Visual Necrosis Score



Average Necrosis Score by Treatment



Visual Necrosis Score Classification

Conclusion

- Achieved 90% weed mortality within 48 hours with a high-power diode blue light laser
- Prevented crop damage by sub-millimeter delta-robot targeting
- Future work would involve real-time stem emergence point detection
- Integration with AI-based vision system would enable fully autonomous and organic weed control in Vidalia Onions

Discussion: Future Direction

Real-time Detection

Zed-2i depth camera localizes stem-emergence points in real-time

Integrated Setup

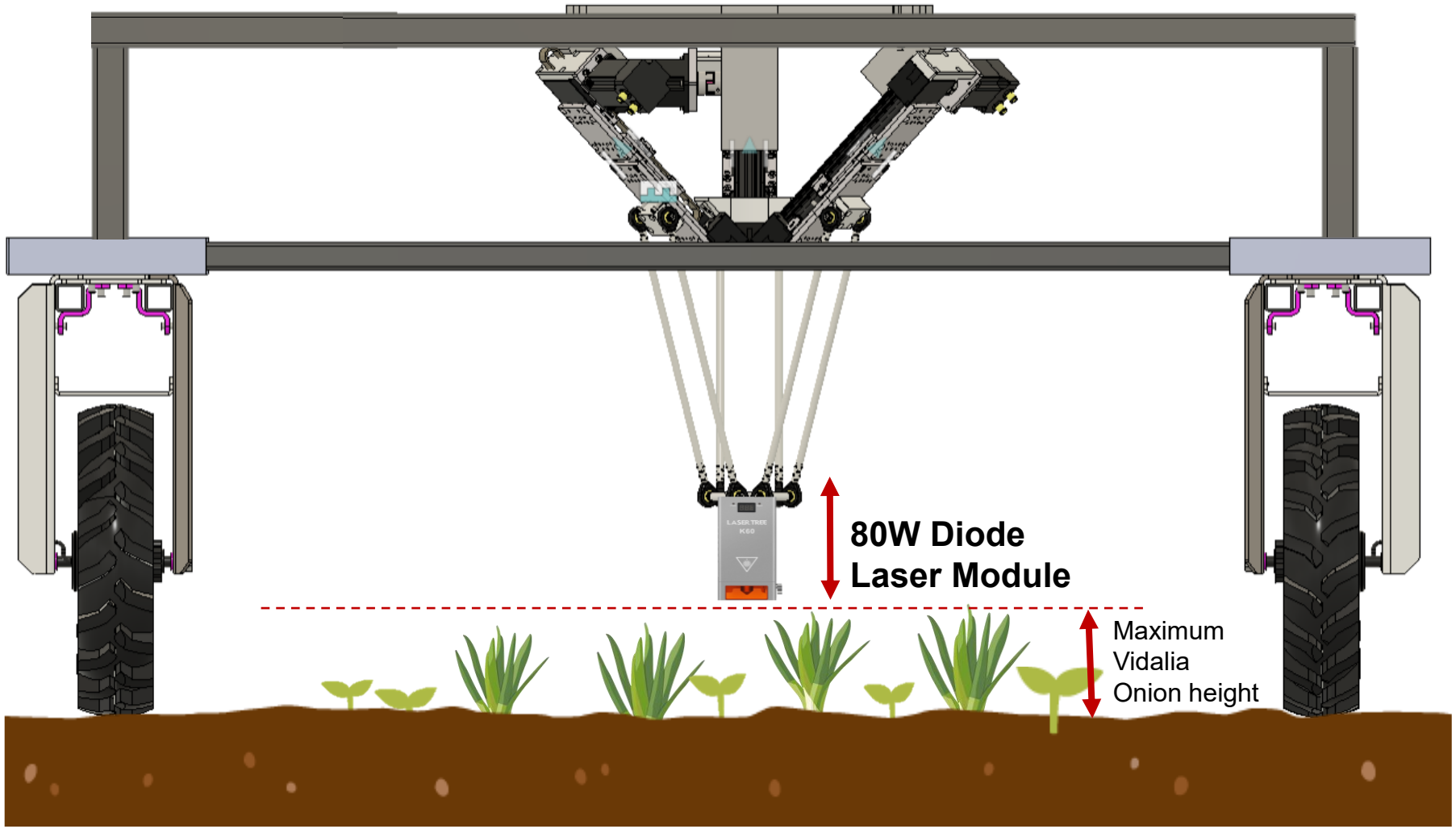
Integrate the Delta robot, diode laser, and ZED-2i onto a Farm-NG Amiga with Nvidia Jetson compute for fully autonomous, real-time laser weeding

Controlled Testing

Validate detection and targeting accuracy (mm) using set weed targets

Field Deployment

Assess weed kill rate, efficacy and crop safety in Vidalia onion plots



Acknowledgements

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VIDALIA® ONIONS

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Thank You

For further queries:

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