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An UGV-based Precision Spraying System for Chemical Apple Blossom Thinning on Trellis Trained Canopies

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INTRODUCTION

- More than 19,500 acres of apples are planted in Pennsylvania by about 2,400 farmers (USDA NASS, 2019).
- Apple blossom thinning plays an important role to ensure the quantity and quality of the crop production.
- Precision apple blossom thinning remains as a challenge: inadequate thinning / excessive thinning.

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INTRODUCTION

- Precision apple blossom thinning
- Automatically detect flower clusters and spraying chemical thinner onto targets

BUT

- Need human labor to drive around orchard
- Extremely slow due to the speed of linear actuator

Cartesian target spraying system developed in 2022

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GOAL & OBJECTIVES

❖**Goal: Develop an autonomous robotic system that can perform chemical thinning process for the apple canopies to reduce labor cost and minimize the chemical thinner usage.**

❖**Objectives:**

- Develop a machine vision system that automatically detects and locates the position of thinning targets (apple flower clusters).
- Transform pixel coordinates into geographic coordinates for the communication between vision system and RTK GPS.
- Evaluate the performance of the overall system and compare with other spraying techniques.

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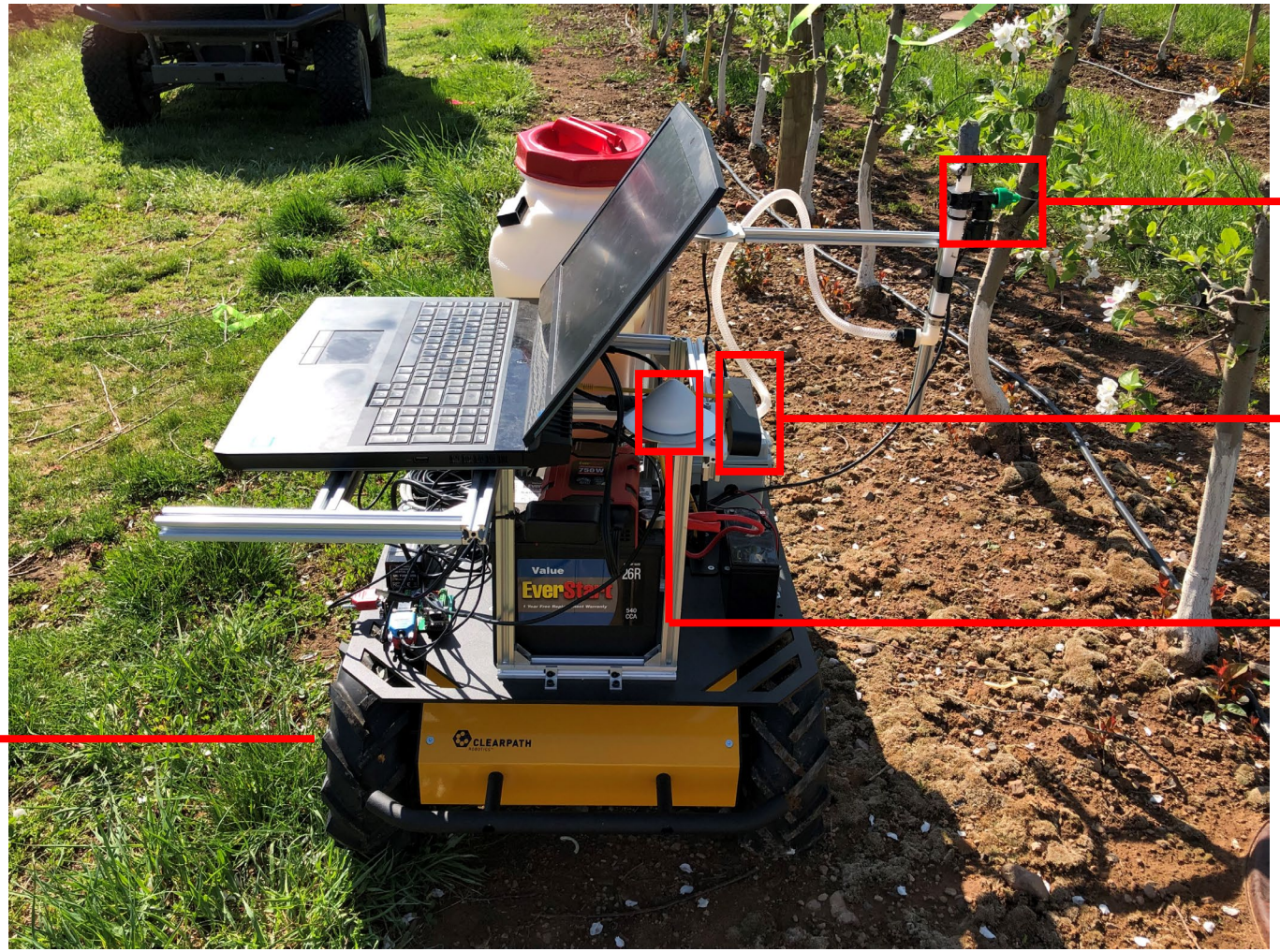
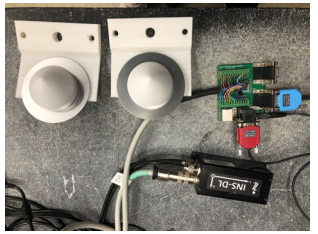
METHODOLOGY



TeeJet Flat-Shaped Nozzle

ZED2 Camera



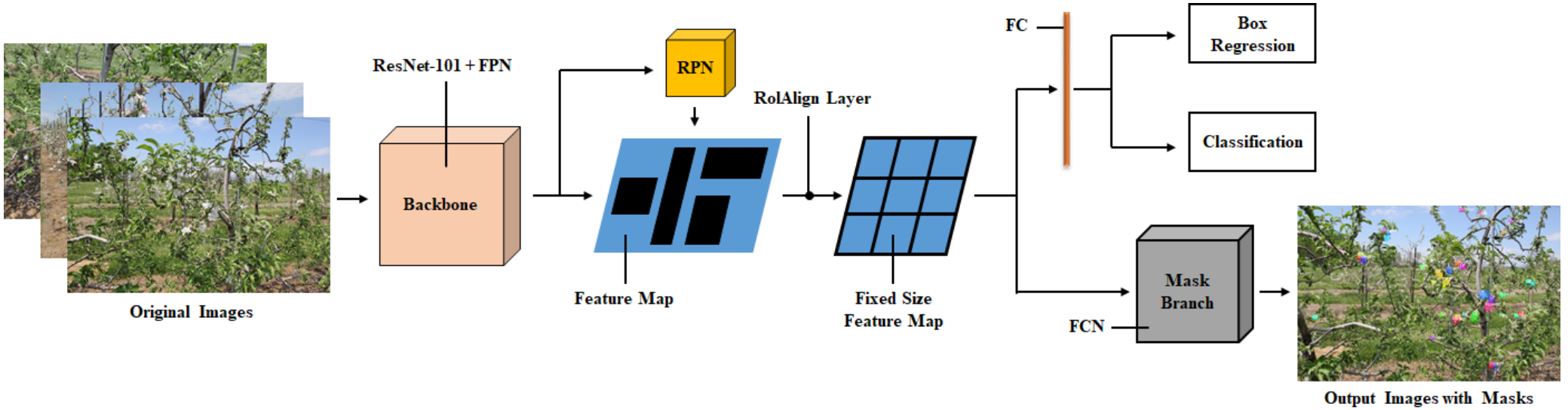
Inertial Labs RTK GPS

Husky A200

METHODOLOGY

❖ Mask R-CNN Based Instance Segmentation

- Transfer learning: COCO dataset
- Training-testing split ratio: 2000:400 (5:1)
- Loss function converged after 100,000 iterations



METHODOLOGY

❖Object Localization and Georeferencing

Start spraying
(x_s , y_s)

Stop spray
(x_e , y_e)

$$\begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}$$

$$\begin{bmatrix} X_{\text{ecef}} \\ Y_{\text{ecef}} \\ Z_{\text{ecef}} \end{bmatrix}$$

$$\text{longitude} = \text{atan2}(Y_{\text{ecef}}, X_{\text{ecef}})$$

$$\text{latitude} = \text{atan2}\left(Z_{\text{ecef}} + e^2 \cdot b \cdot \sin^3(\theta), p - e^2 \cdot a \cdot \cos^3(\theta)\right)$$

$a = 6378137.0$ (Semi-major axis of the Earth in meters)

$f = \frac{1}{298.257223}$ (Flattening factor of the Earth)

$b = a \cdot (1 - f)$ (Semi-minor axis of the Earth in meters)

$e = \sqrt{2f - f^2}$ (Eccentricity of the Earth)

$p = \sqrt{X_{\text{ecef}}^2 + Y_{\text{ecef}}^2}$ (Distance from the Z-axis in meters)

$\theta = \text{atan2}\left(Z_{\text{ecef}} \cdot a, p \cdot b\right)$ (Angle between Z-axis and XY-plane)

$$\begin{bmatrix} \text{on}) & 0 \\ \sin(\text{lon}) & \cos(\text{lat}) \\ \text{in}(\text{lon}) & \sin(\text{lat}) \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}$$

F coordinates

ECEF coordinates to geographic coordinates

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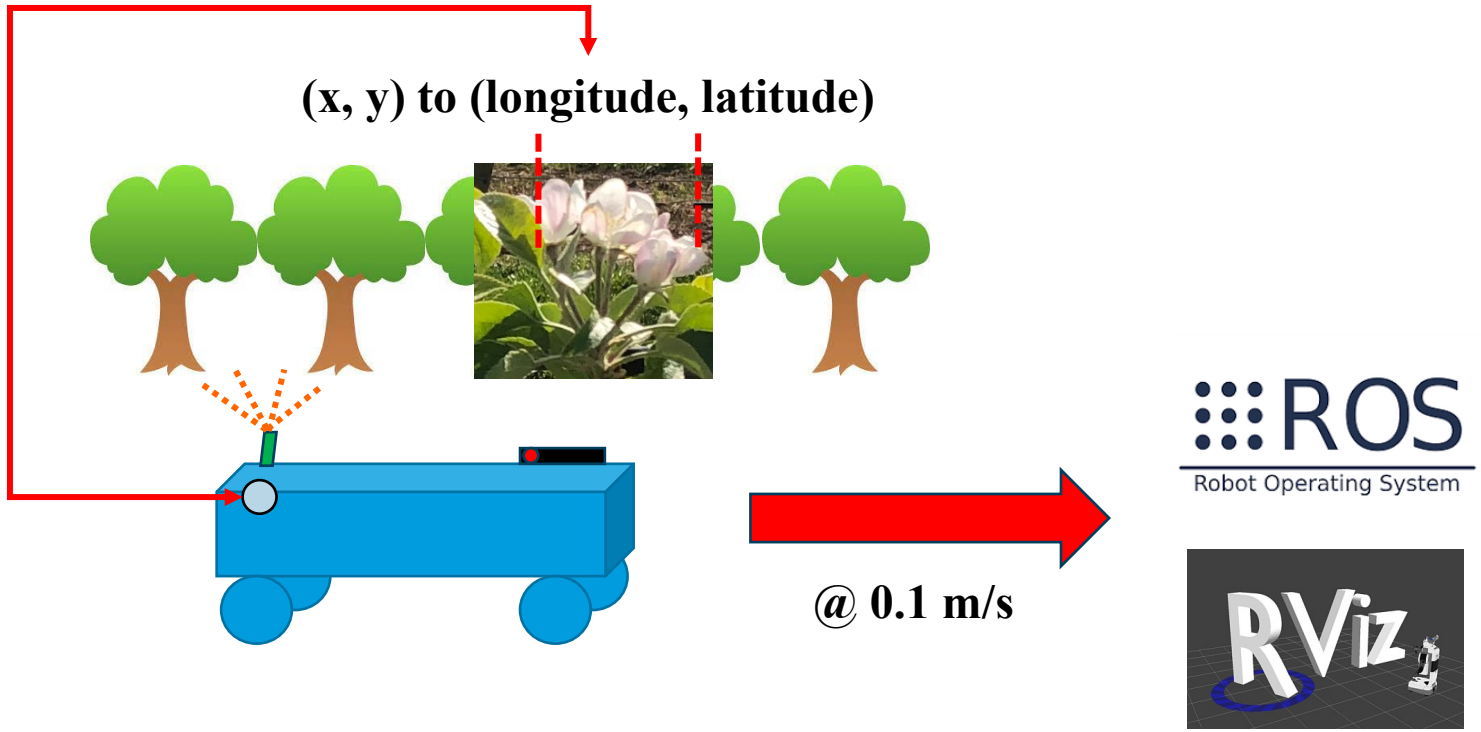
METHODOLOGY

❖Overview of the UGV-based Spraying System

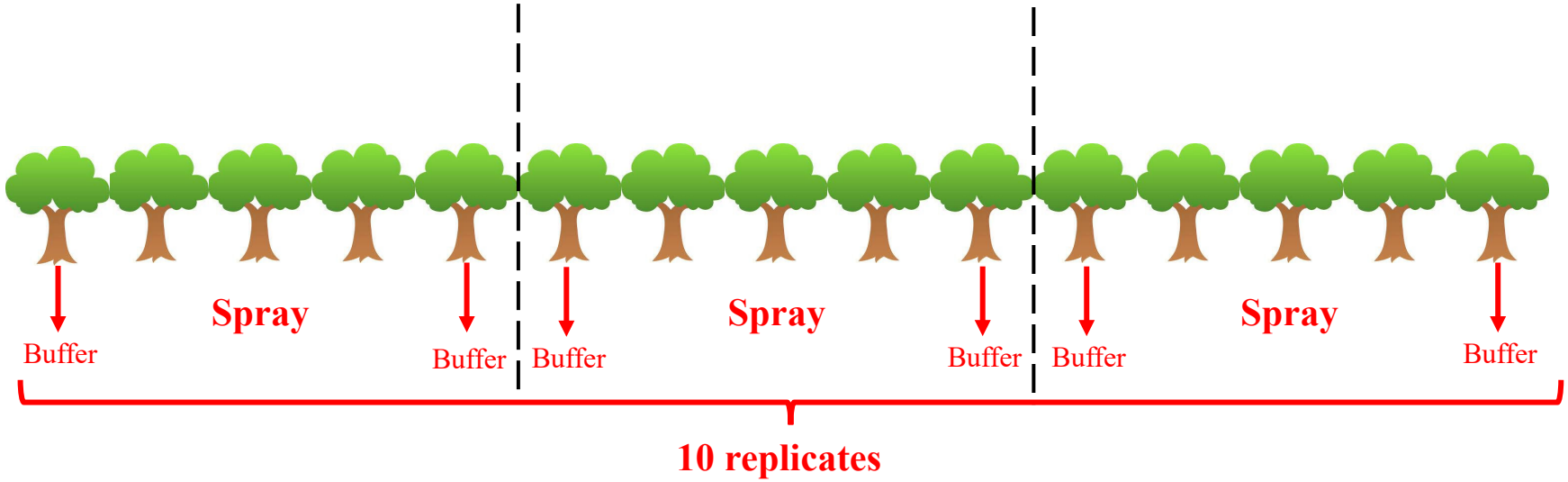


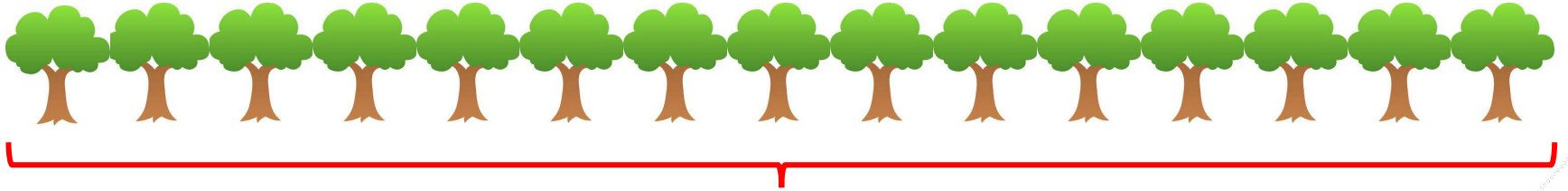
METHODOLOGY

❖Experimental Design

UGV-based sprayer

Air-blast sprayer





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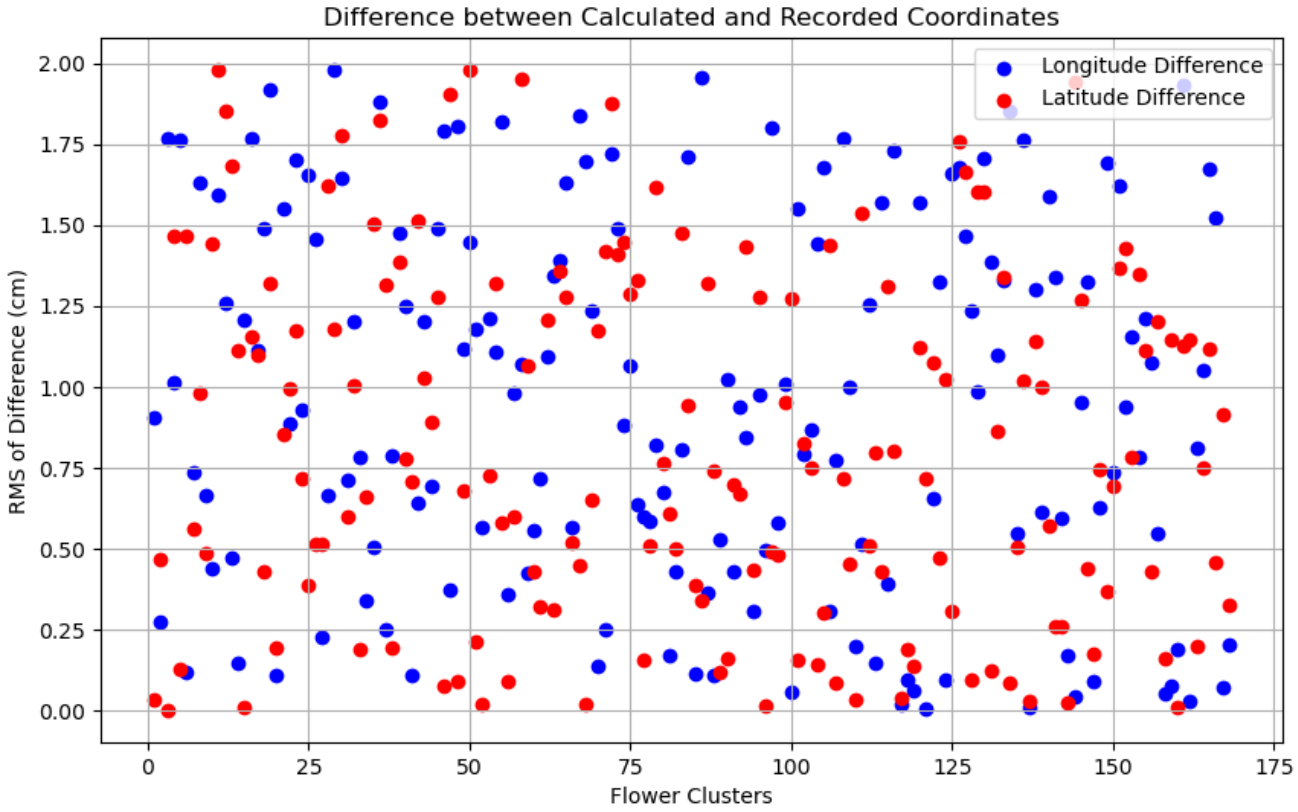
RESULTS

❖Georeferencing Accuracy Assessment



- Ground truth coordinates measured manually using GPS.
- Compare with geographic coordinates computed by vision system.
- RMSE lies within ±2 centimeters.

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RESULTS

❖Spraying Coverage Test with Blue Indicator

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RESULTS

❖UGV-based Sprayer vs. Air-blast Sprayer vs. Cartesian Sprayer

- UGV-based spraying system took longer time than air-blast sprayer.
- The usage of chemical thinner (Lime Sulfur + Oil) decreased greatly in target spraying.
- Least green fruit set indicates that the UGV-based spraying system obtains the best thinning process.

Spraying System	Average Spray Time per Tree (s) (s)	Chemical Usage (gal) (gal)	Green Fruit Set per Cluster
UGV-based Sprayer	**10.2**	**2.2**	**2.3**
Air-blast Sprayer	2.4	4.6	2.6
Cartesian Sprayer	18.6	2.3	2.4

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CONCLUSION

- A novel approach for apple blossom thinning was developed using the UGV-based spraying system.
- The machine vision system correctly detect the target flower clusters and output the location in the format of geographic coordinates with RMSE less than 2cm.
- Comparing to other thinning techniques, the UGV-based spraying system decreases the usage of chemical thinner by 60% and improves the effectiveness of thinning.

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