Autonomous Sensor Insertion and Exchange for Cornstalk Monitoring Robot

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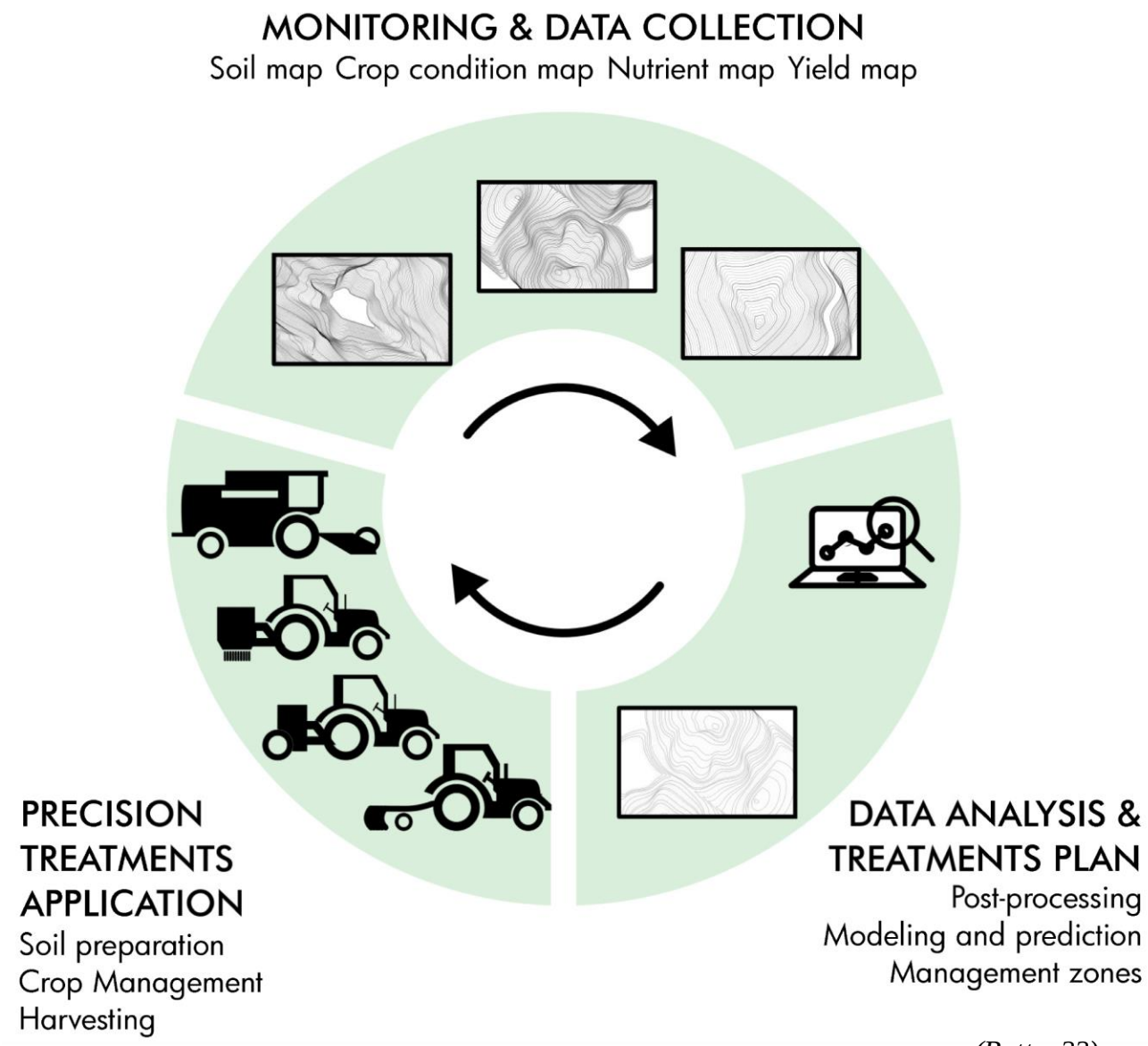
Janice Lee

Committee members:
Oliver Kroemer
George Kantor
Abhisesh Silwal
Moonyoung (Mark) Lee

Robotics in Agriculture

- Growing food demand
- Labor shortage

Precision Agriculture



(Botta, 22)

https://www.azorobotics.com/Article.aspx?ArticleID=113

https://manlybattery.com/definition-and-types-of-agricultural-robots/

https://www.growag.com/highlights/article/how-are-robots-used-in-agriculture

Real-time insights

Data-driven decisions

Monitoring Nitrate Level in Cornstalks

eos.com/blog/fertilizer-burn/

- **Crop Health**
- **Fertilizer Usage**

Over-fertilizing

Fertilizer Burn

pafeplantscenter.com/

Soil Acidification

eos.com/blog/fertilizer-burn/

Nutrient Pollution

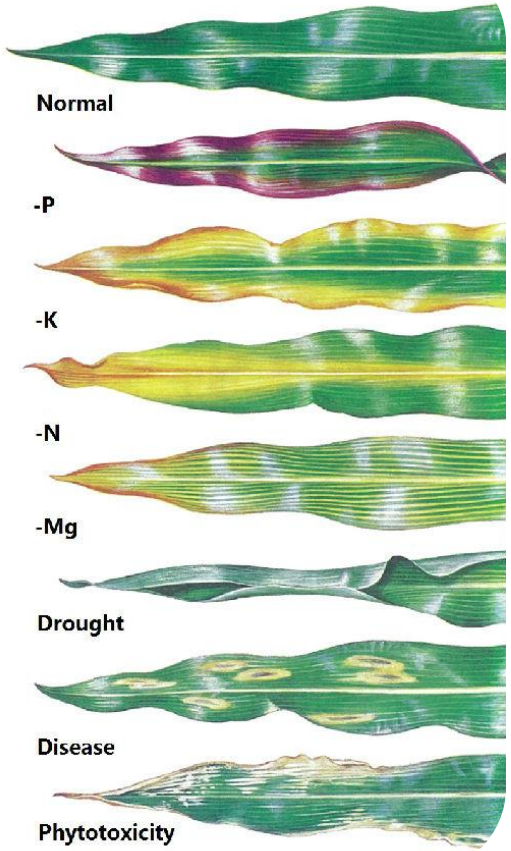
seakeepers.org/2024/08/fertilizer-to-fish-kills-how-nutrient-pollution-affects-water-quality/

Nitrate Sensing Methods

Soil Sampling

Destructive Plant Analysis

Visual Inspection



Contact-based Nitrate Sensing

Manual Sensor Insertion from Iowa State Univ.

Autonomous Robotic System

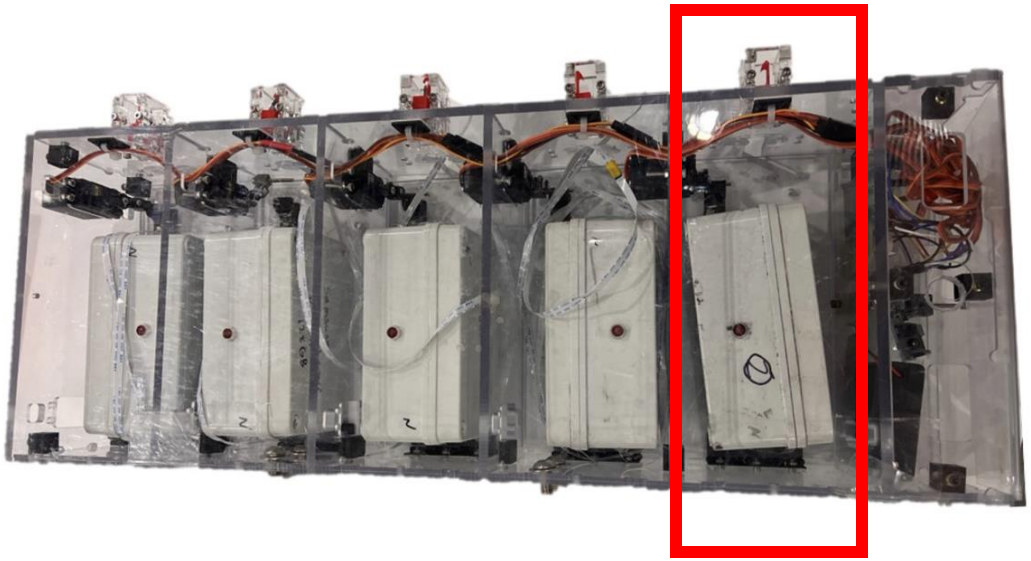
Prior Work

Single Sensor Insertion

- Long-term data collection – 30 days

Limitation

- Data collection after 30 days
- Human operator to reload new sensor and data logging unit



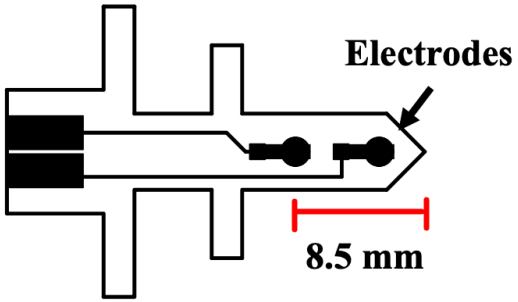
Research Problem

Multiple Sensor Insertion → **Enable Real-time Data Collection**

Autonomous Sensor Exchange → **Enhance Autonomy for Long-term Field Deployment**

Contact Interaction Challenges

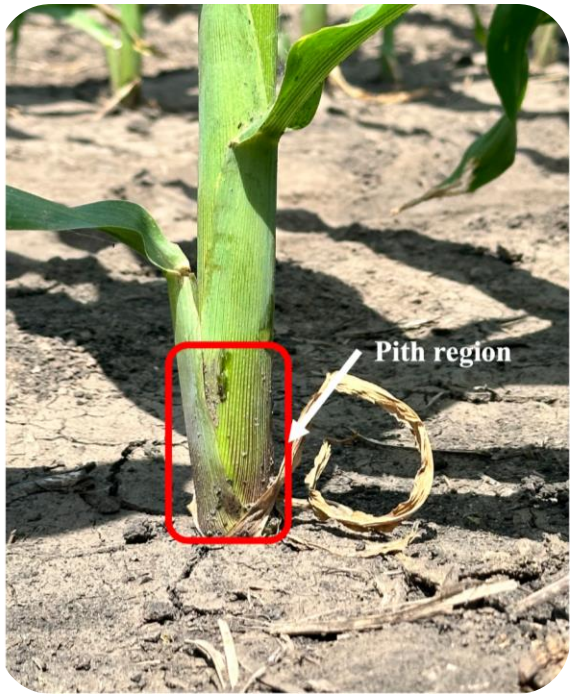
Precision



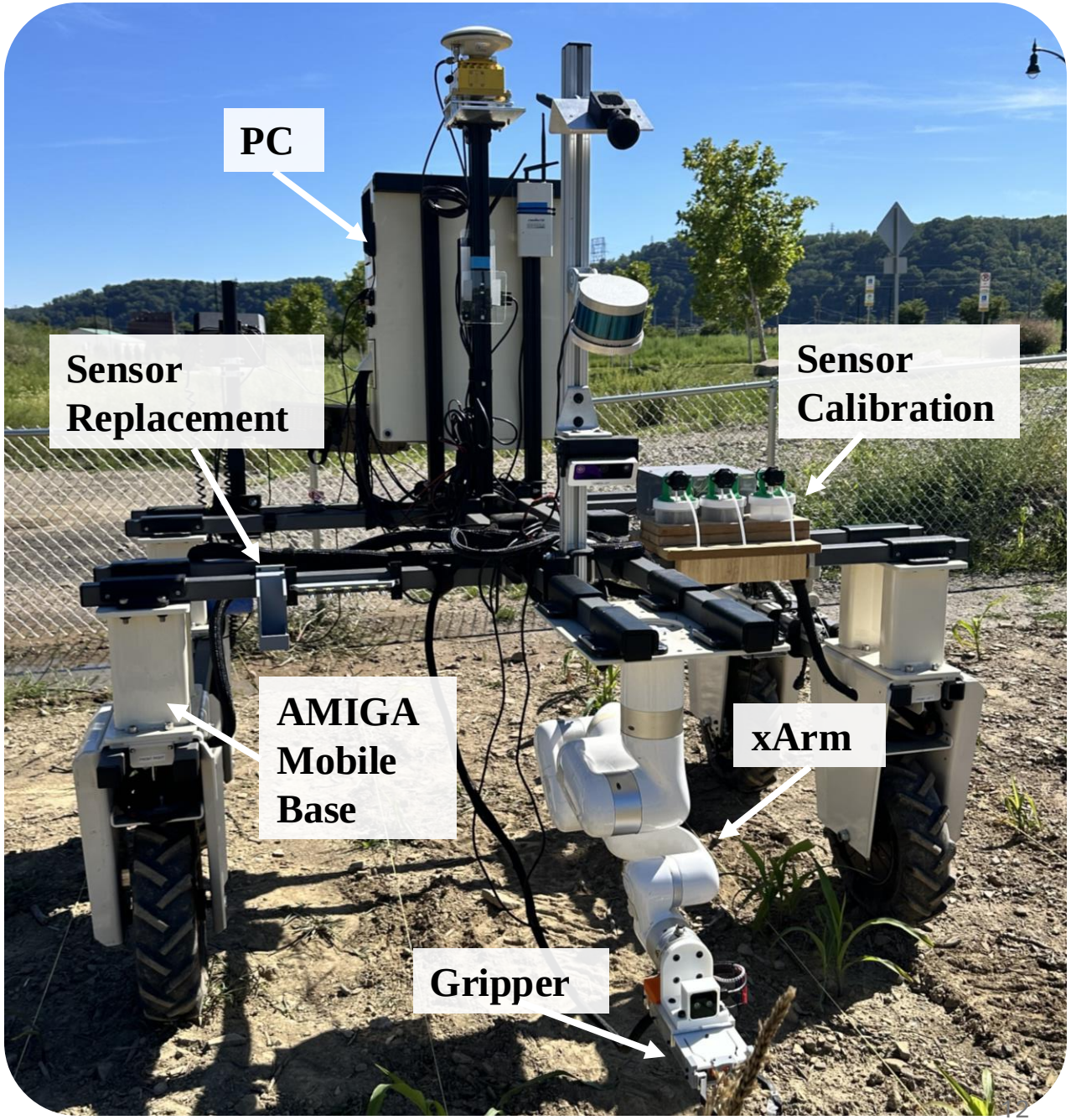
Variation in Diameter (15 – 35mm)

Collision with Stalks

Collision with Ground

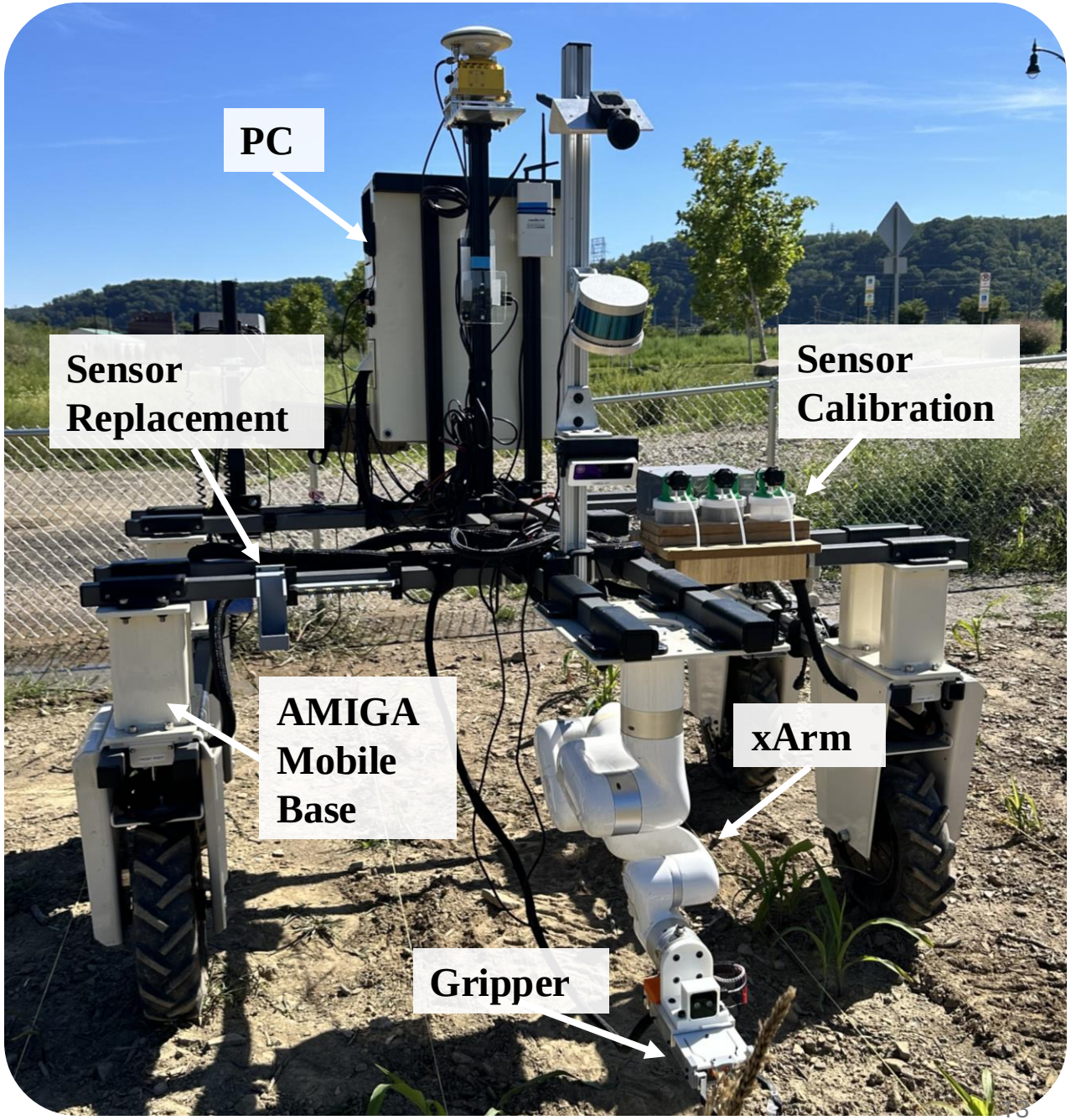


Robot System

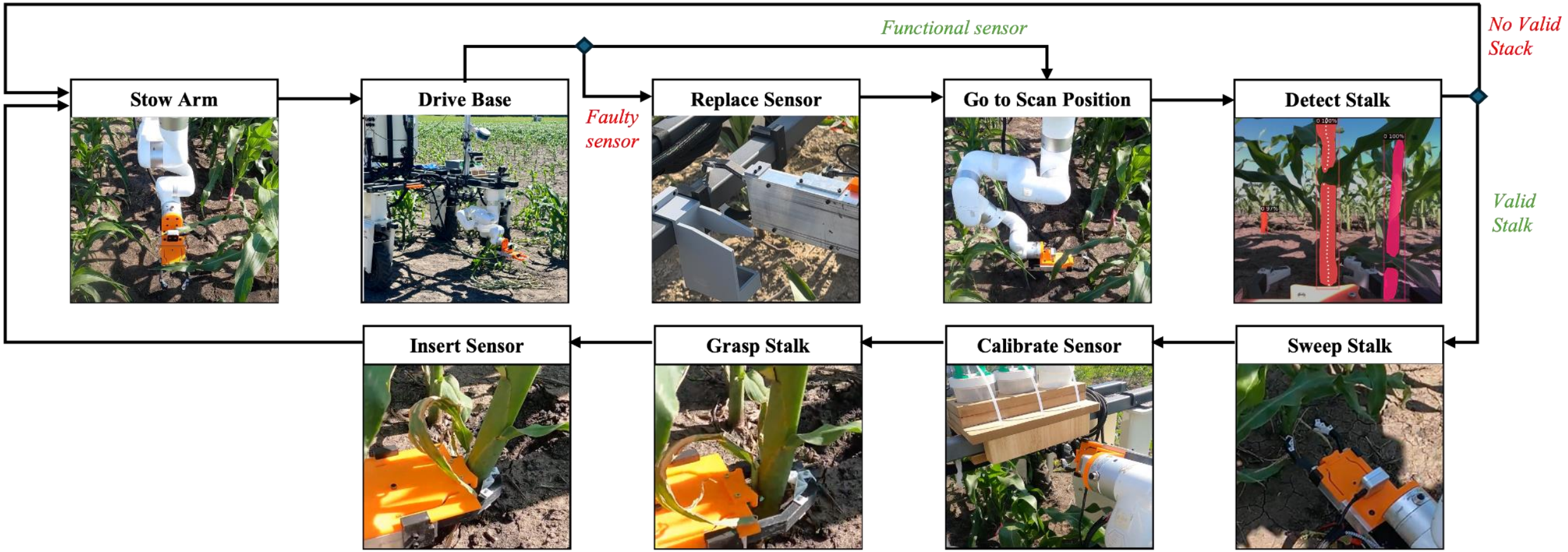


Content Overview

- Motion Sequence
- Gripper
- Sensor Exchange
- Visual Servoing
- Subsystem Testing
- Field Deployment



Motion Sequence



Content Overview

Motion Sequence

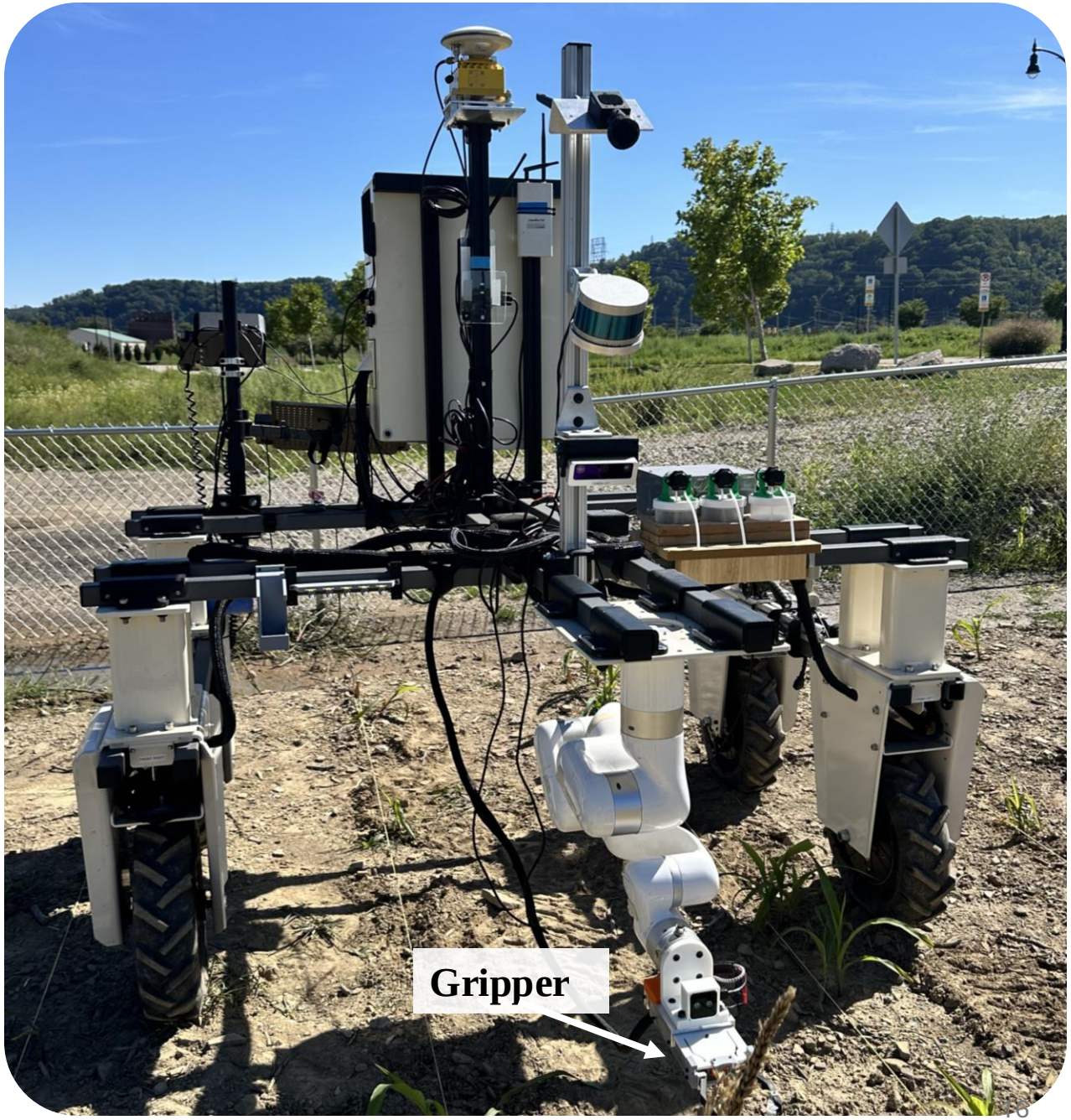
Gripper

Sensor Exchange

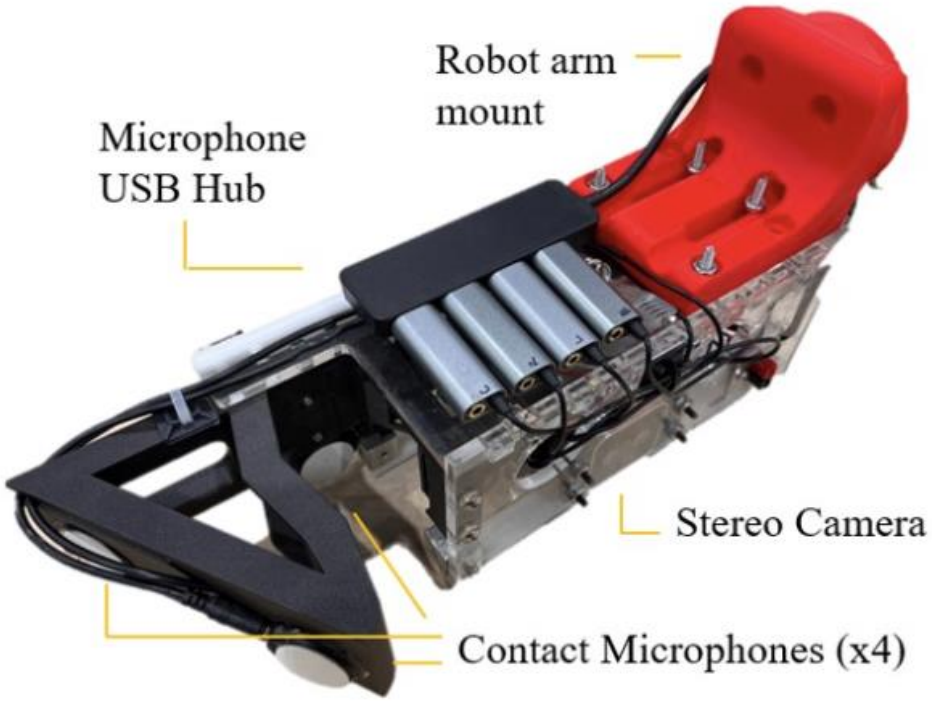
Visual Servoing

Subsystem Testing

Field Deployment



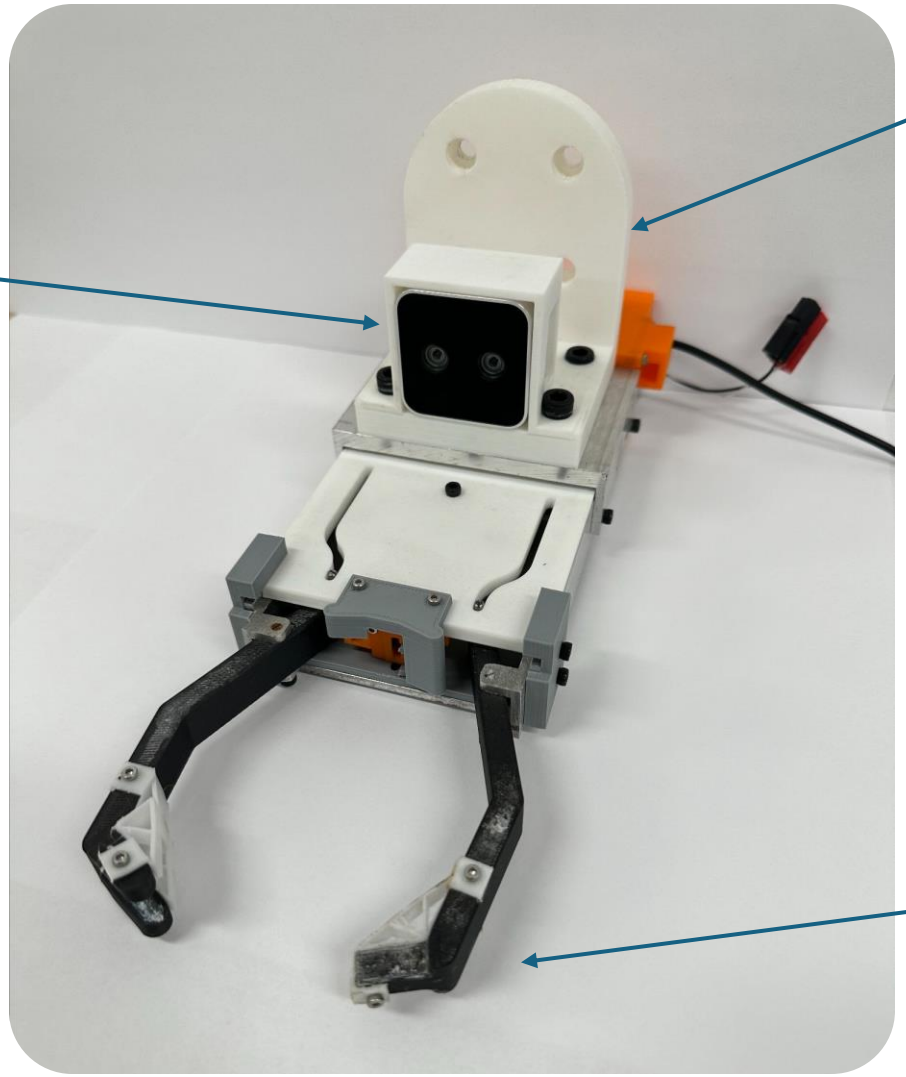
Related Works



Gripper Design

Gripper Mount

RealSense D405



Two-finger Design

Gripper Design Motivation

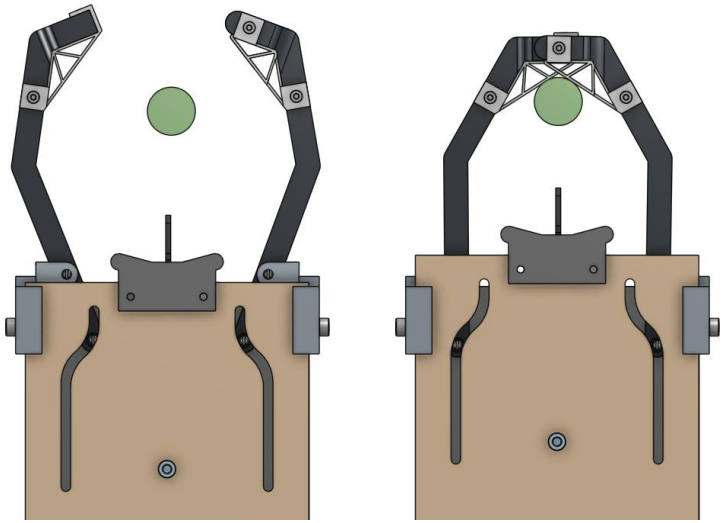
Adaptive to Varying Stalk Diameter

Compact to Avoid Collision

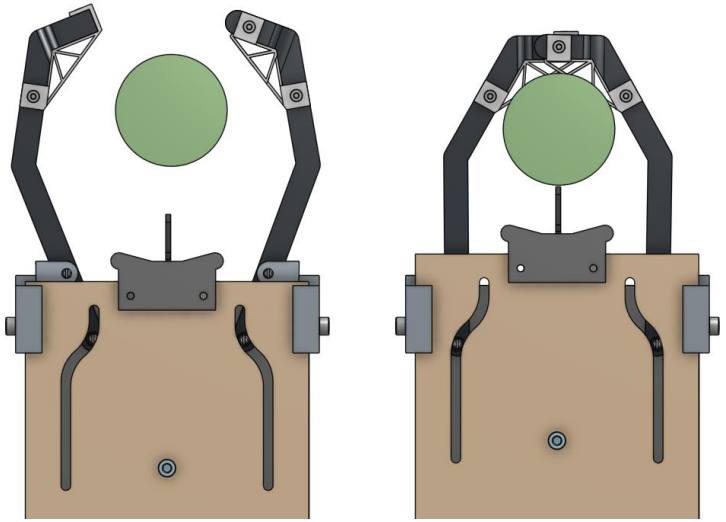
Two-finger Design

Compliant soft pads

15 mm



35 mm

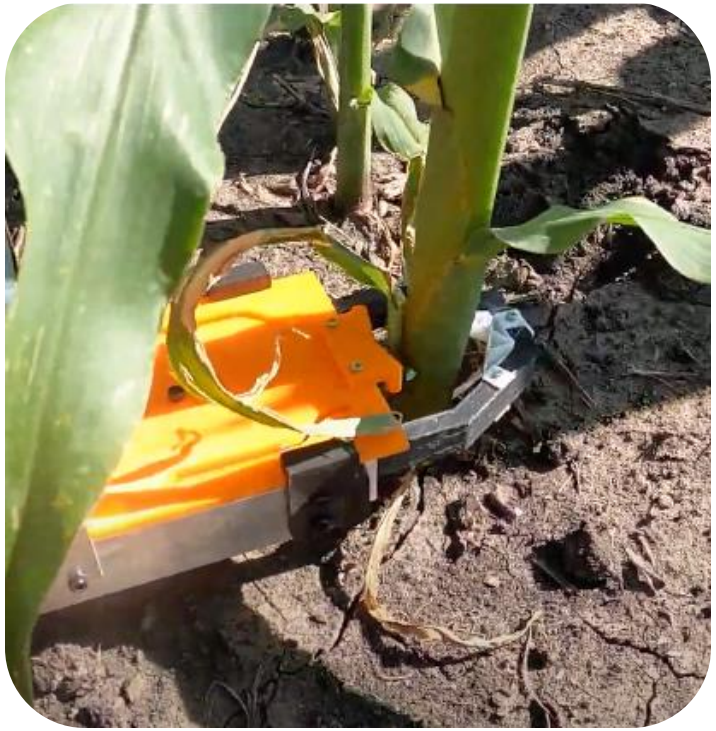


Gripper Design Motivation

Adaptive to Varying Stalk Diameter

Compact to Avoid Collision

Gripper Functions

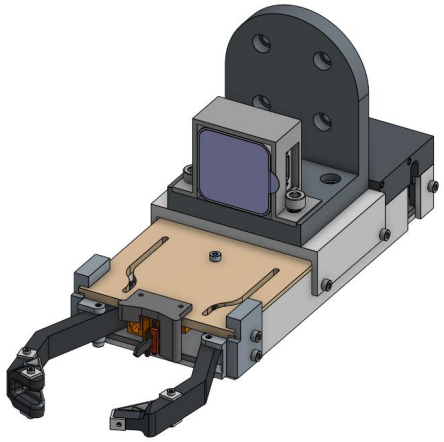


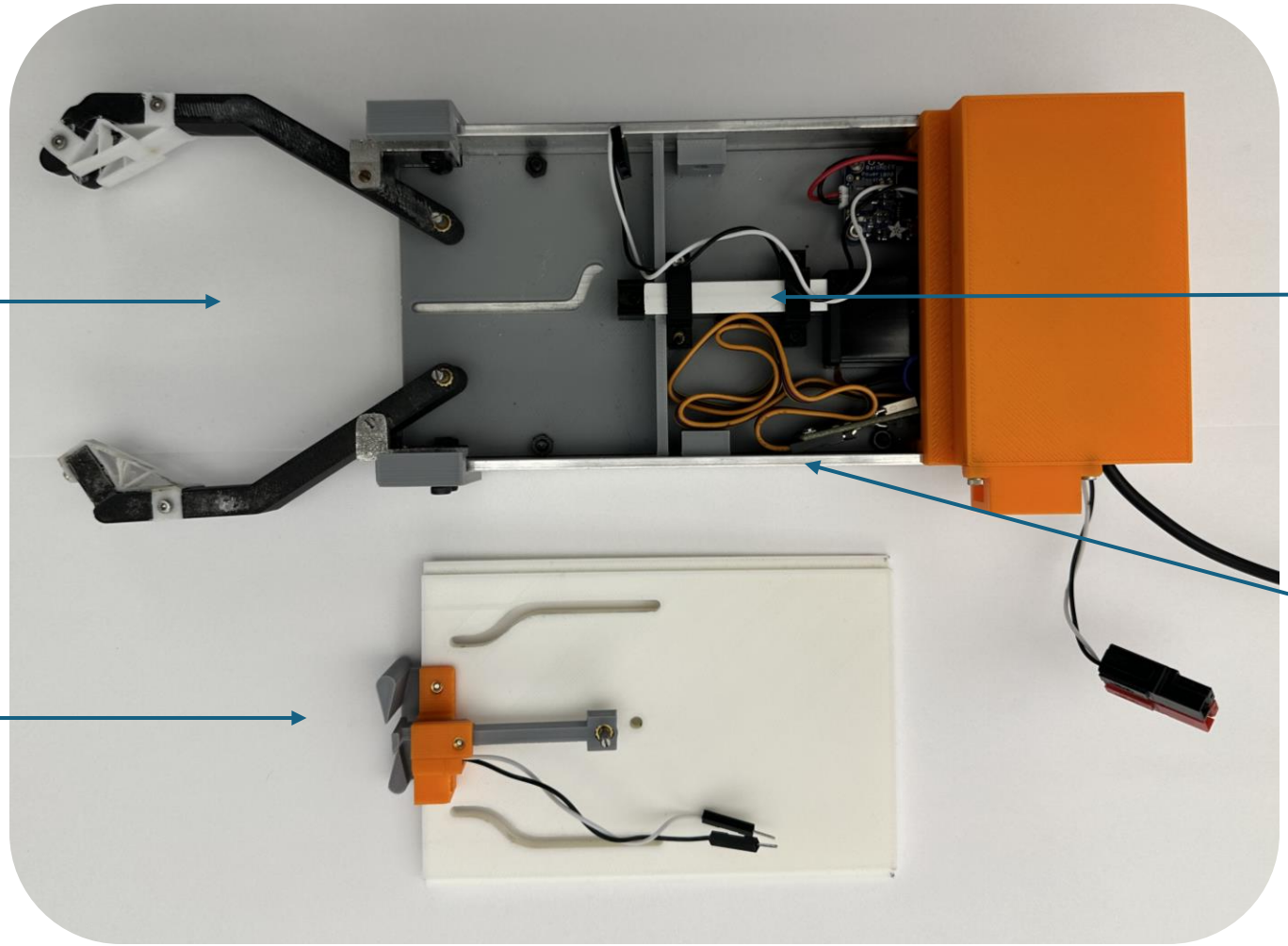
Grasp Stalk

Insert Sensor

Exchange Sensor

Coupled Sliding Mechanism

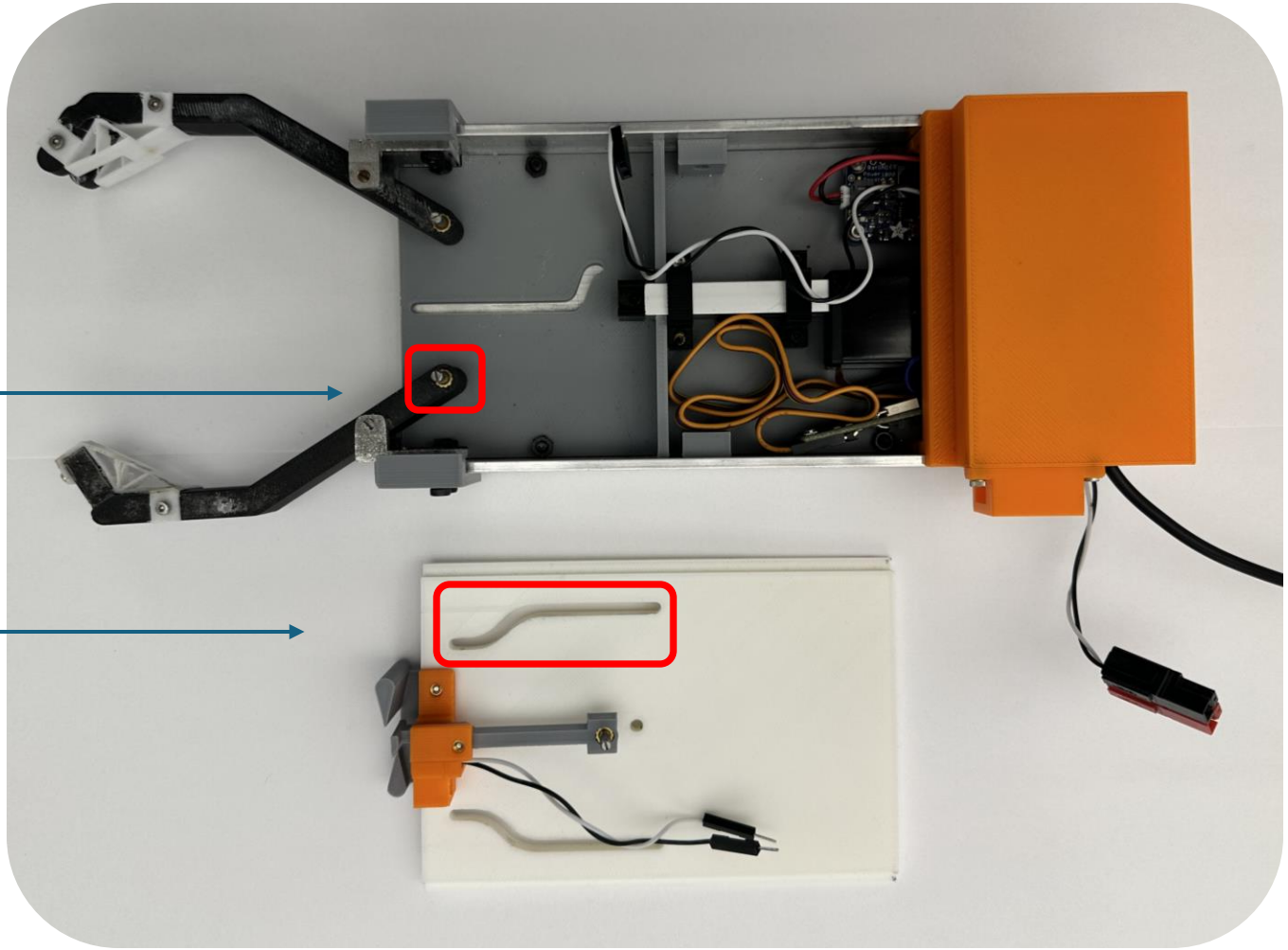




Coupled Sliding Mechanism

Finger Pin

Finger Track

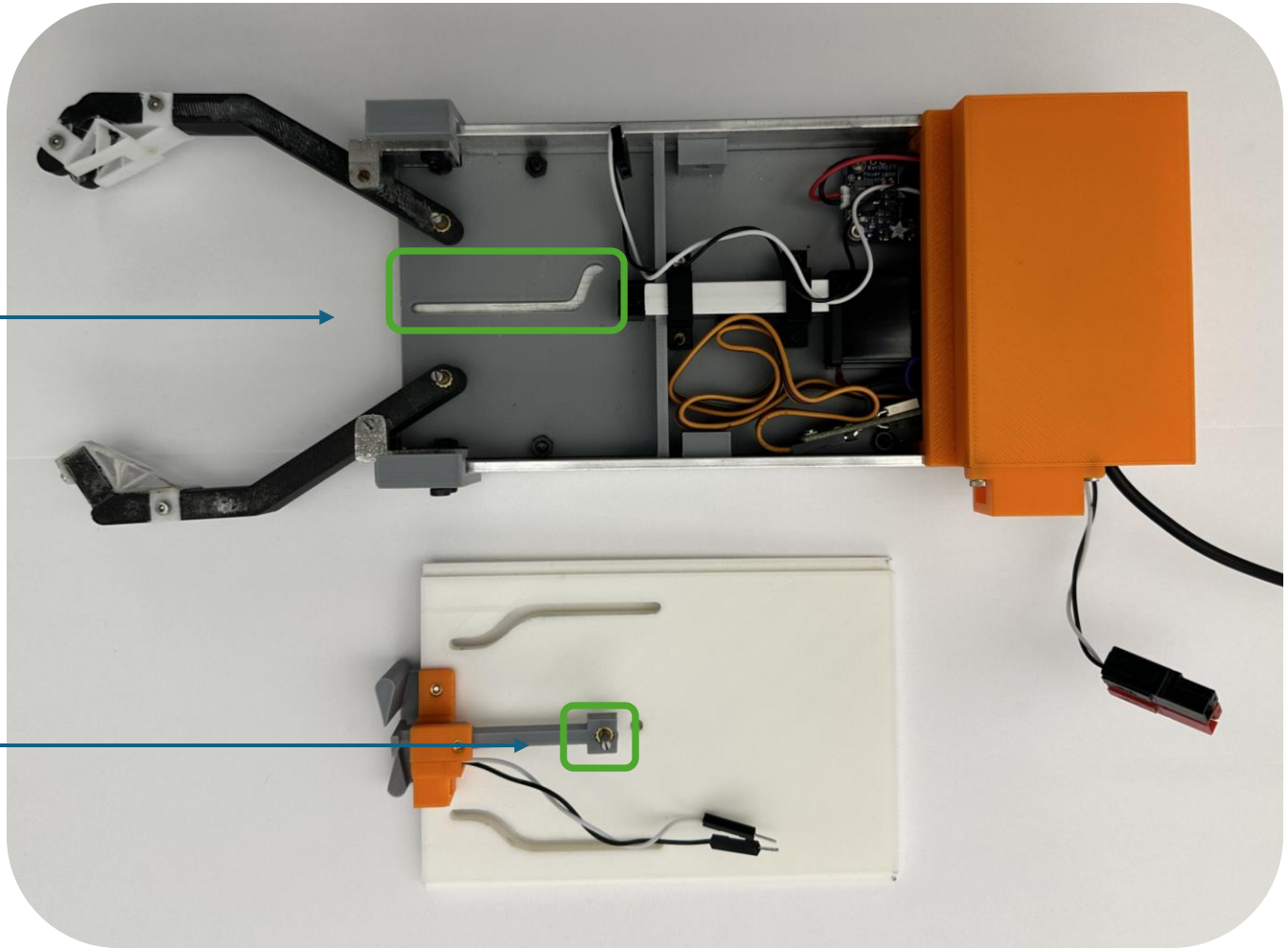


- **Open Finger**
- **Close Finger**

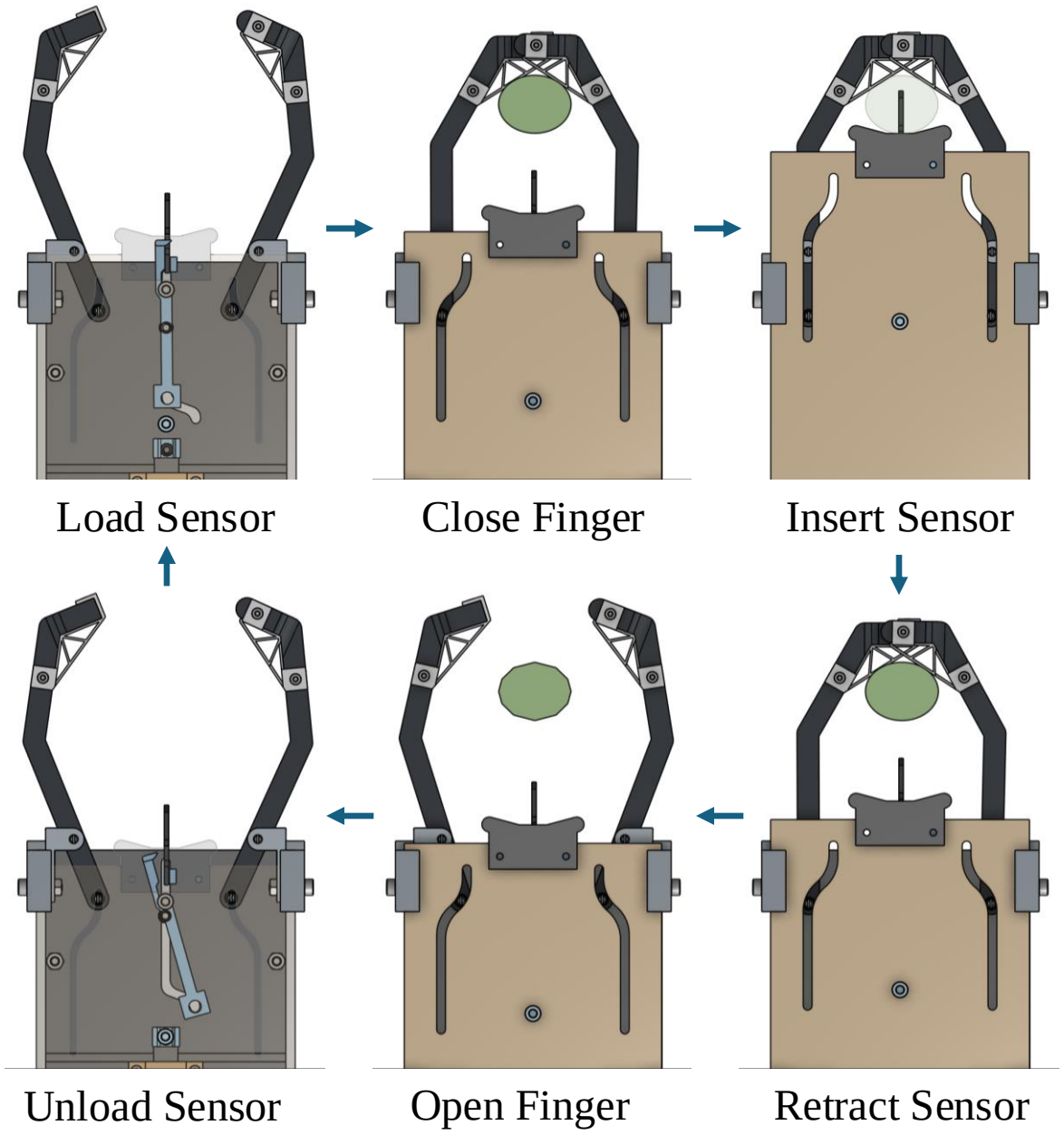
Coupled Sliding Mechanism

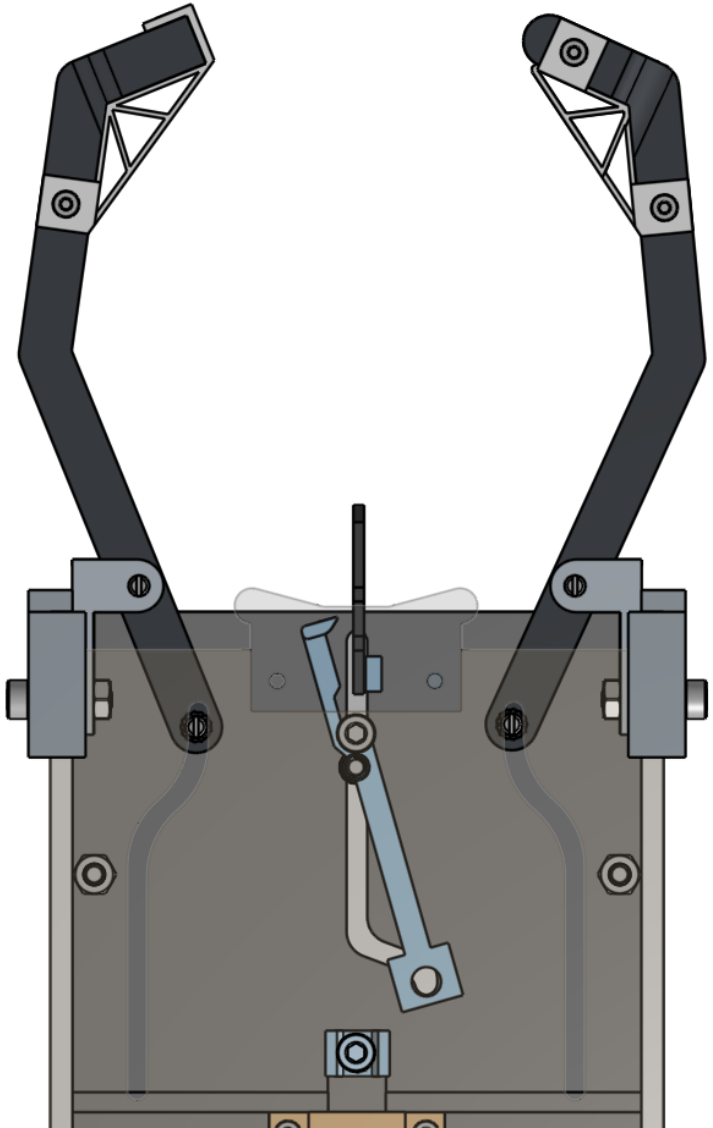
Lever Track

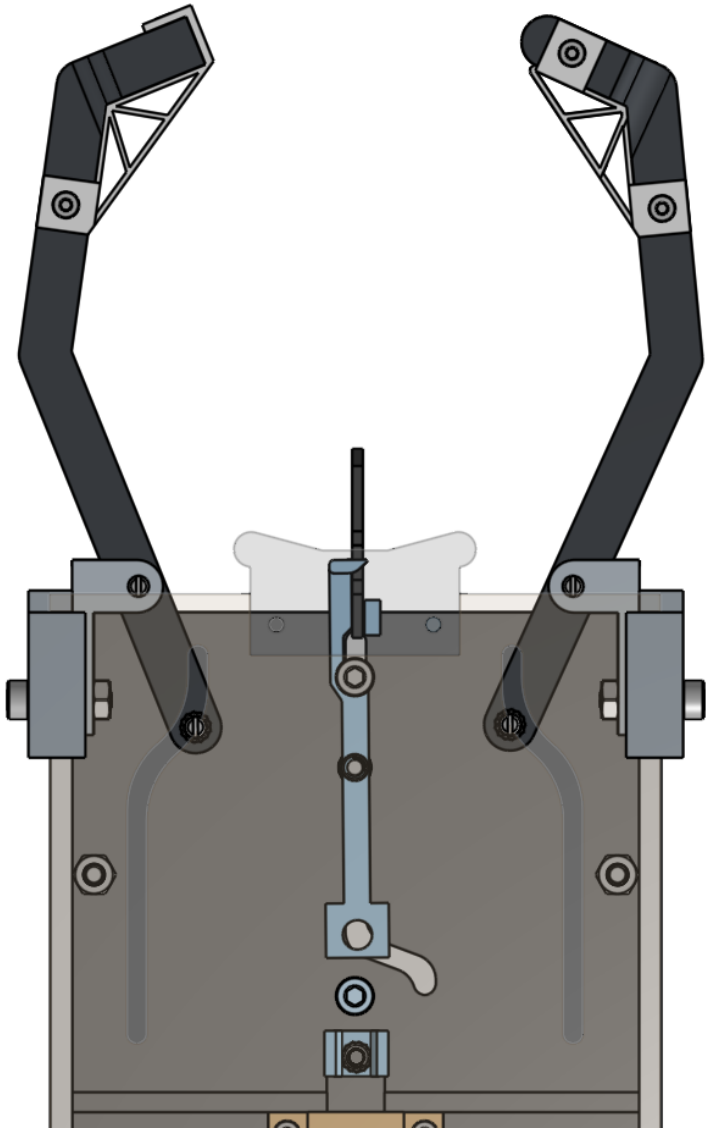
Lever Pin

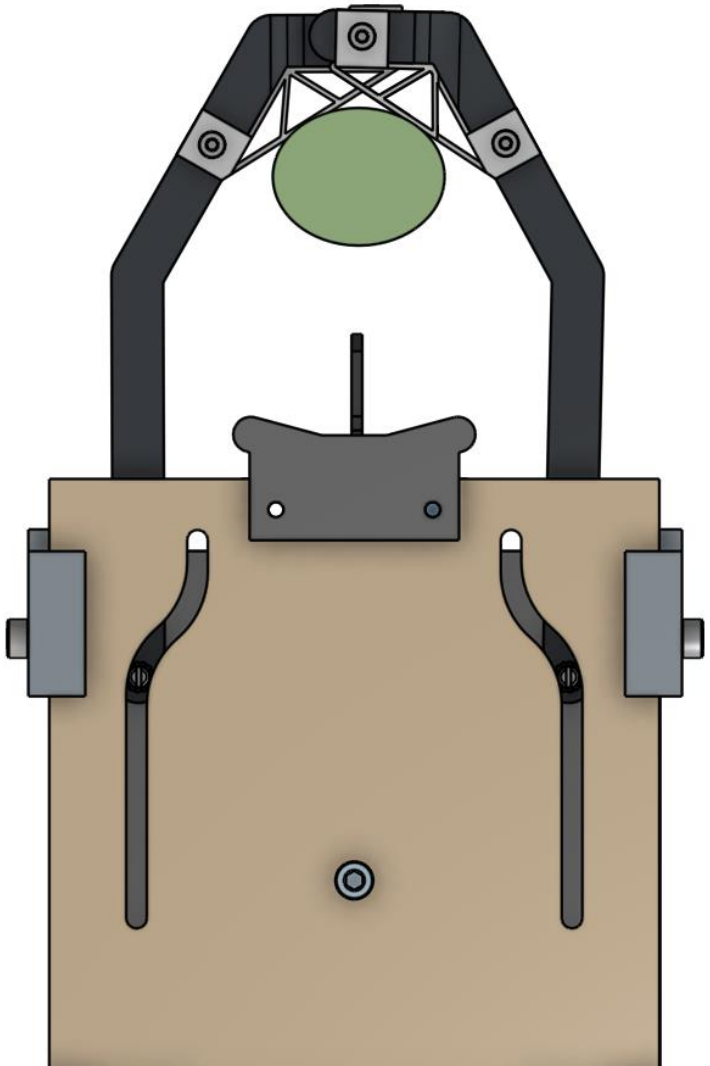


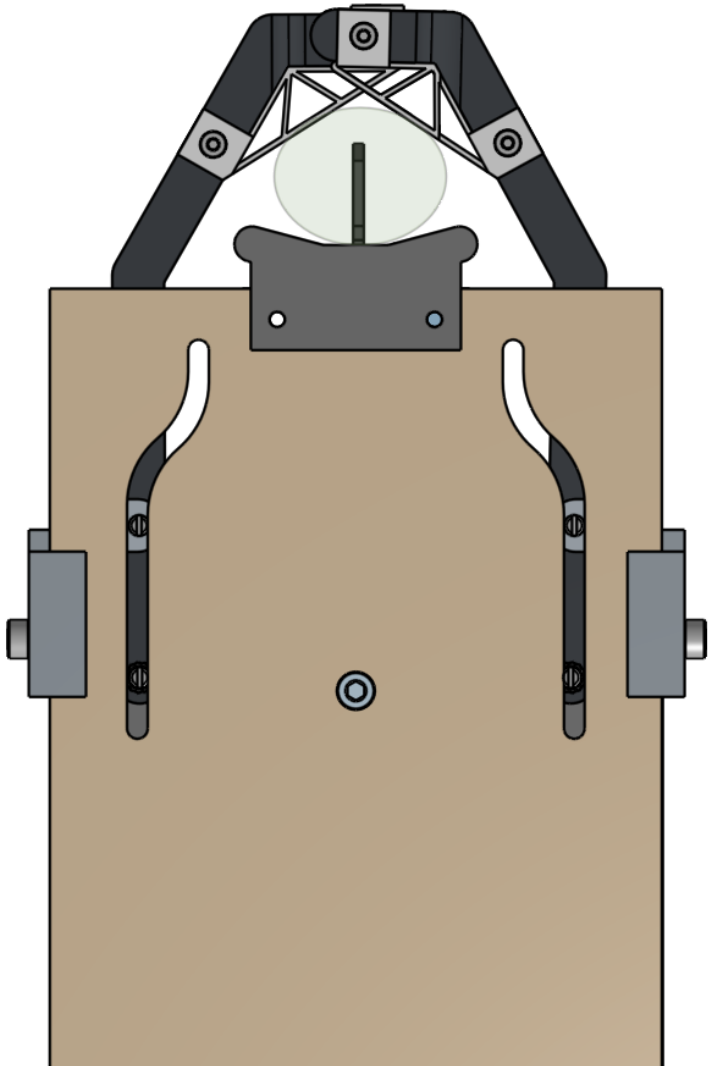
- **Hook Sensor**
- **Unhook Sensor**

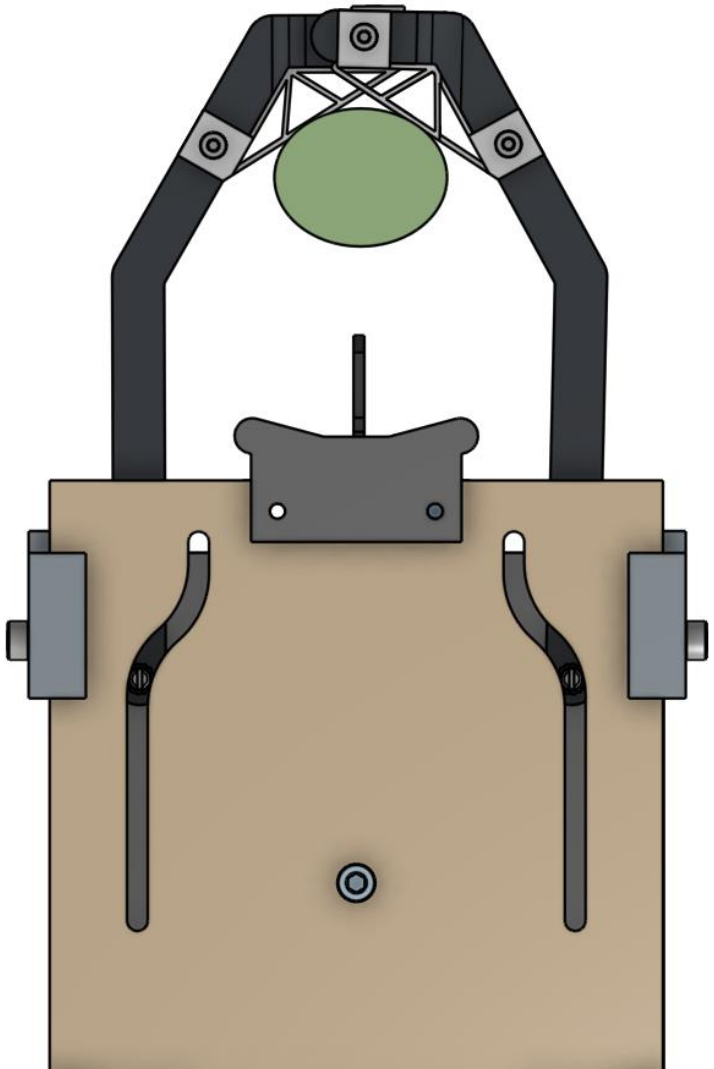

Load Sensor
Close Finger
Insert Sensor
Unload Sensor
Open Finger
Retract Sensor

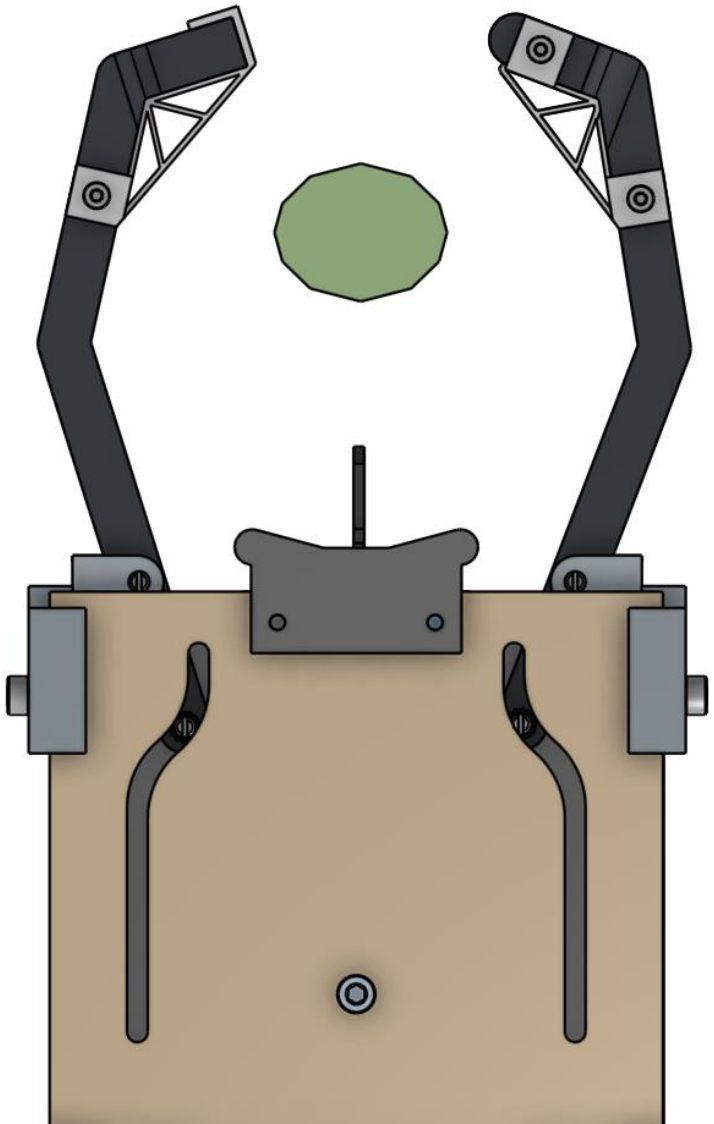


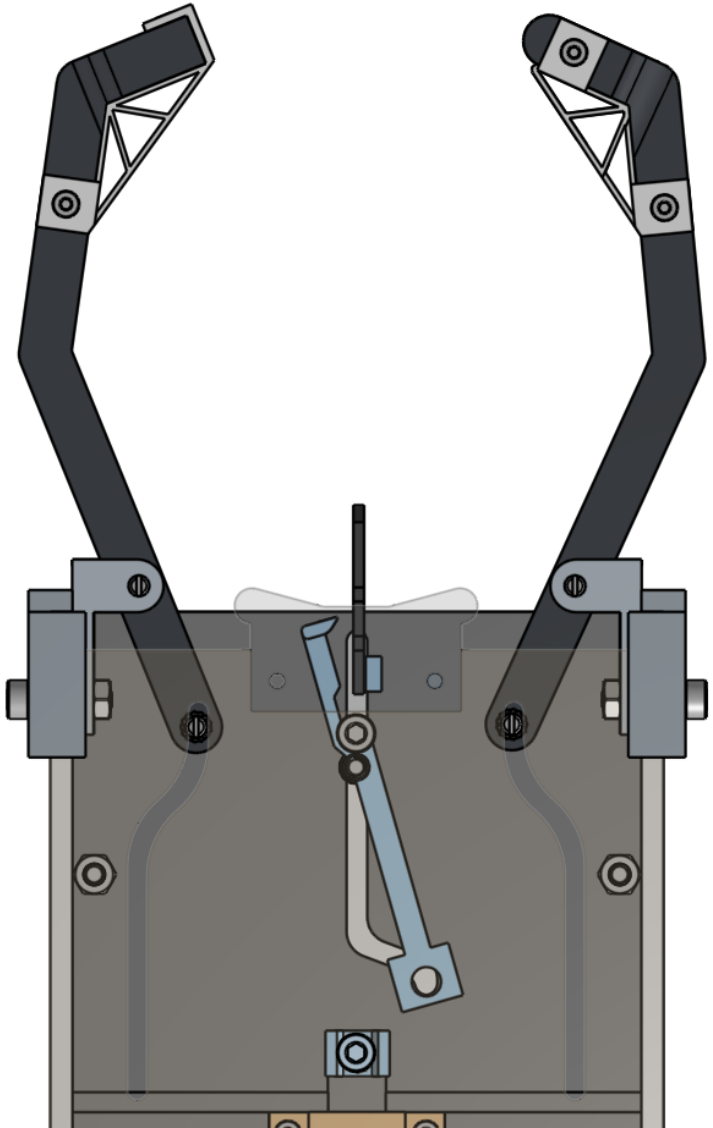












Gripper Motion

Sensor Insertion

Sensor Exchange

Content Overview

Motion Sequence

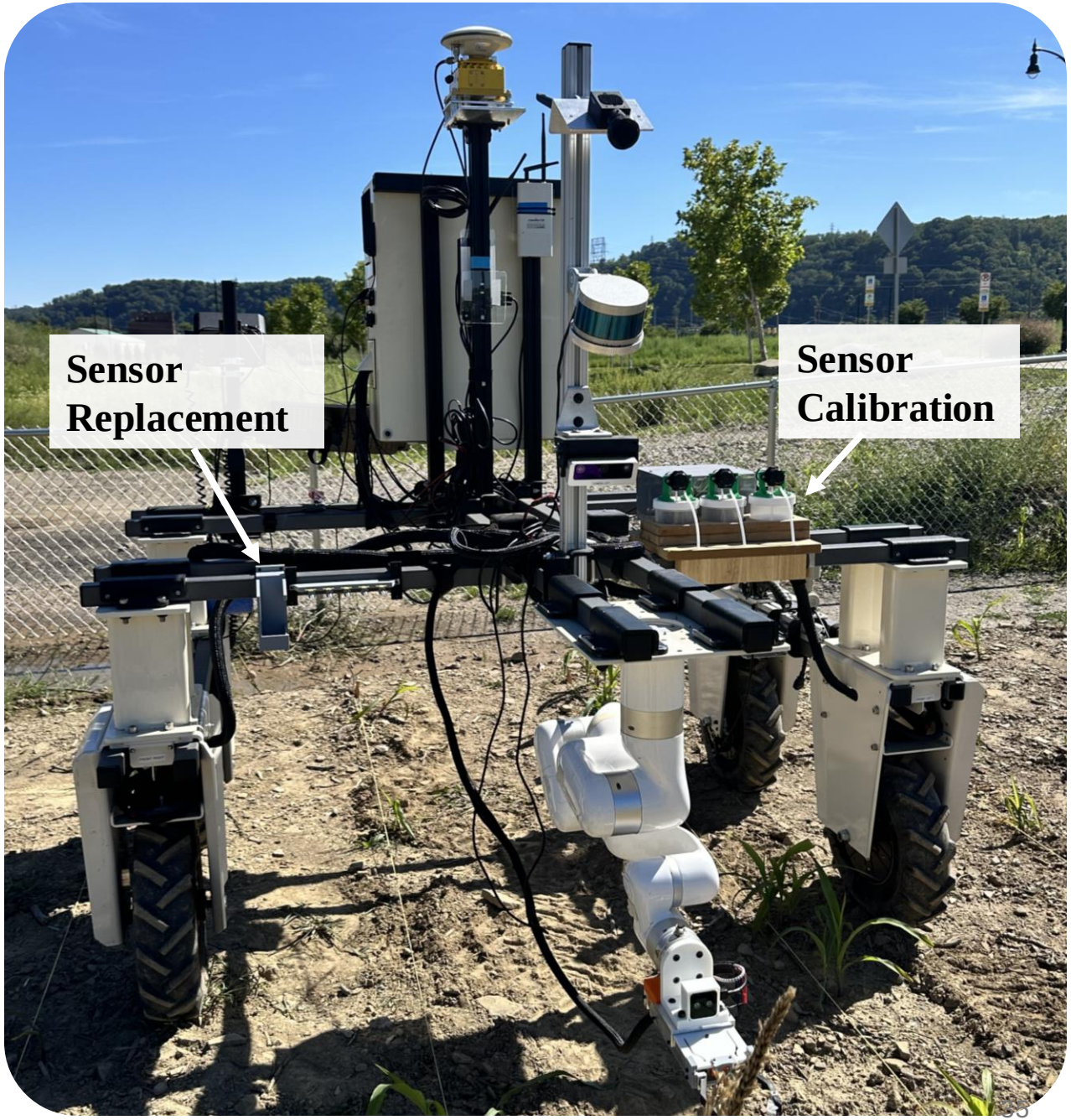
Gripper

Sensor Exchange

Visual Servoing

Subsystem Testing

Field Deployment



Autonomous Sensor Exchange

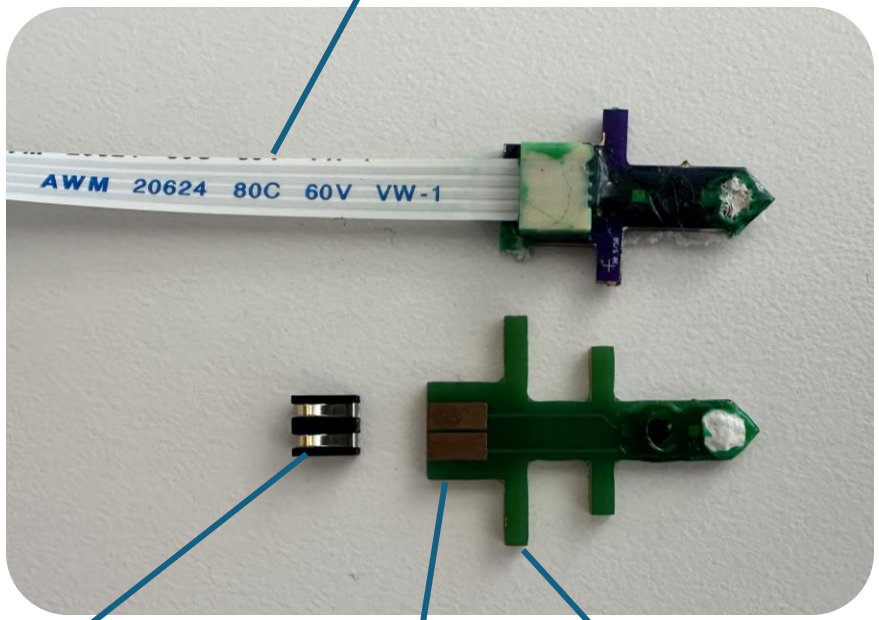
Sensor Replacement

Sensor Calibration

Sensor Modification

Original Sensor

Modified Sensor



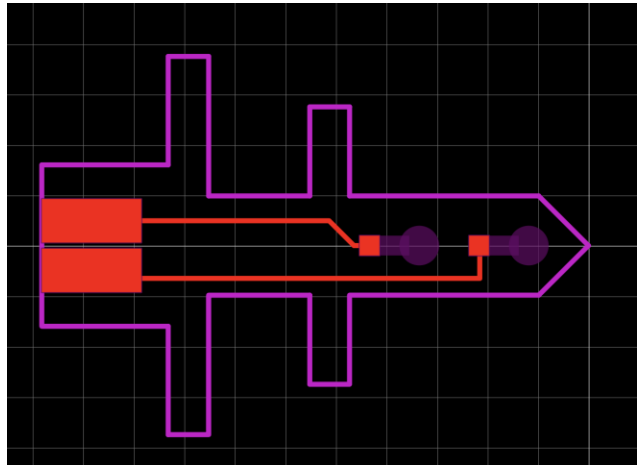
Ribbon Cable

Battery Connector

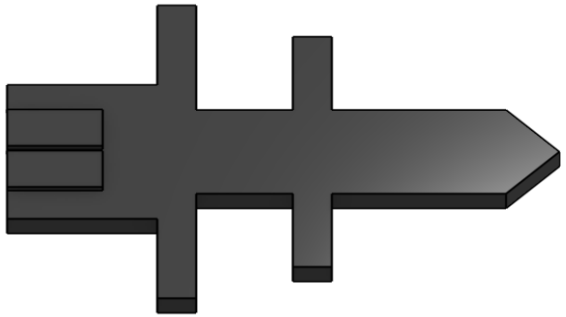
Gold Finger

Additional Wing

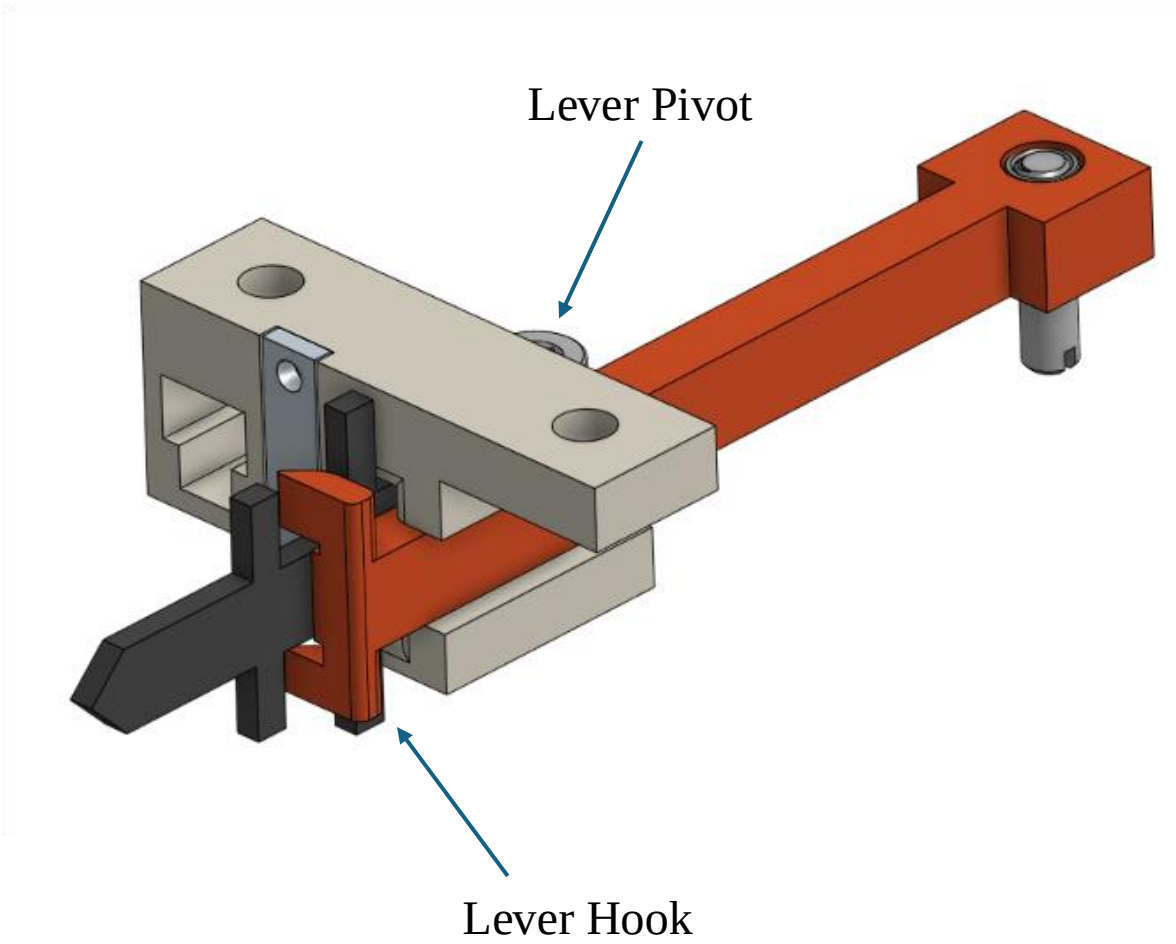
PCB Modification

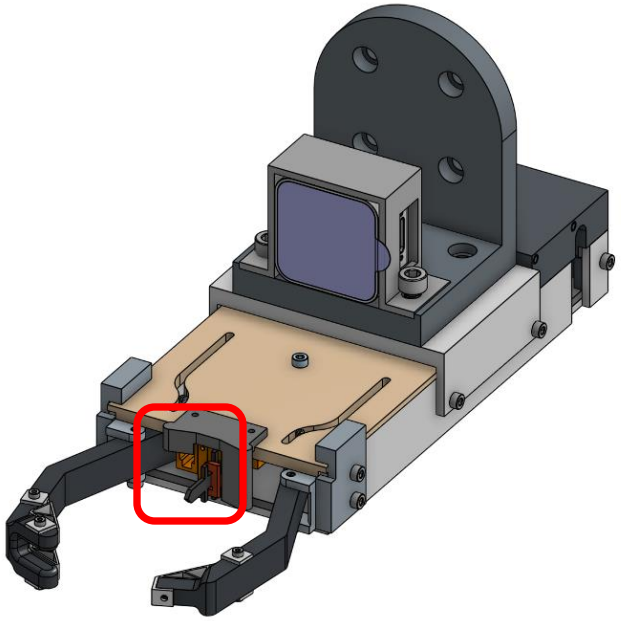


CAD Modification

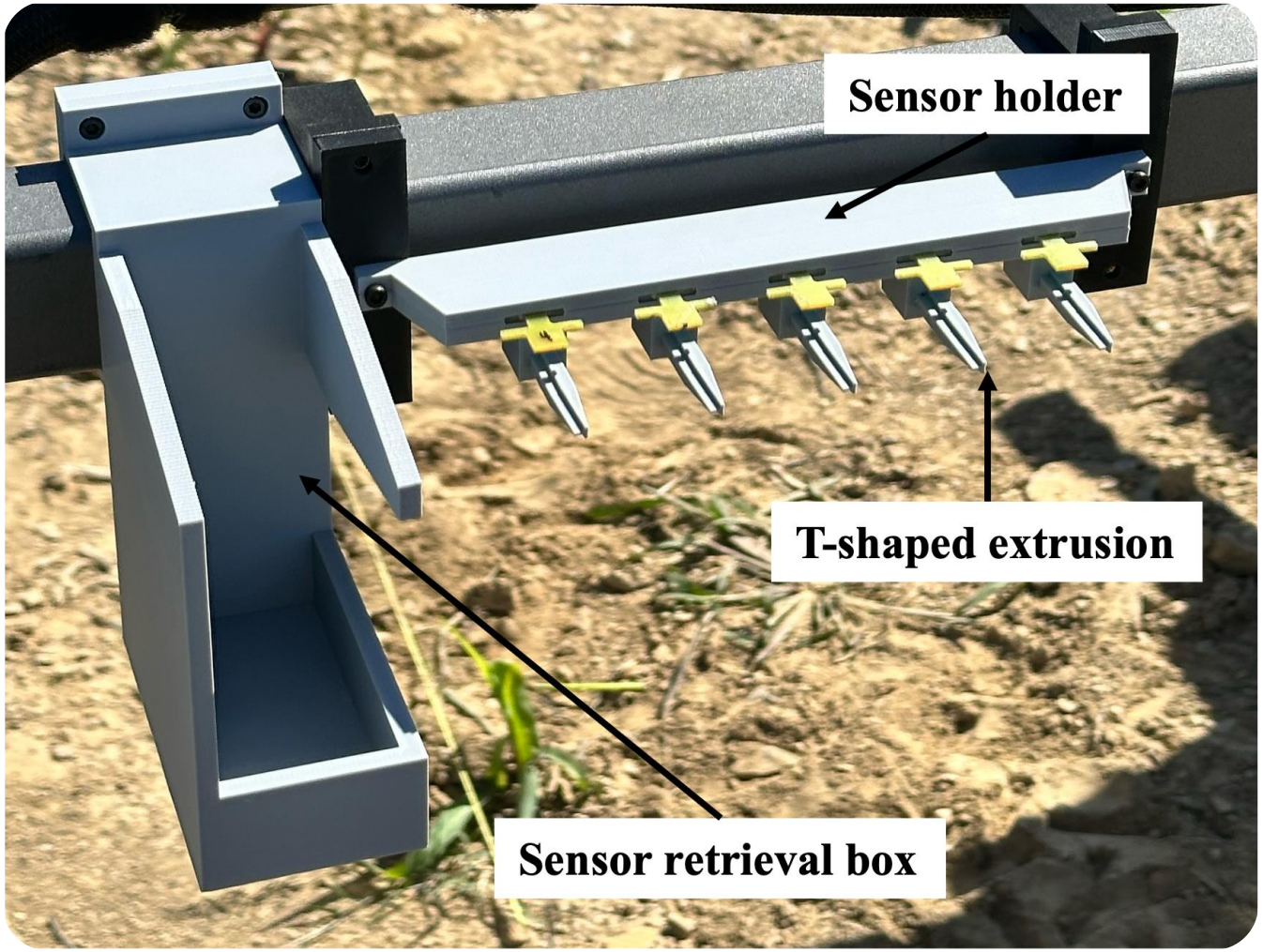


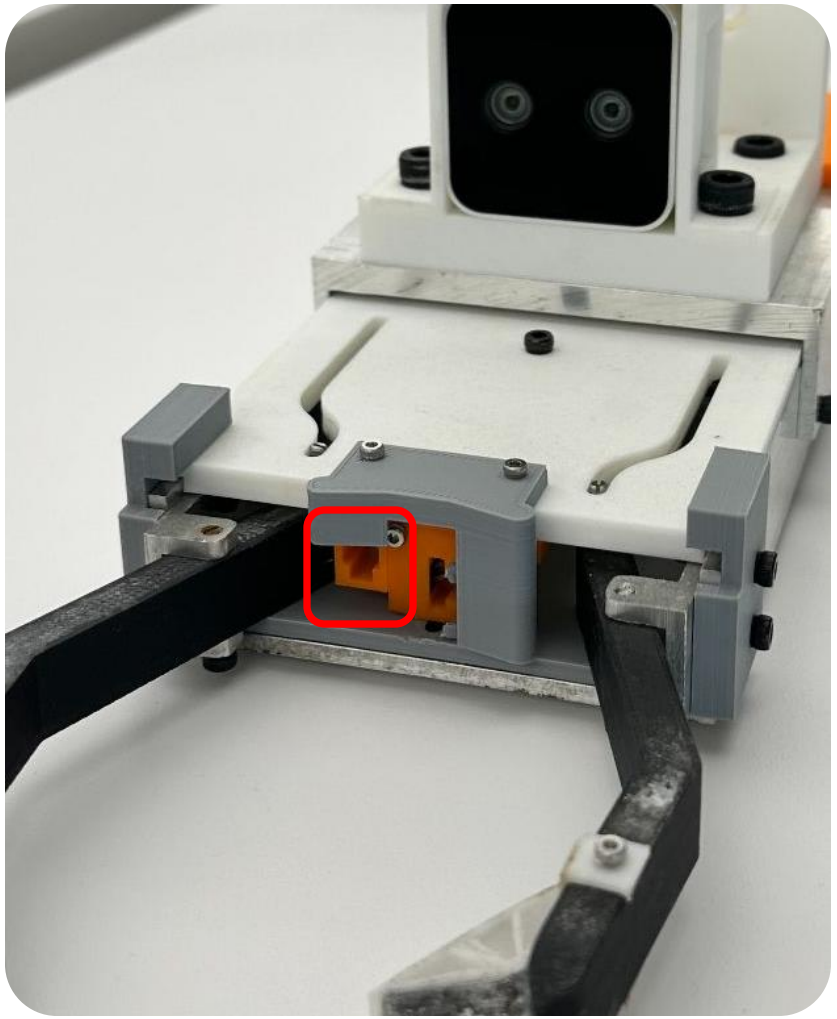
Lever in Gripper

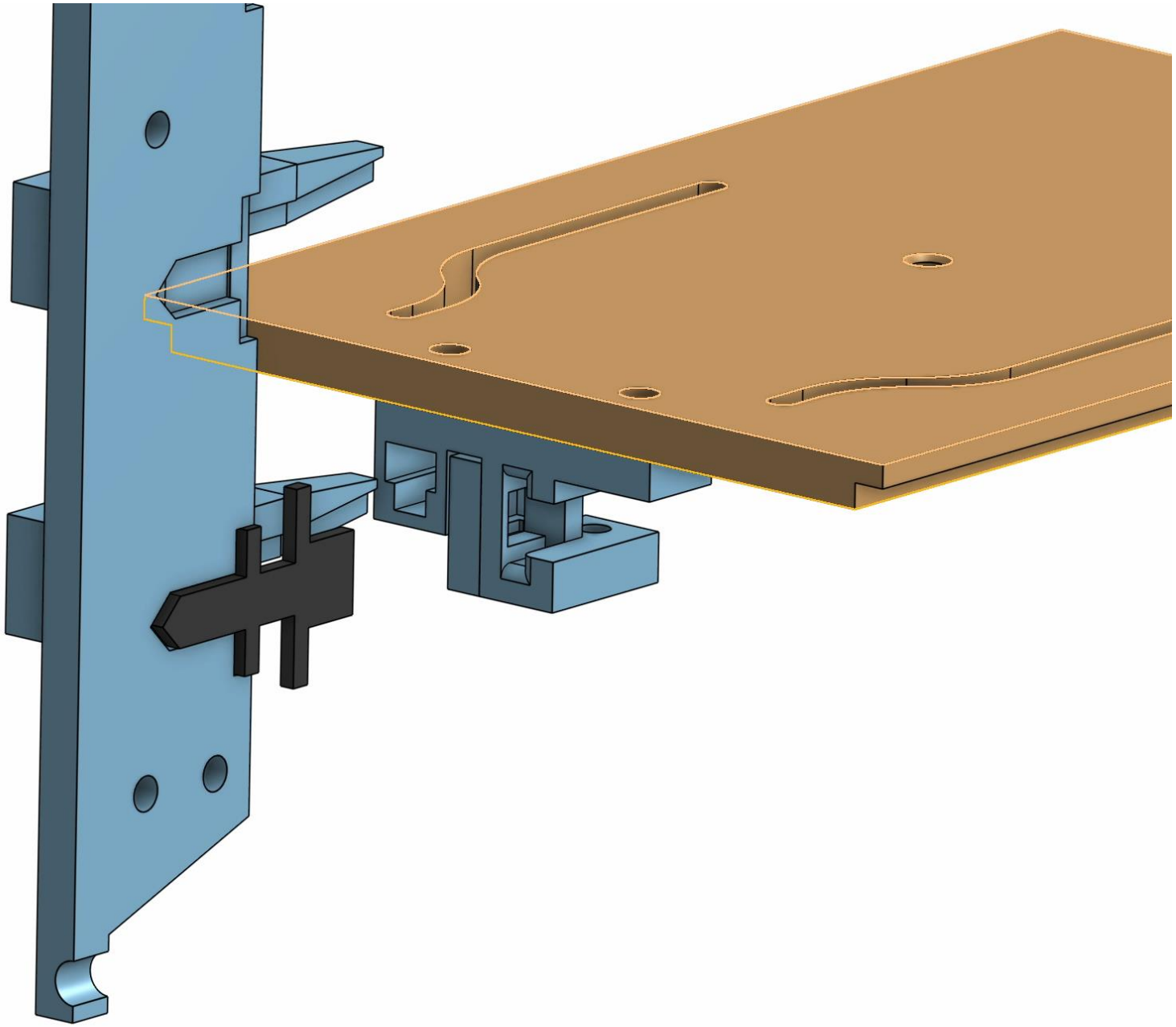




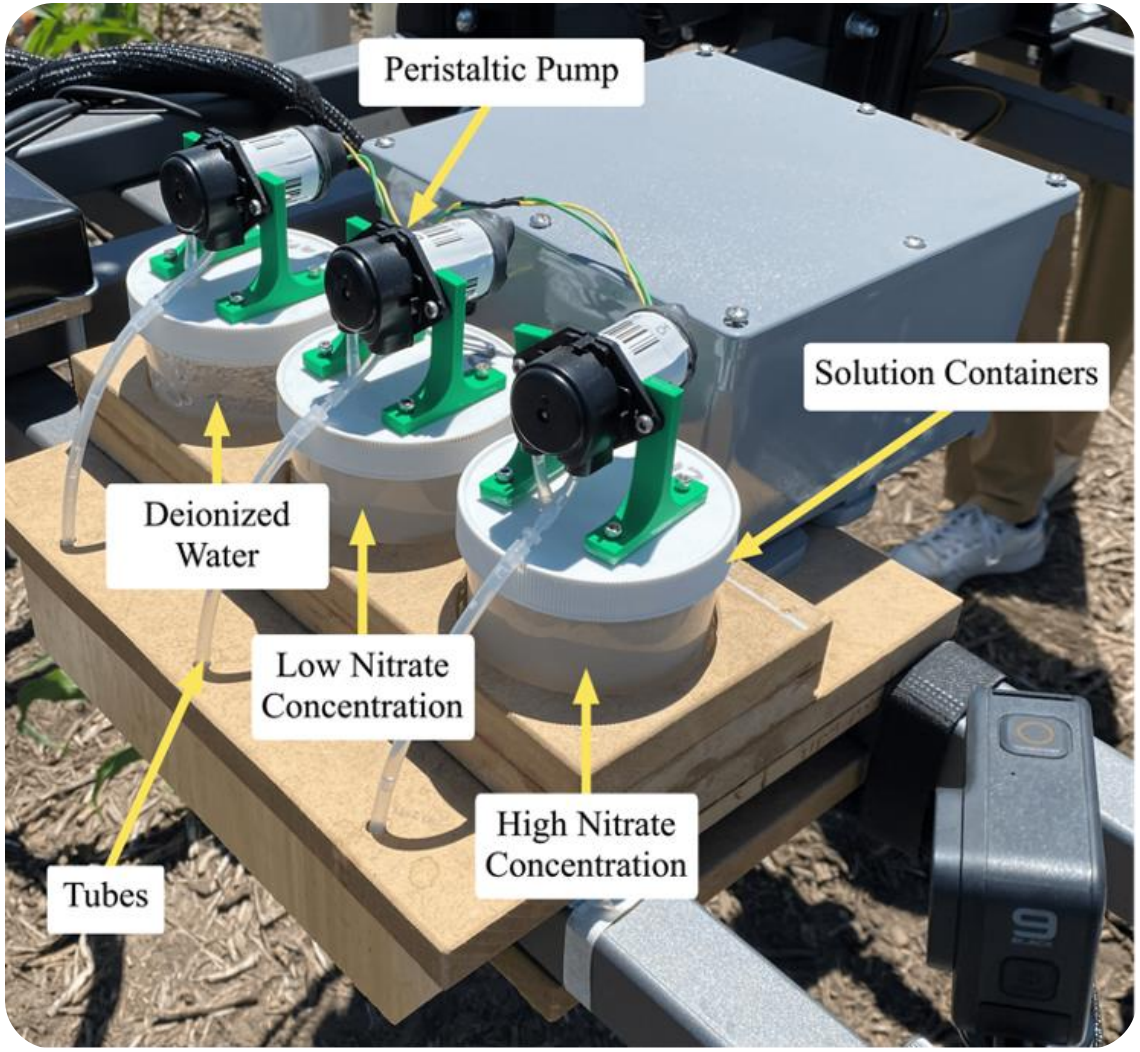
Funneling Mechanism for Alignment



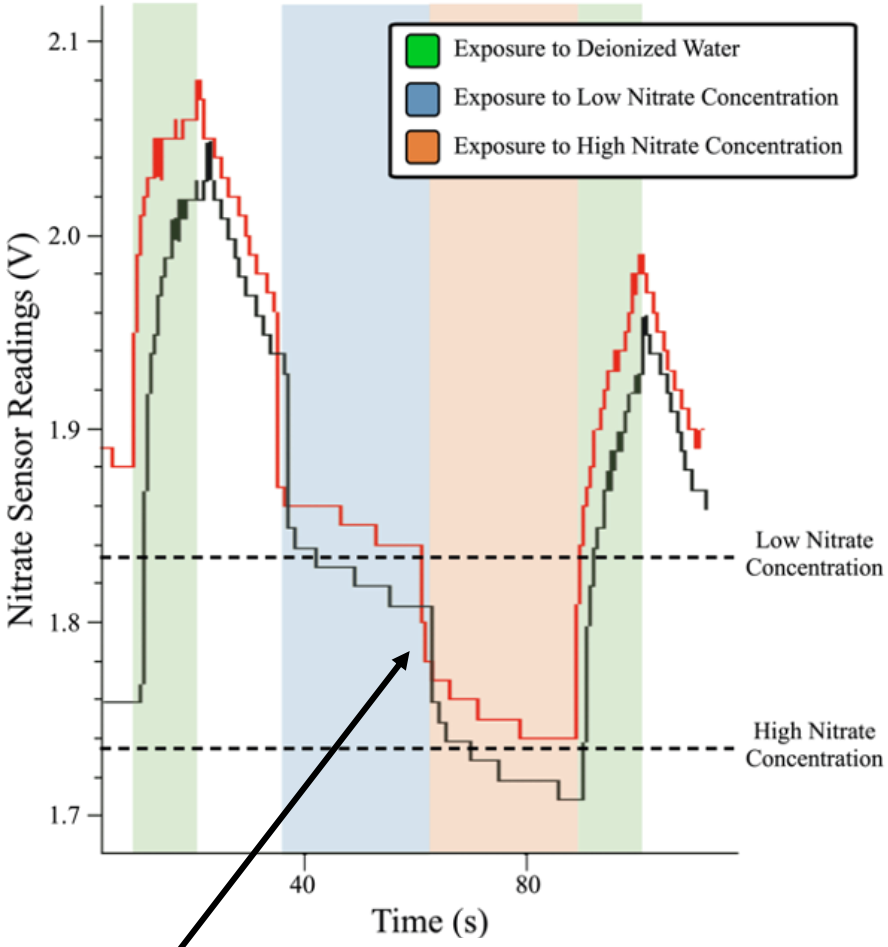




Sensor Calibration



Two-point Calibration



Linear Relationship

Content Overview

Motion Sequence

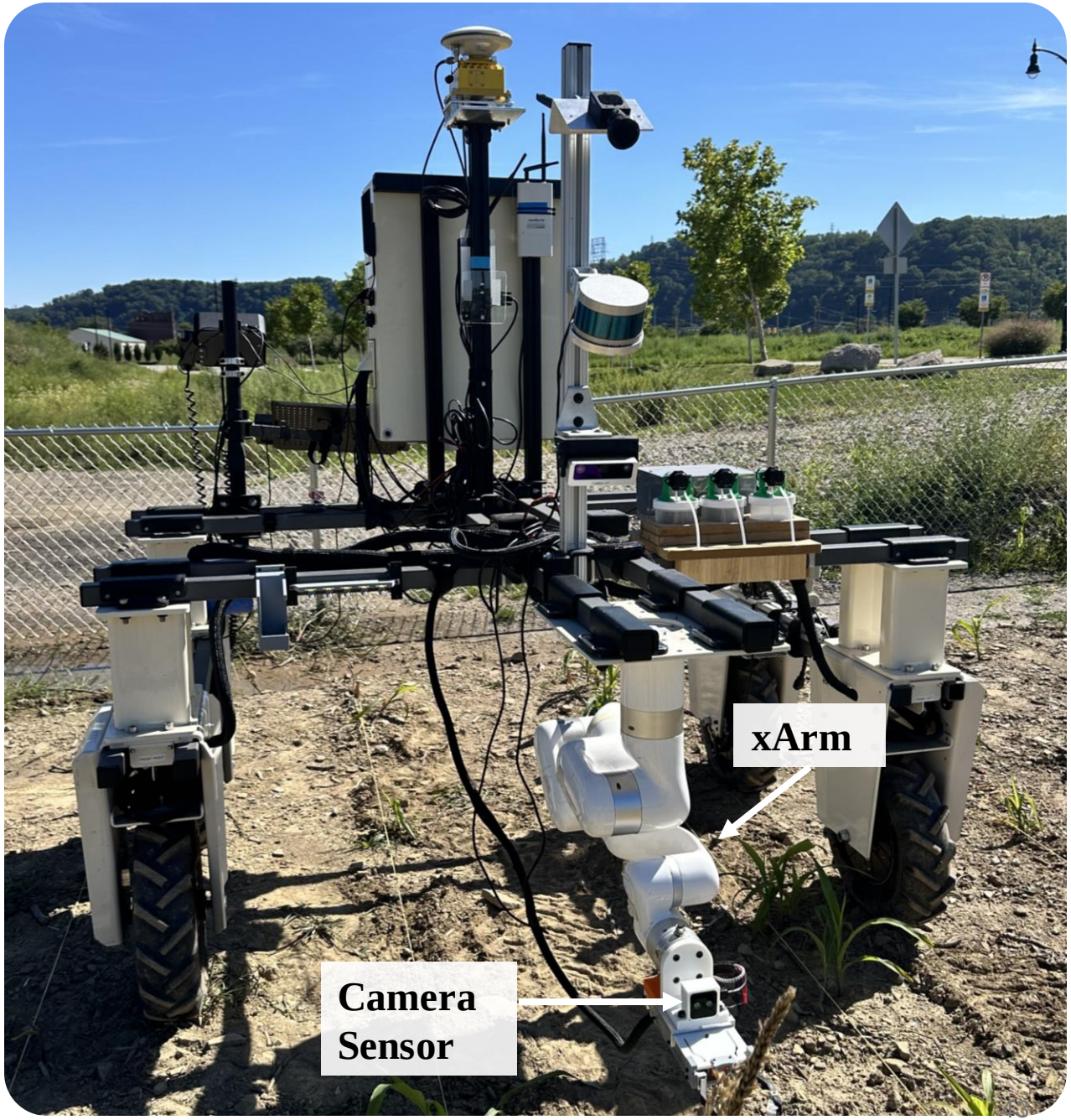
Gripper

Sensor Exchange

Visual Servoing

Subsystem Testing

Field Deployment

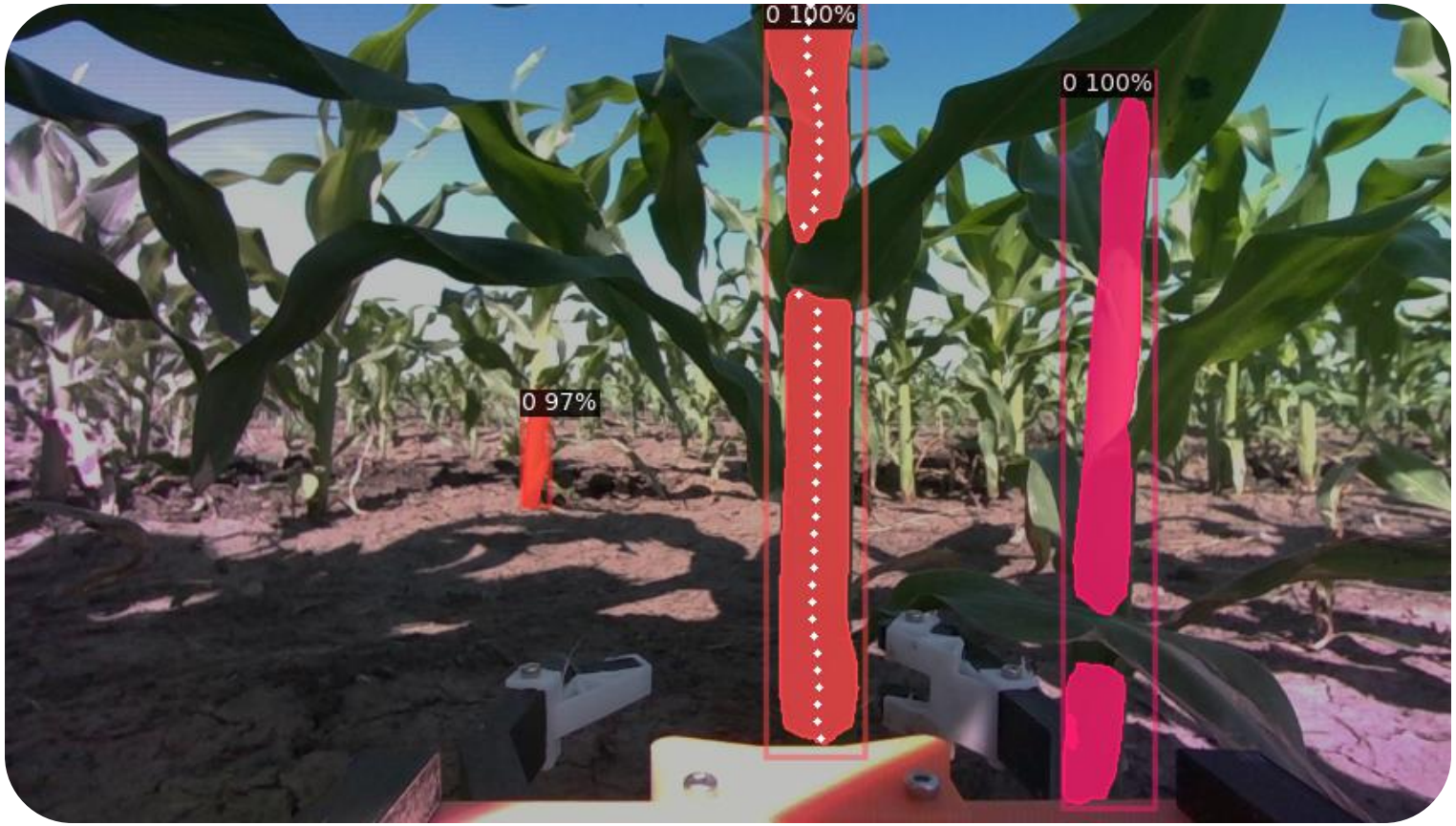


Visual Servoing Motivation

Wind

Abrupt Base Movements

Visual Detection



RGB - frames

↓

2D Segmentation
Mask R-CNN

↓

3D Stalk Fitting

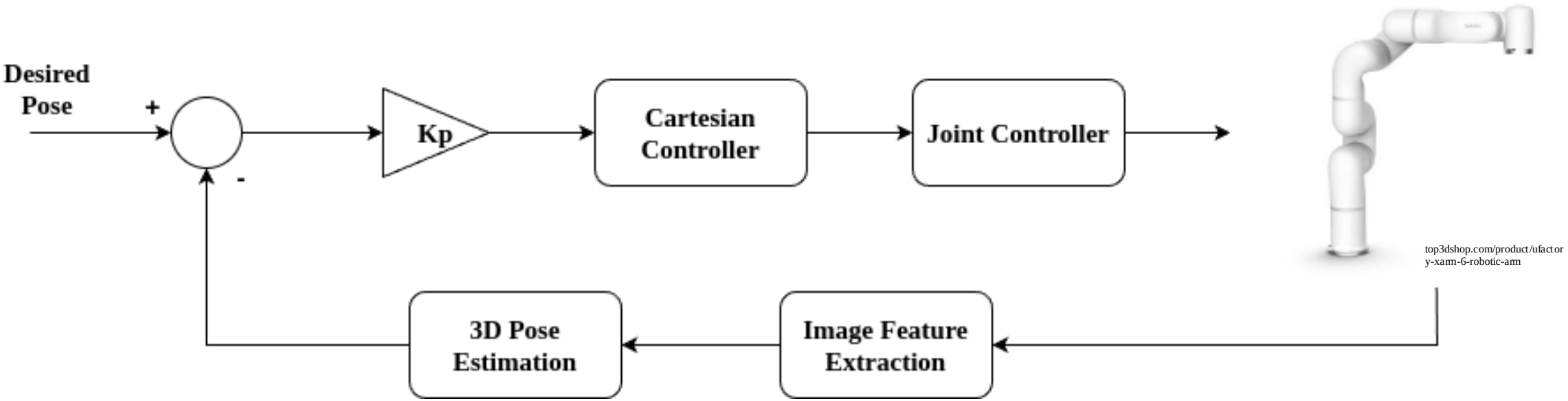
↓

Best Stalk Scoring

↓

3D Insert Point

Position-based Visual Servoing



Sweep Motion and Width Detection

Content Overview

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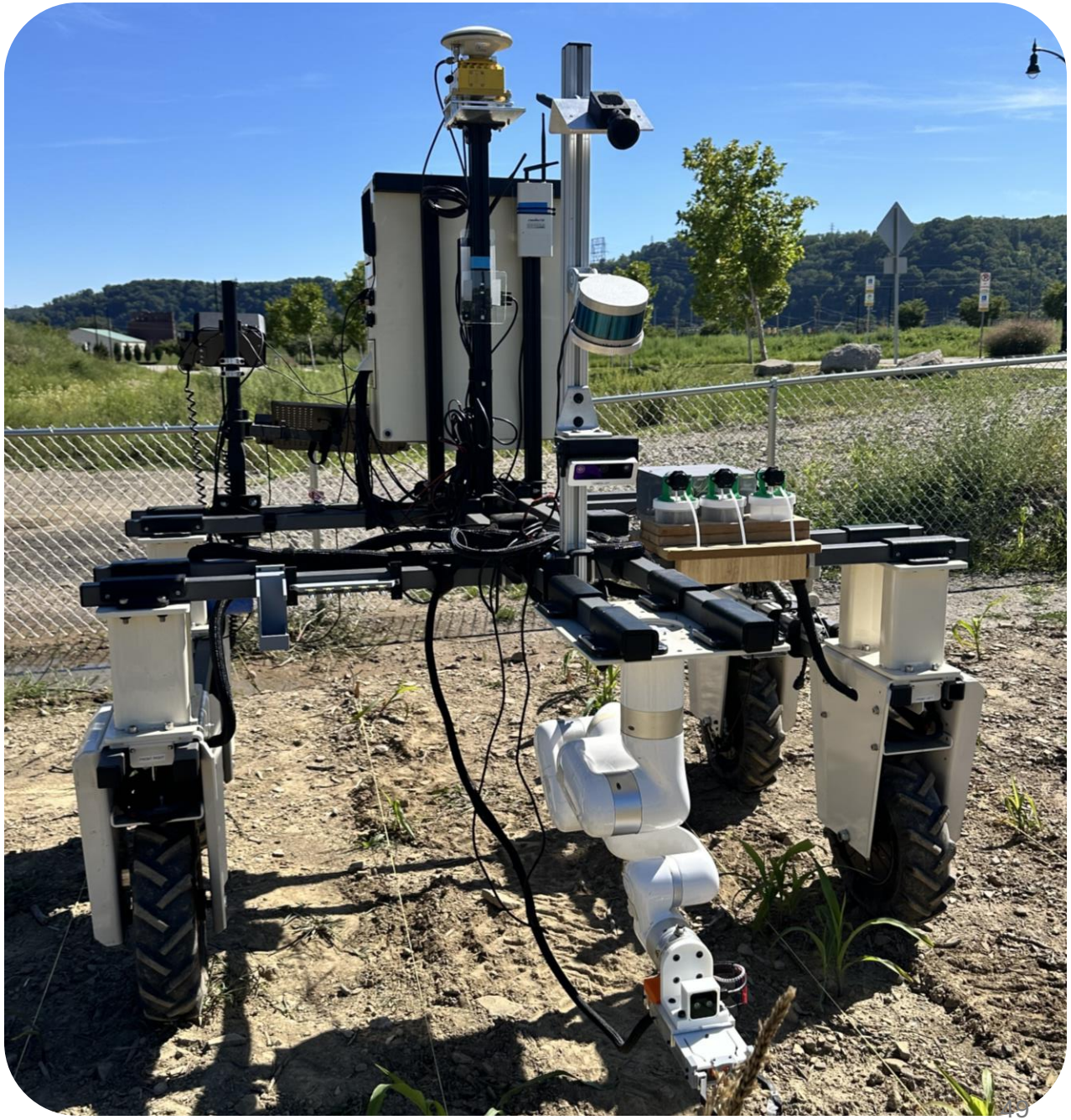


Gripper Insertion Testing

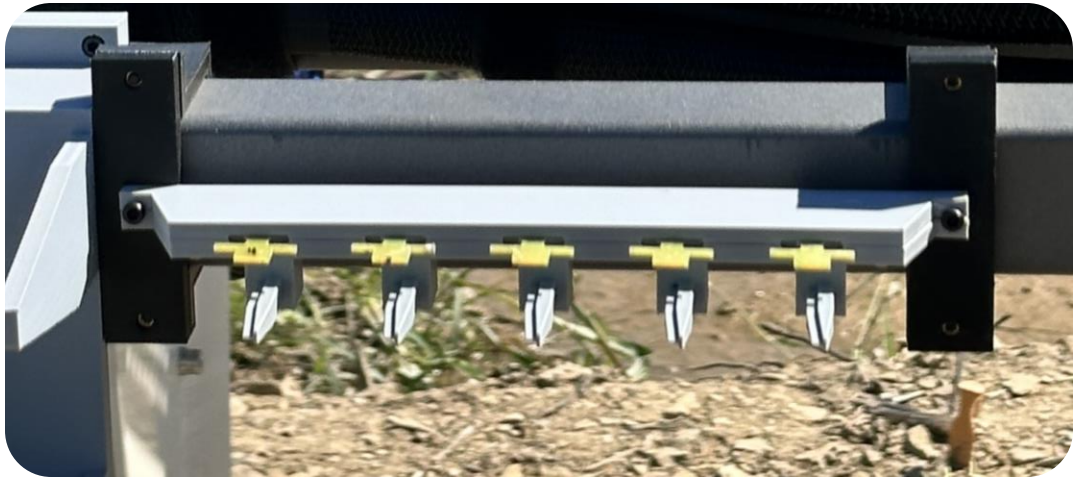
Greenhouse Cornstalks

Artificial Cornstalks

Leek

Navigation Integration Testing

Sensor Replacement Testing



- Tested 50 iteration of sensor replacement

	Unload	**Load**
With Funneling	100 %	100 %
Without Funneling	24 %	24 %

Sensor Calibration Testing

- 40 test runs across 25 sensors
- 61.4% success

Content Overview

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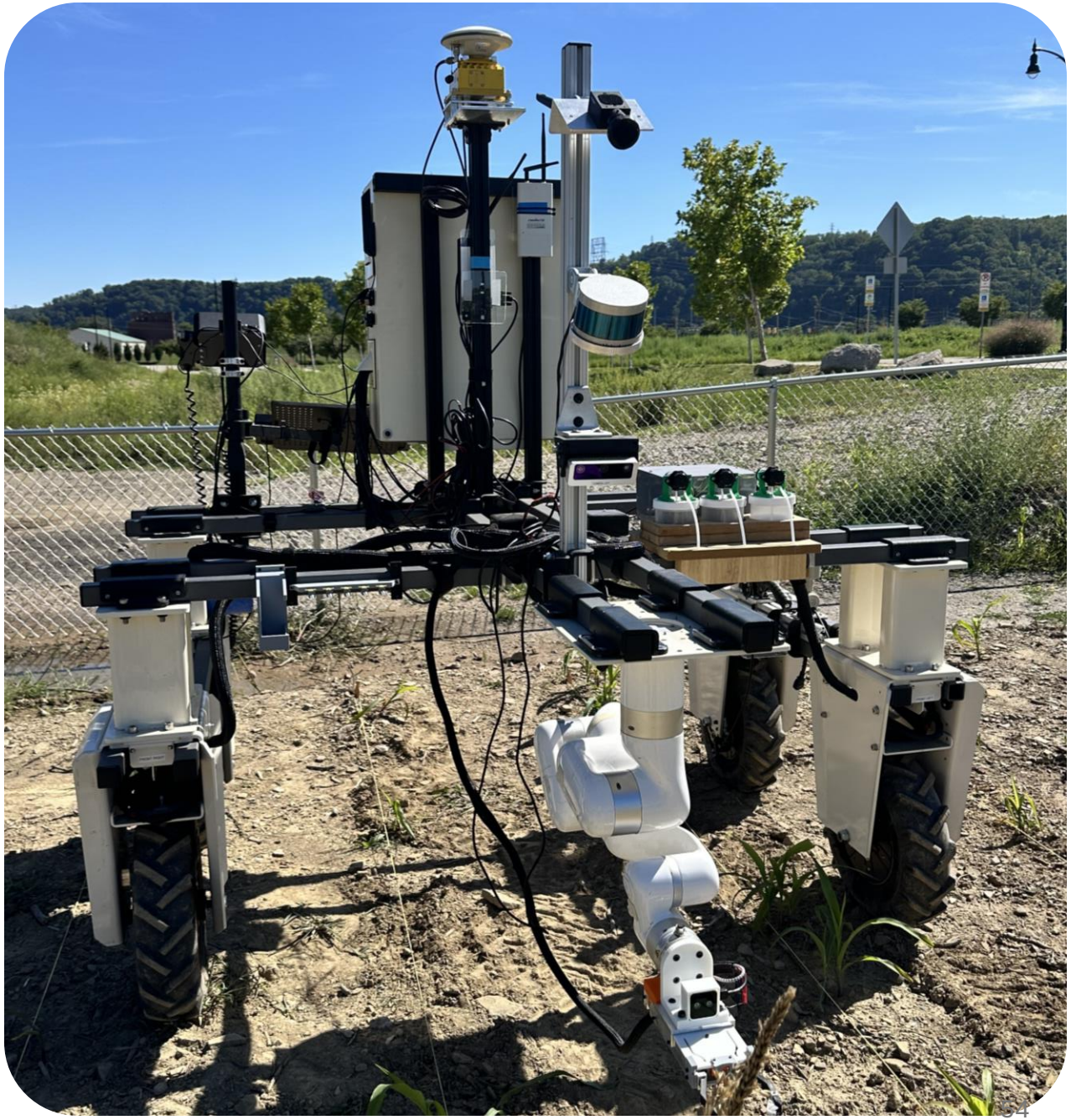


Pittsburgh Rivendale Farm

Iowa Ames Curtis Farm

Pittsburgh Hazelwood Field

Rivendale Farm Testing

- Initial full system autonomy testing

Iowa Ames Curtis Farm

- Evaluated overall insertion process

Evaluation: Overall Insertion

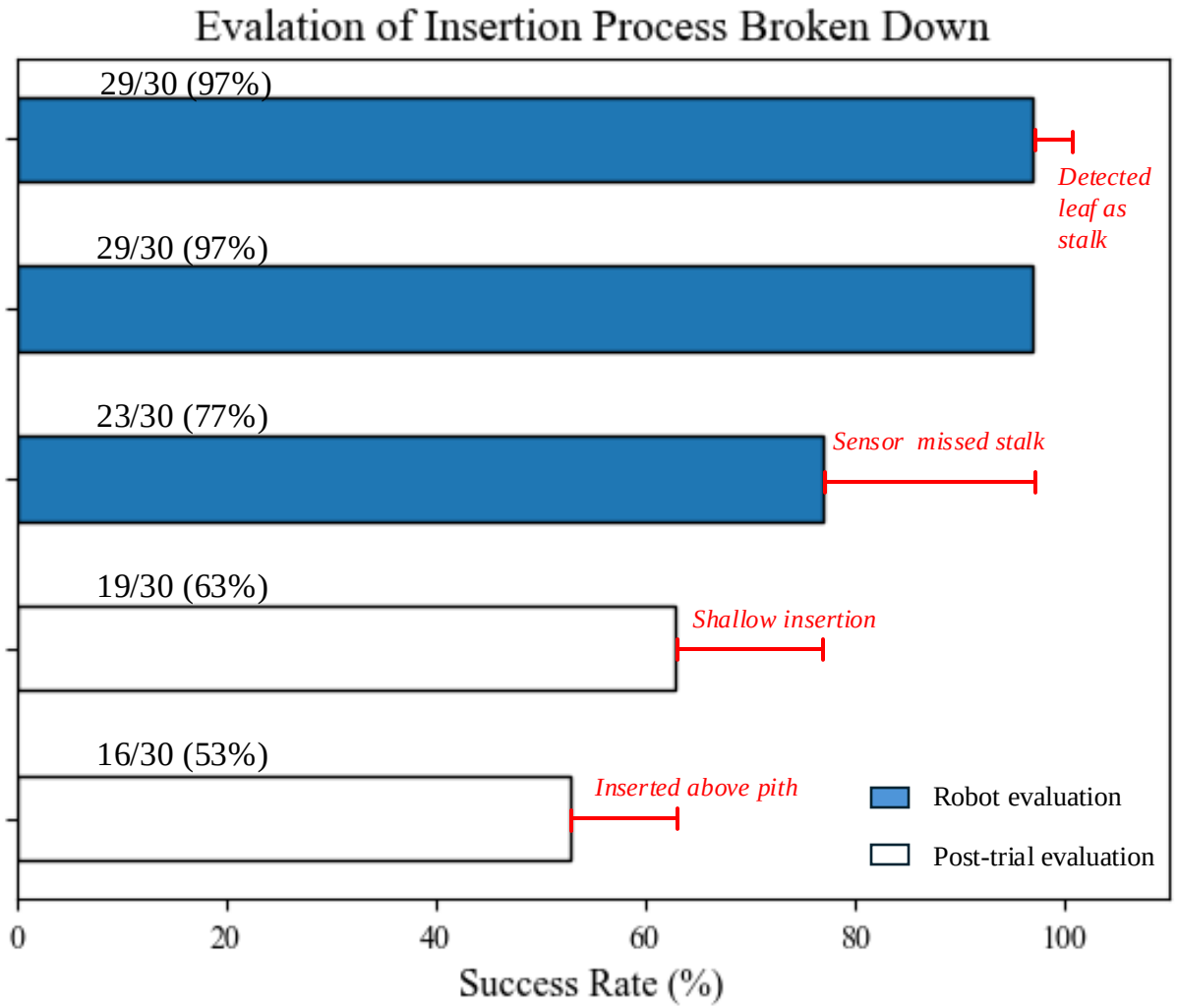
1. Stalk detected

2. Stalk grasped

3. Sensor inserted

4. Inserted deep

5. Inserted in pith



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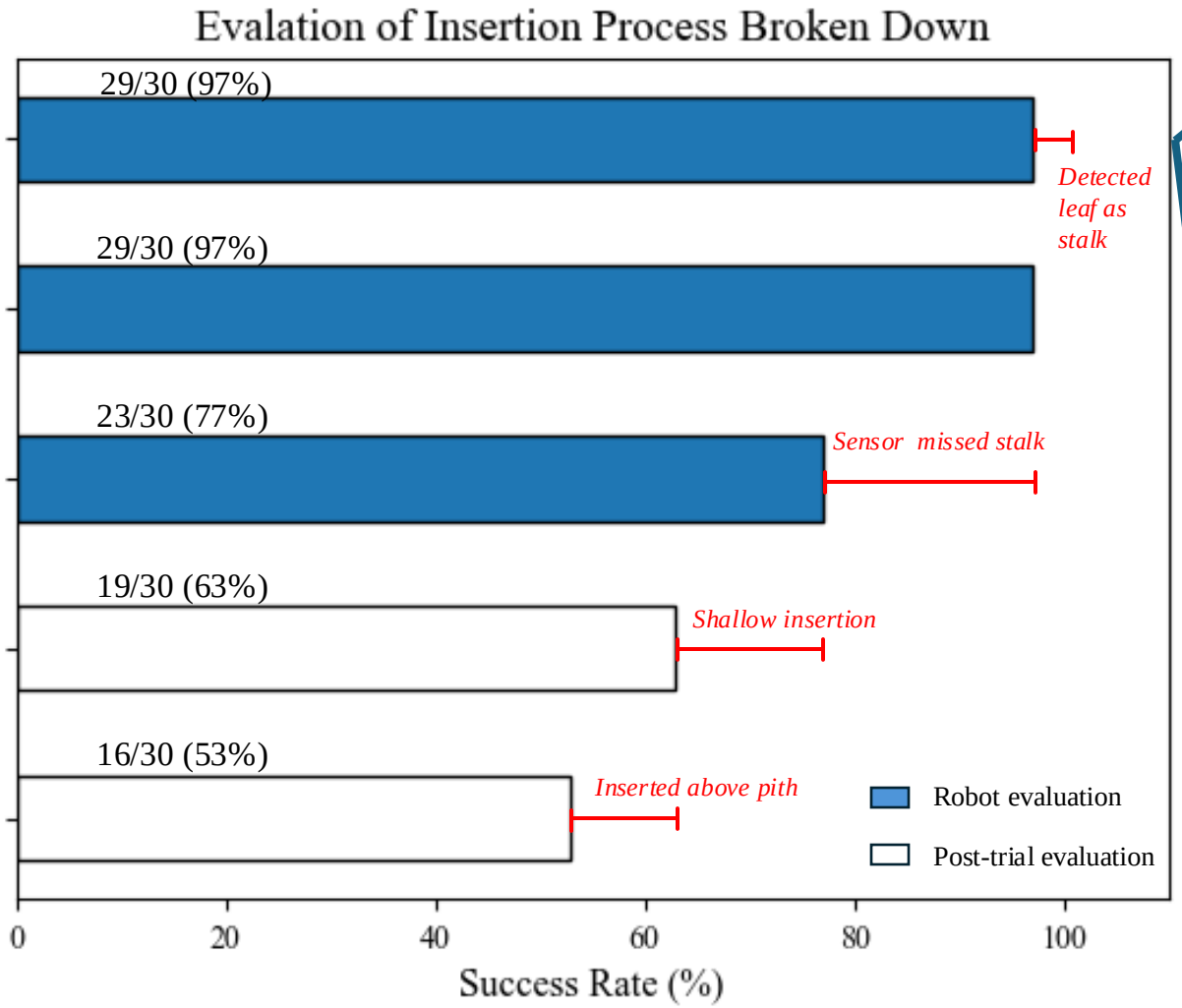

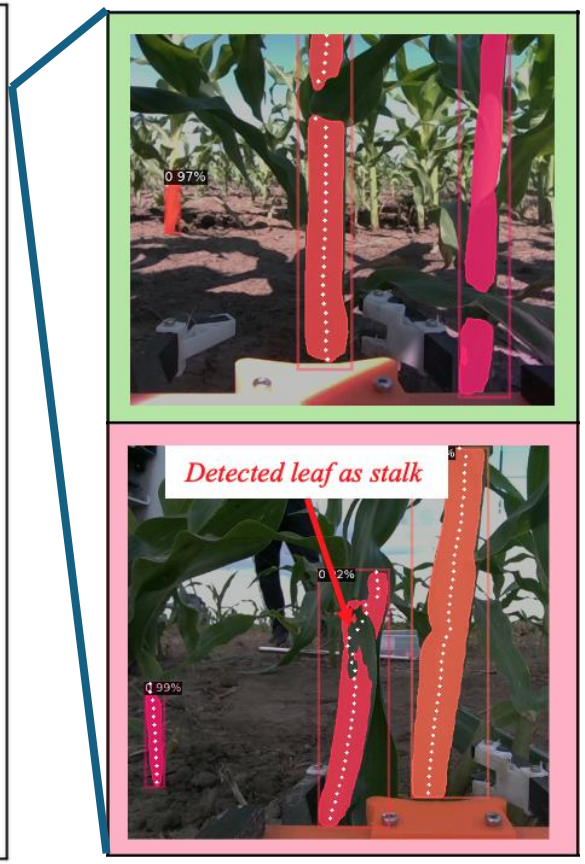

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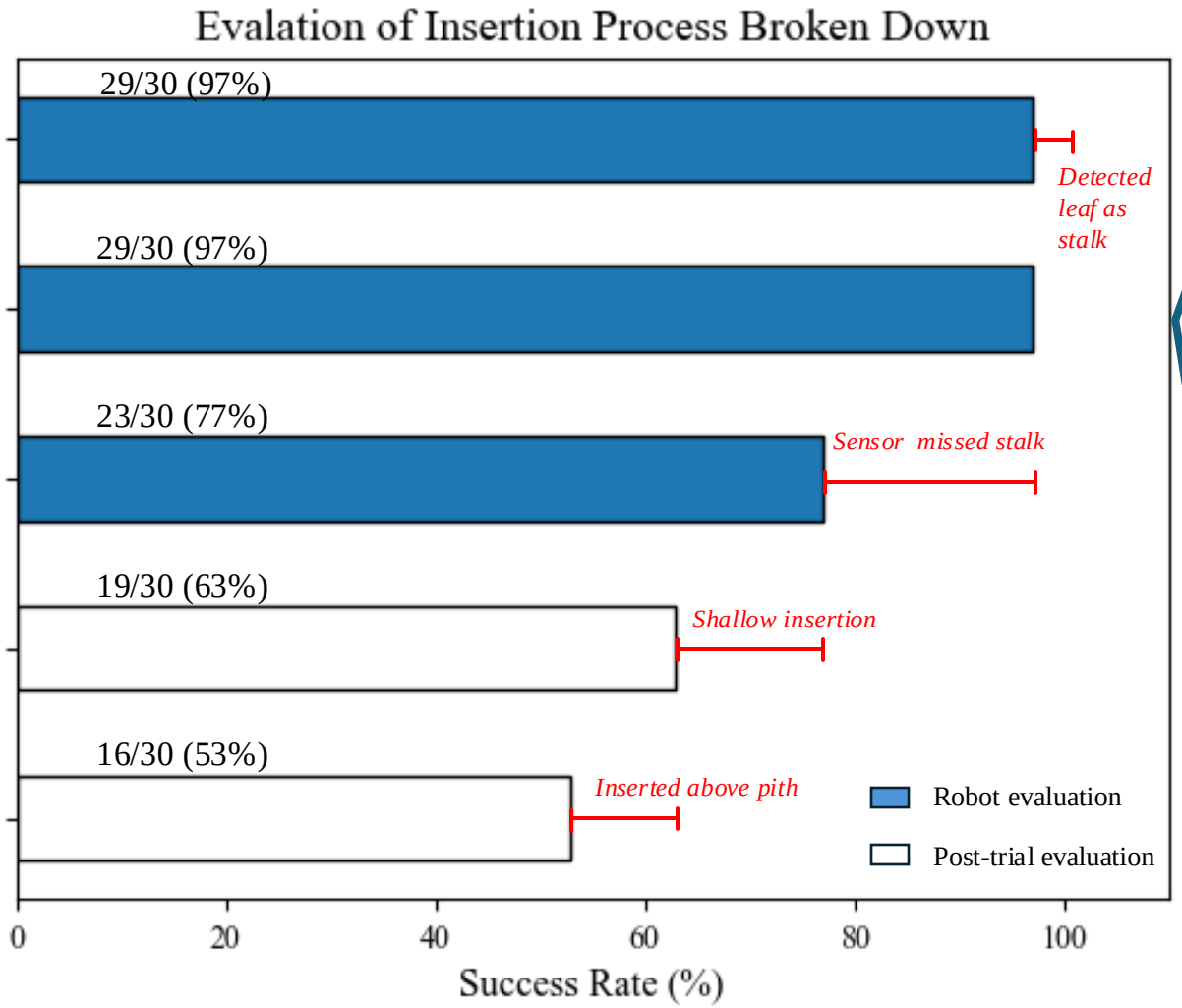
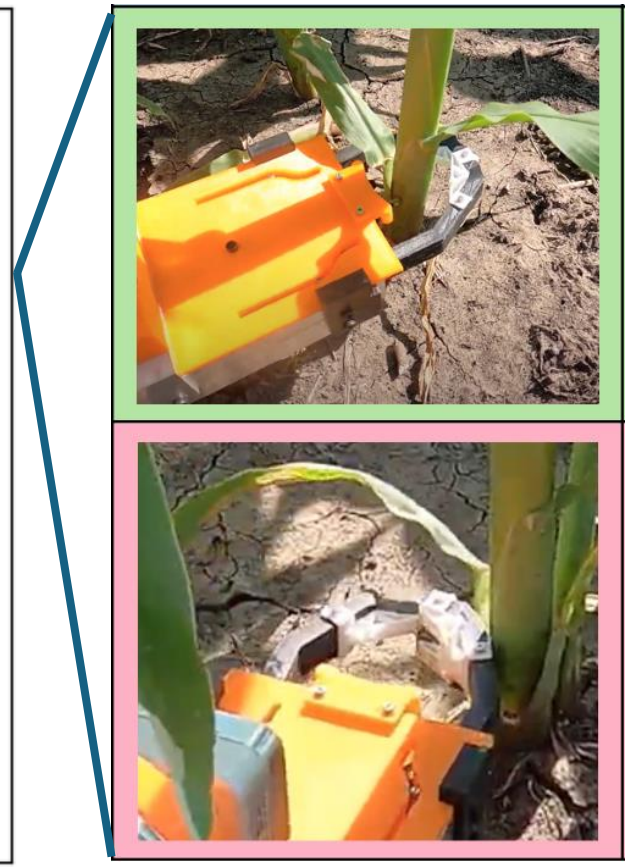




Evaluation: Overall Insertion

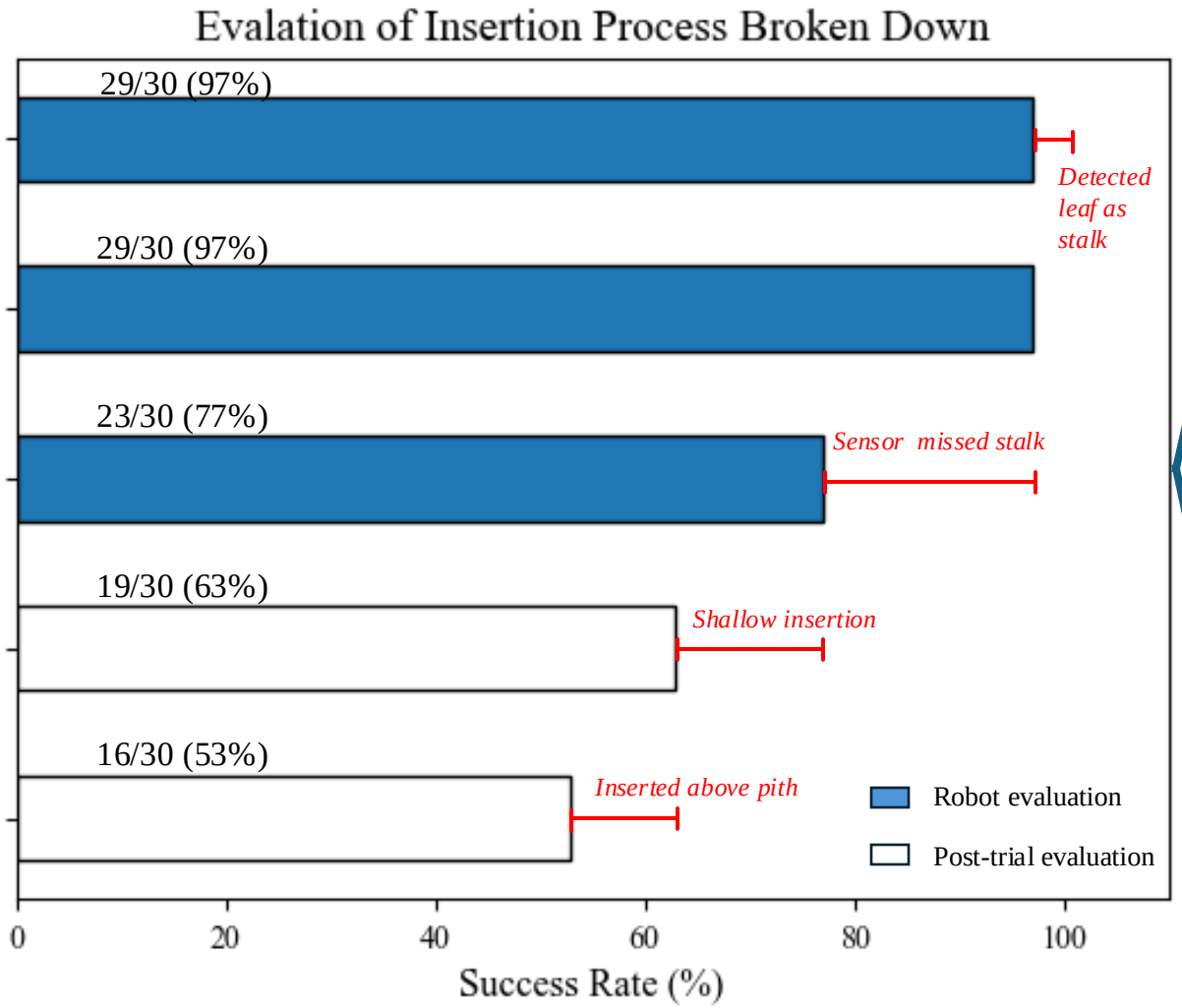
1. Stalk detected

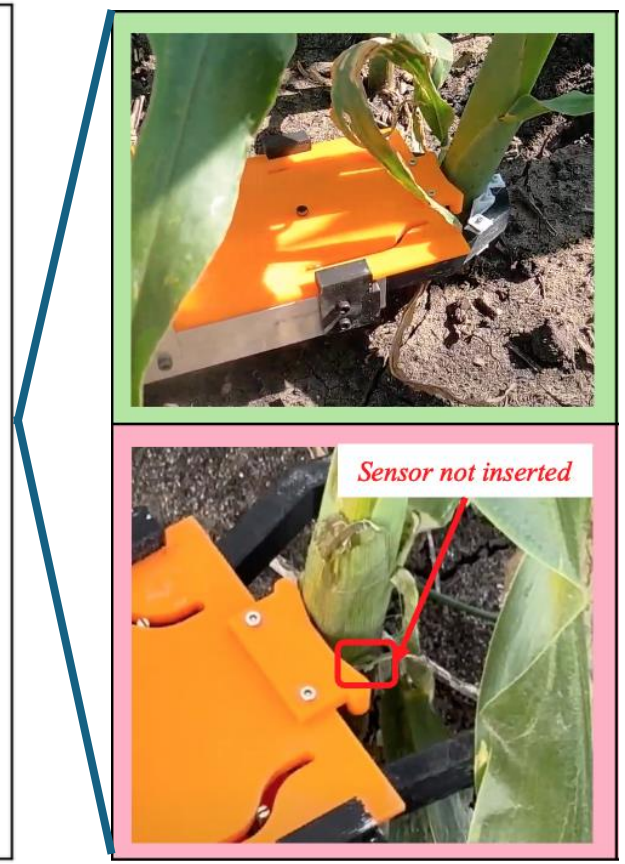
2. Stalk grasped

3. Sensor inserted

4. Inserted deep

5. Inserted in pith





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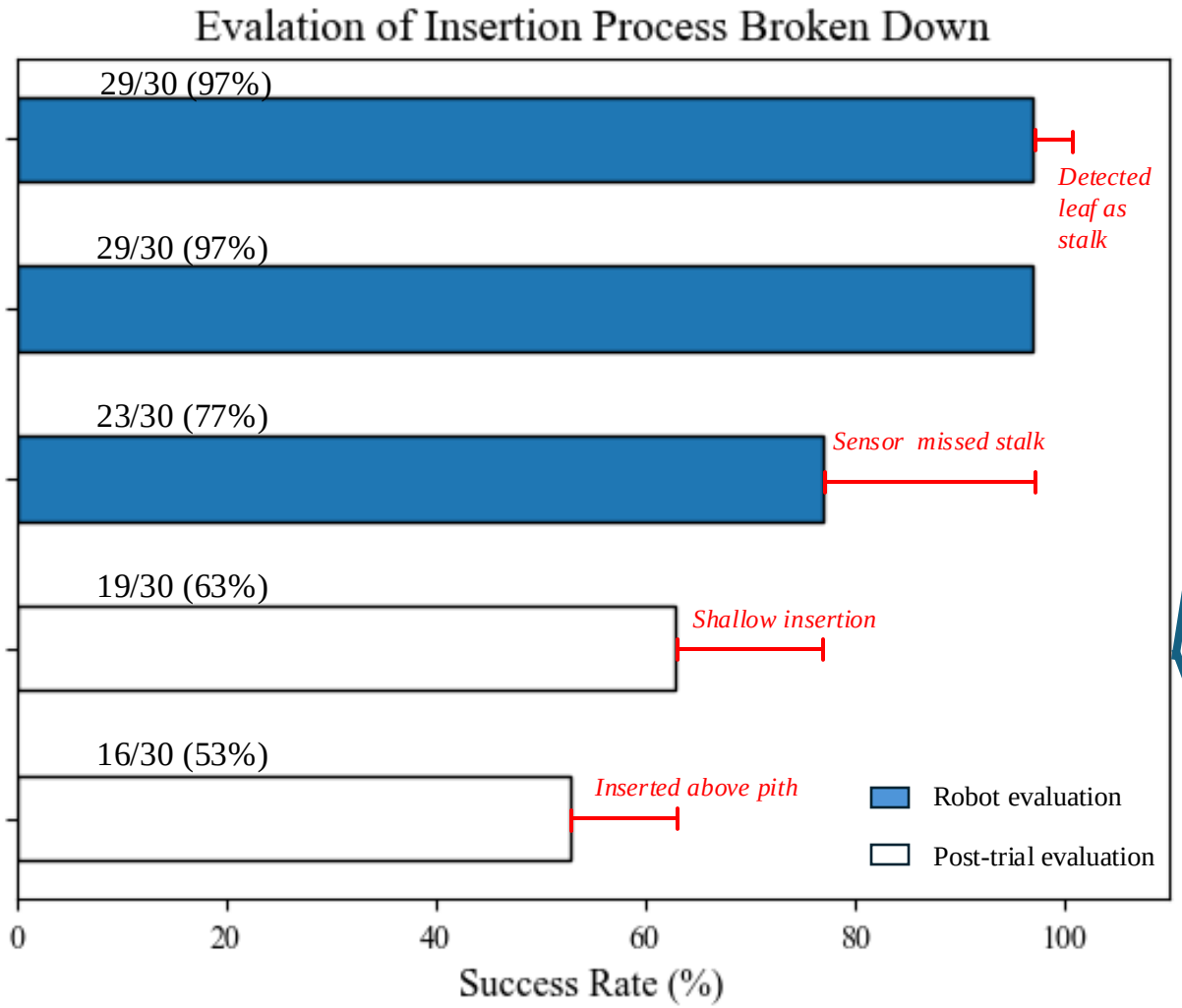
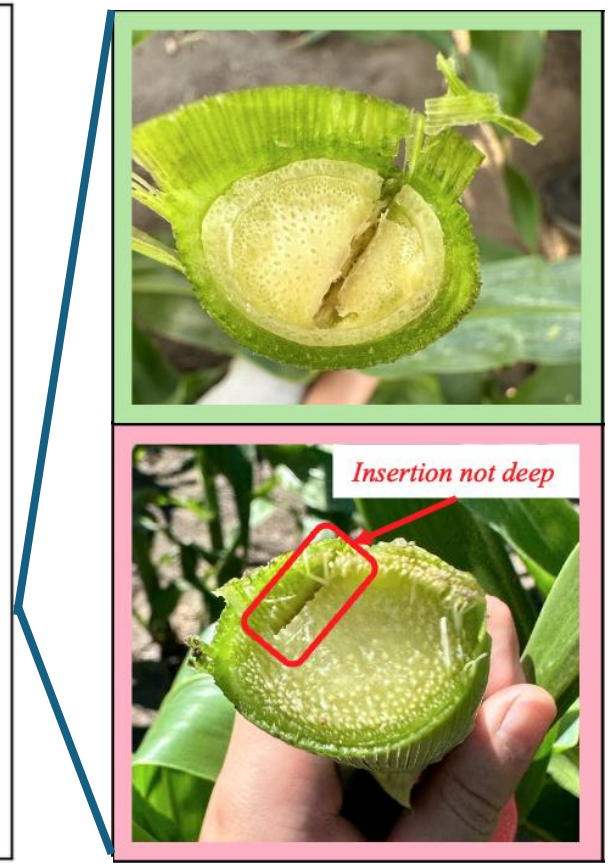
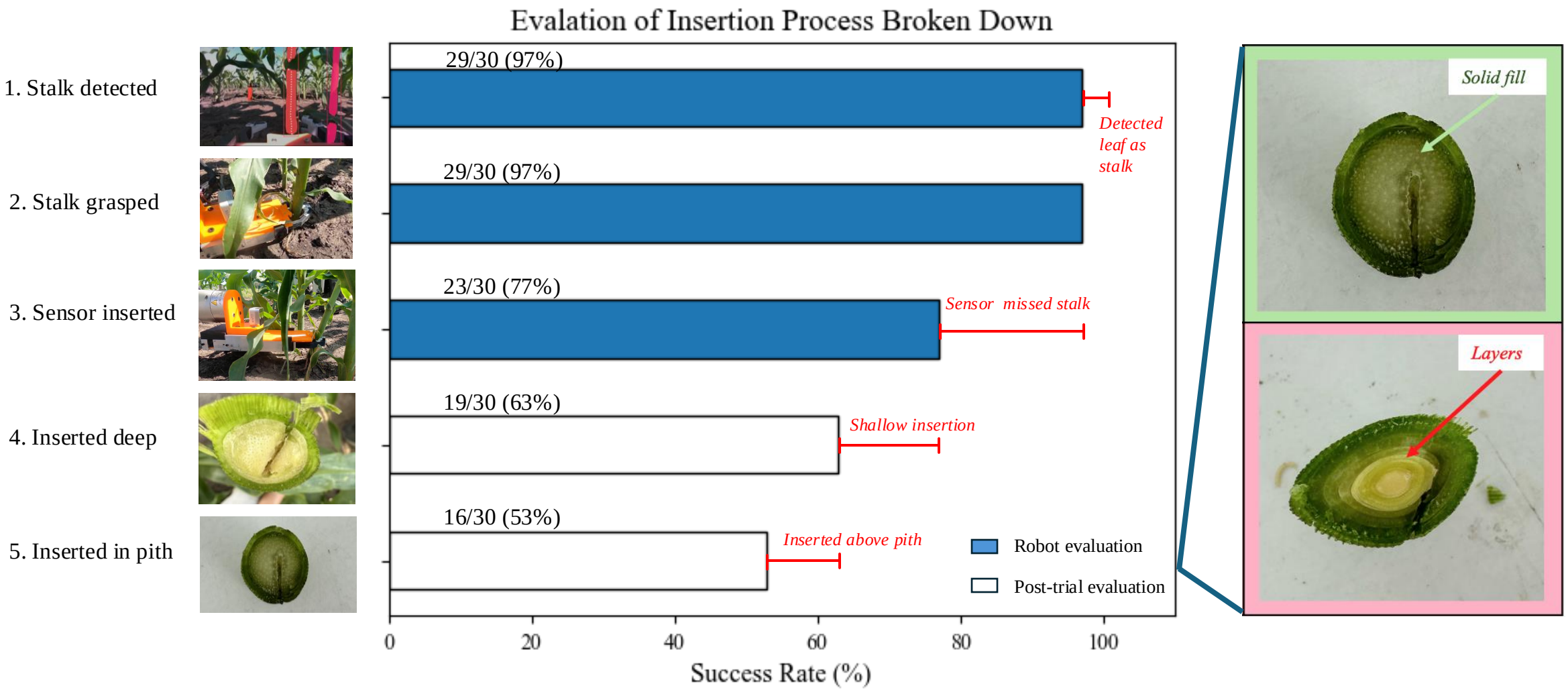
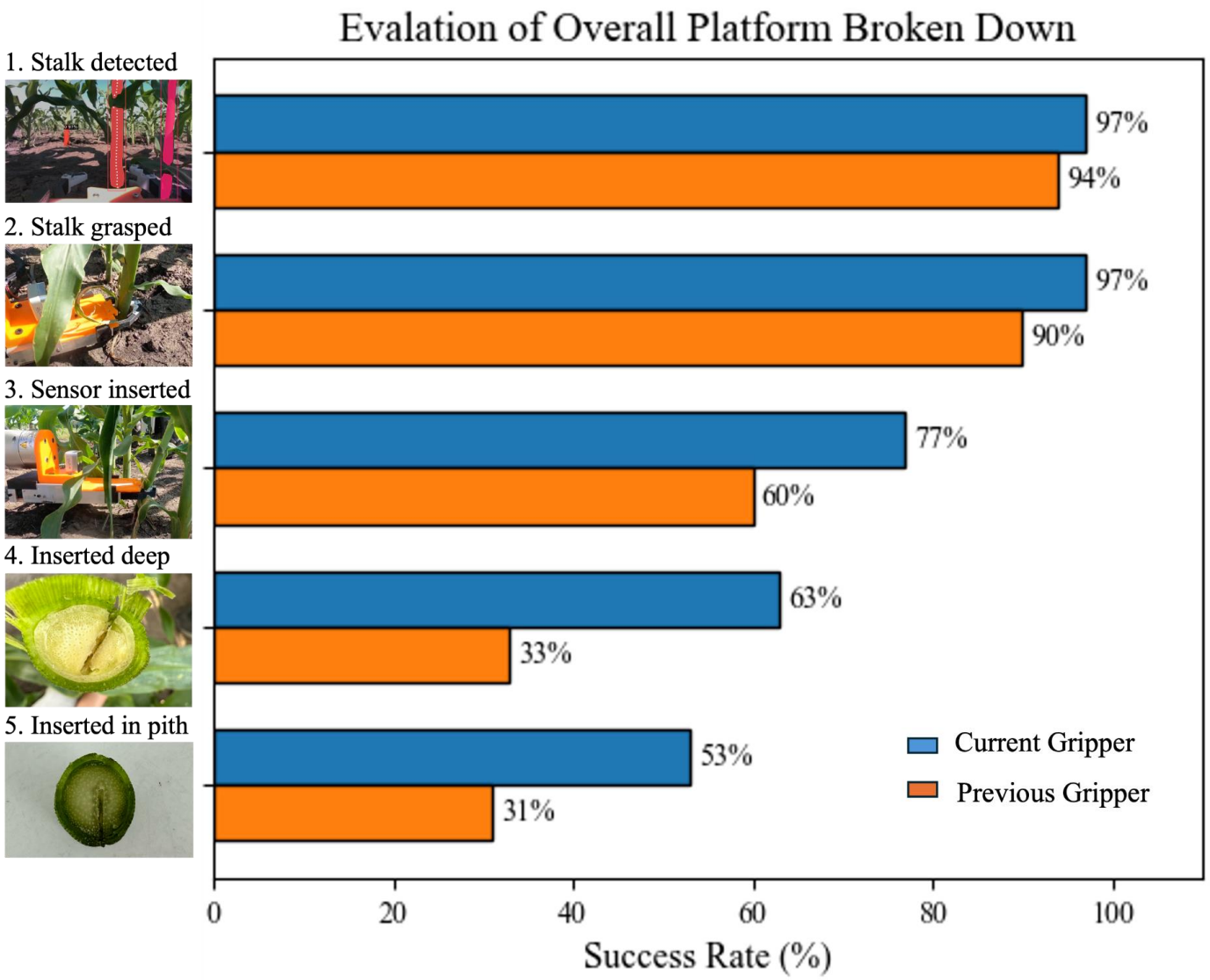




Evaluation: Overall Insertion



Baseline Comparison



Pittsburgh Hazelwood Field Testing

- Evaluated visual servoing controller

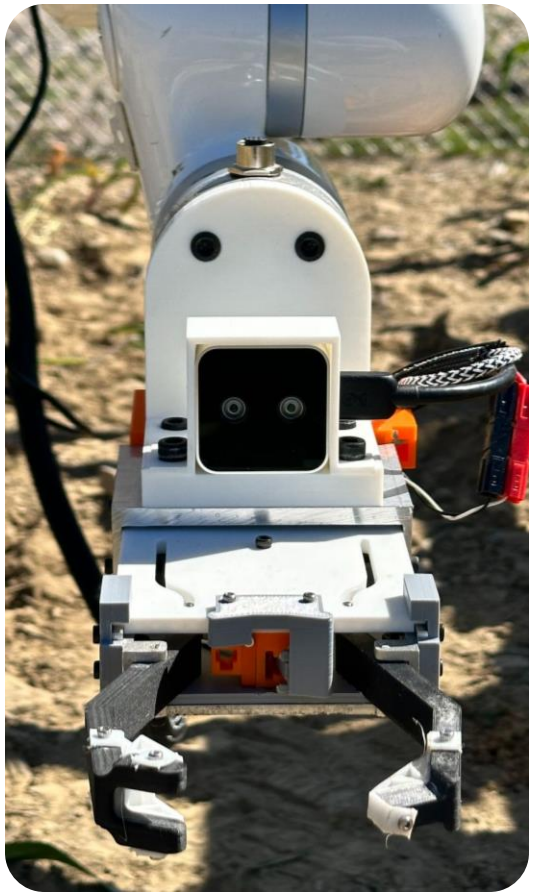
Evaluation: Visual Servoing

- Insertion success: 80% (out of 30 insertions)
  - Baseline (Iowa insertion result) : 77%

- Distance from the center

	Median	Mean
Visual servoing	**3.30 mm**	**2.60 mm**
Open-Loop control	4.00 mm	4.21 mm

Conclusion



Gripper Design

Sensor Exchange

Visual Servoing

Field Deployment

Future Work

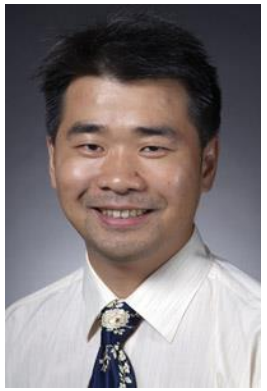
- Generalizing mechanism for different robotic applications
  - Funneling mechanism - high-precision alignment
  - Coupled sliding mechanism – compact design
  - Soft fingertip pads - compliant grasping

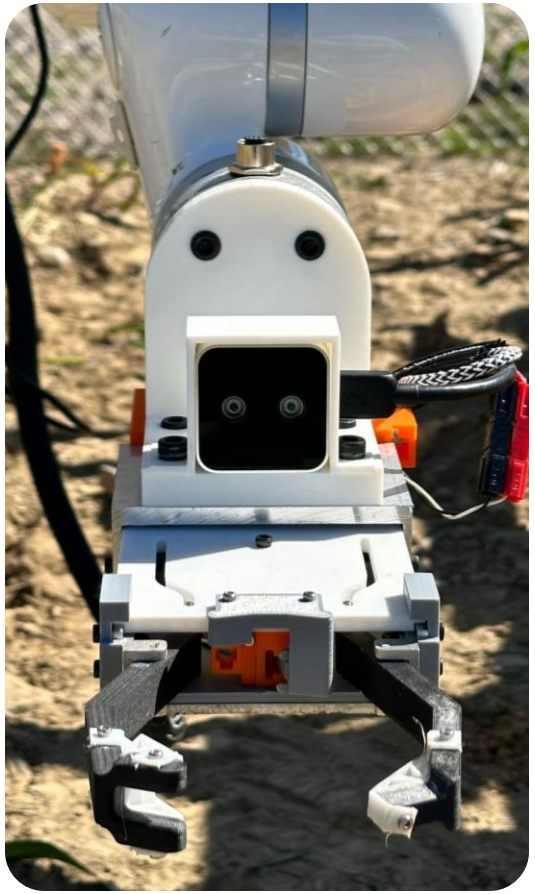
- Improving the robustness of the Cornstalk Monitoring Robot
  - Enhanced pith detection
  - Automatic detect of sensor failure
  - Developing faster and reliable visual servoing controller

Acknowledgment

Committee members

Collaborators at Iowa State Univ.



Collaborators at CMU

Thank you!