Demonstrating CropFollow++: Robust Under-Canopy Navigation with Keypoints

Arun Narenthiran Sivakumar[1], Mateus Valverde Gasparino[1], Michael McGuire[2], Vitor Akihiro Hisano Higuti[2], M. Ugur Akcal[1], Girish Chowdhary[1]

[1]University of Illinois Urbana-Champaign

[2]Earthsense Inc.

Under-Canopy Agricultural Robots

Challenges in Under-Canopy Navigation

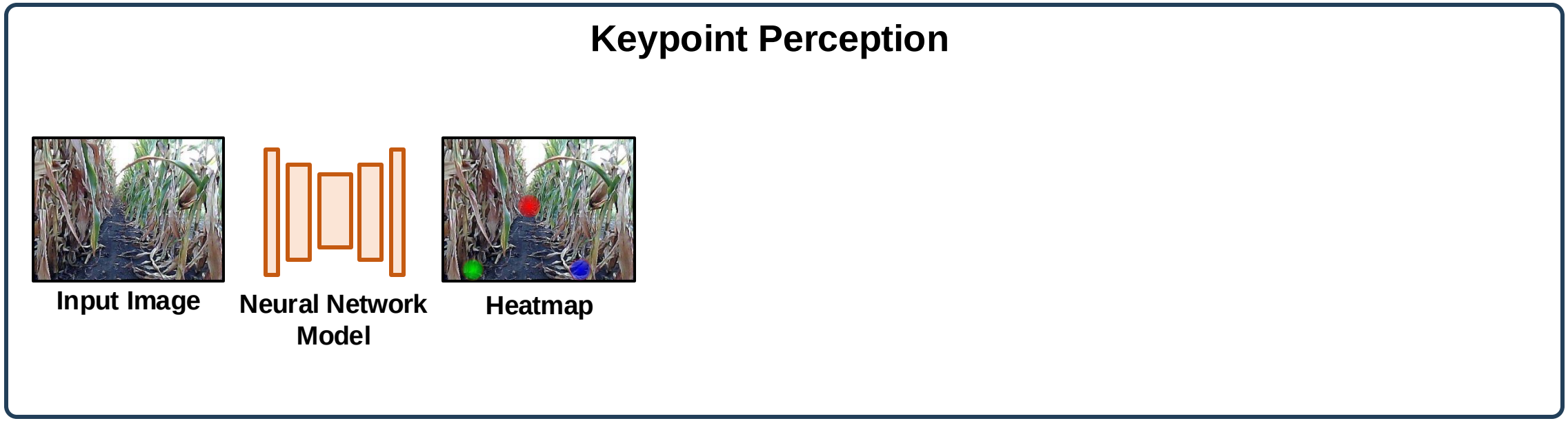
- Unreliable GPS, LiDAR
- Lots of occlusion and clutter
- Large variability in appearance of soil and crops
- Small margin of error due to tight space and speed

View from on-board camera of the robot

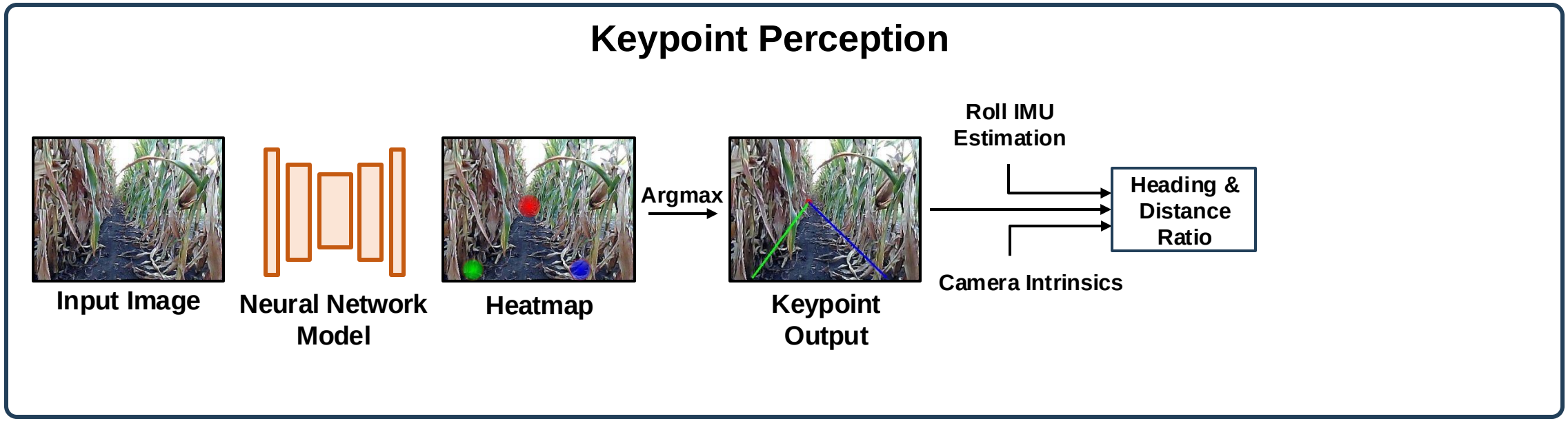
CropFollow++ Contributions

- A modular, interpretable, and anomaly-aware under-canopy navigation system with semantic keypoints
- Deployment over 25km on multiple under-canopy cover crop planting robots
- Discussion of various failure modes during deployment

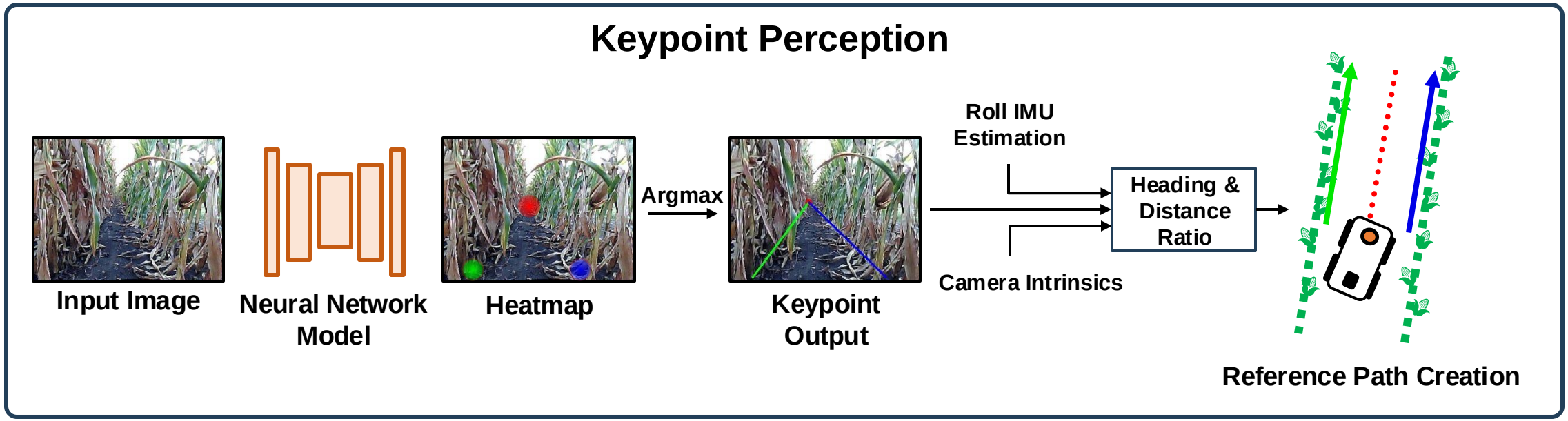
CropFollow++ Overview



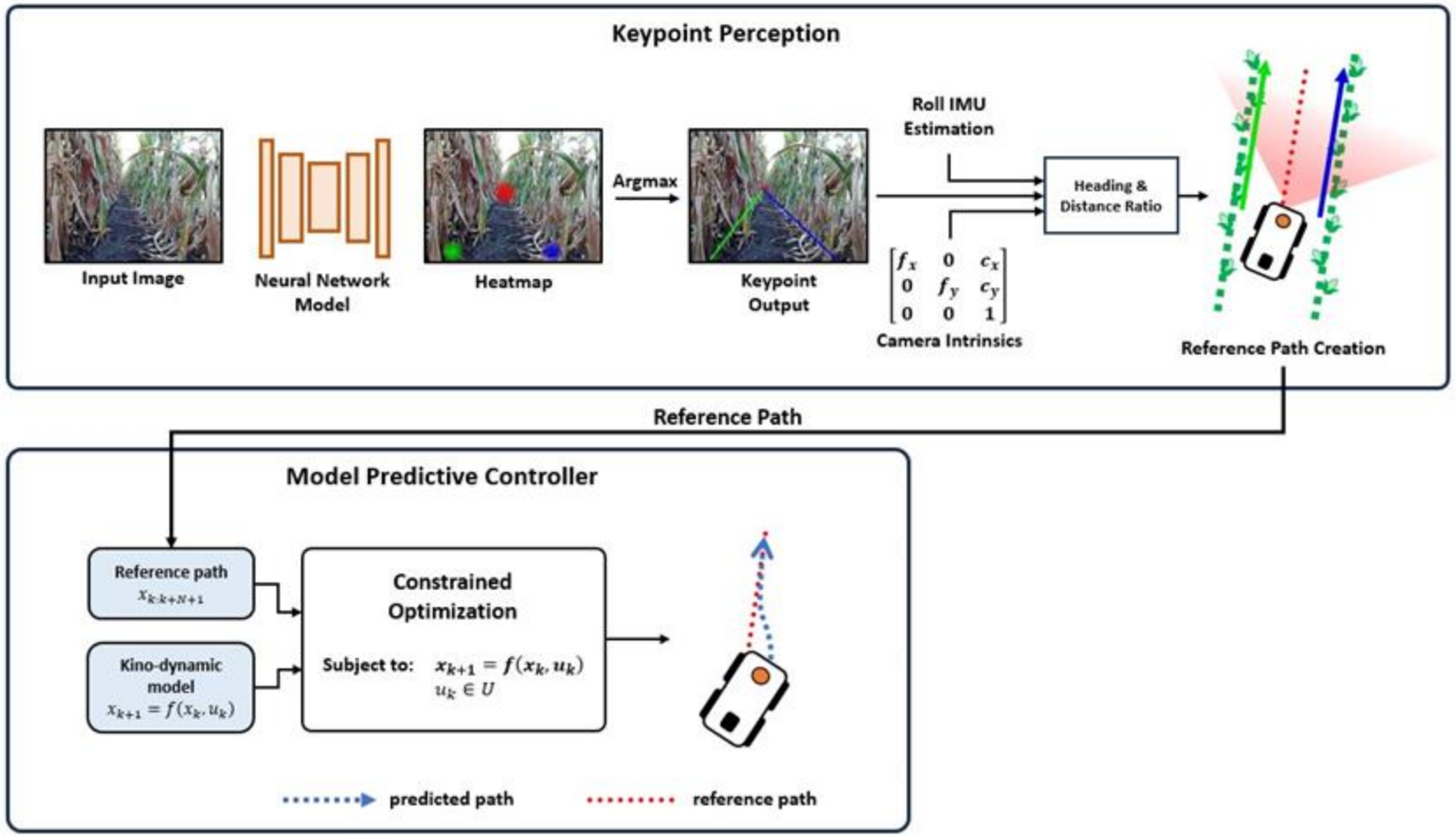
CropFollow++ Overview



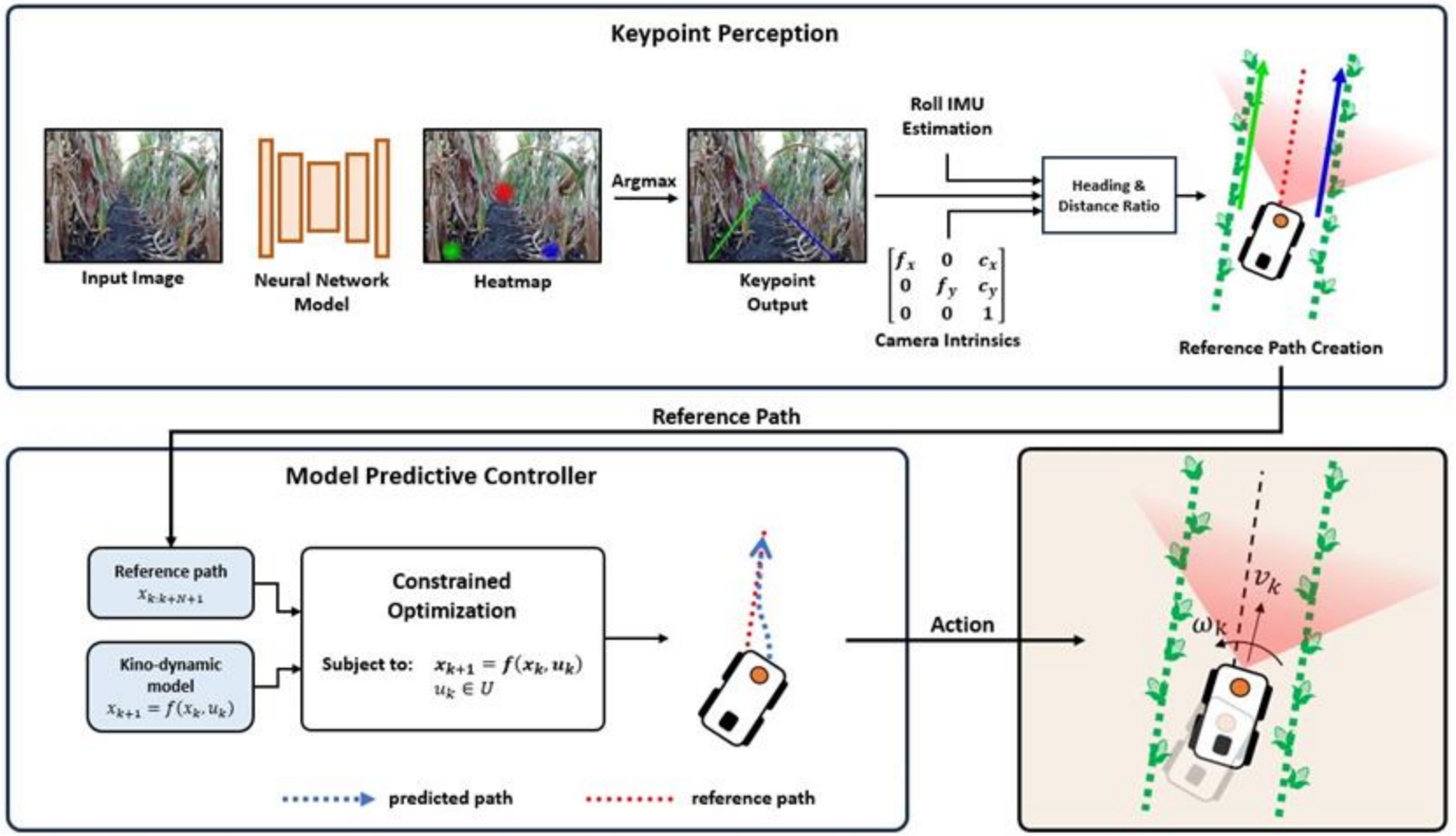
CropFollow++ Overview



CropFollow++ Overview



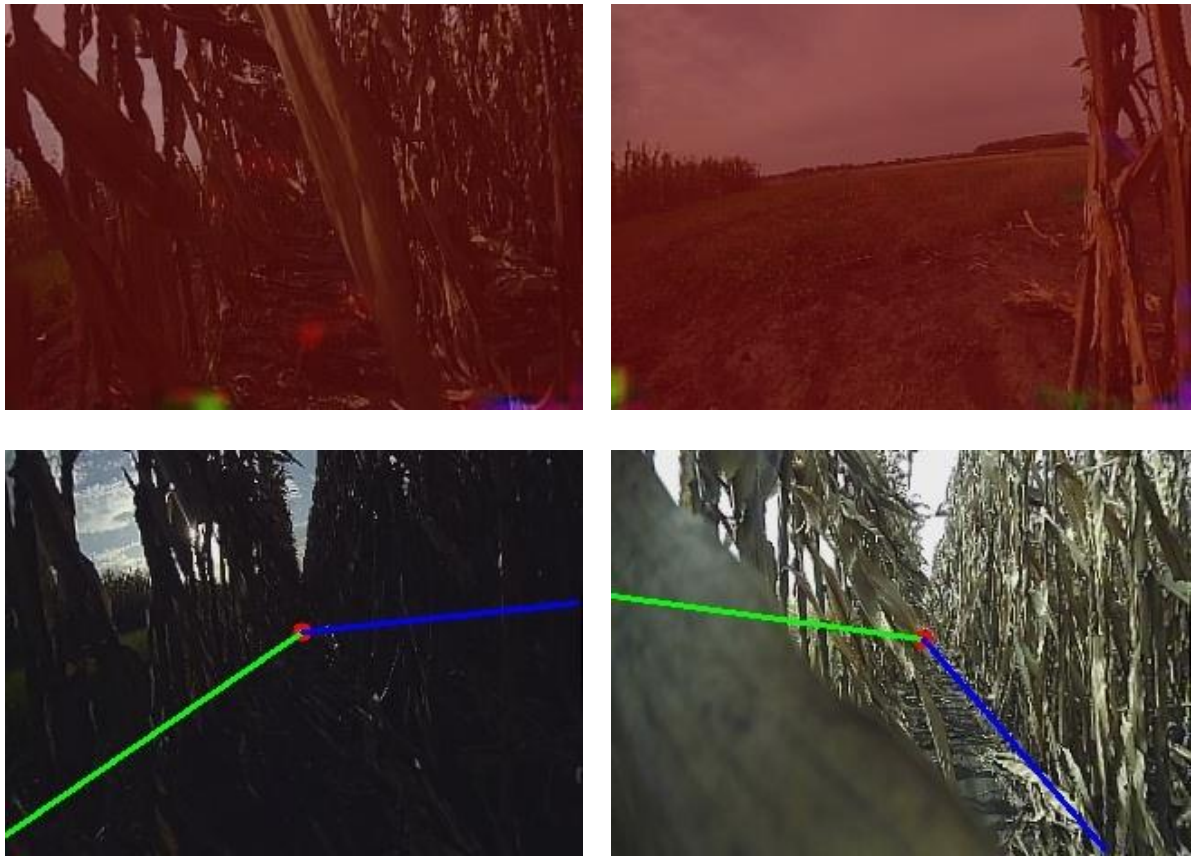
CropFollow++ Overview



Outlier Detection Heuristics

- Variance of vanishing point heatmap enables anomaly detection

- Heuristic check on geometry of triangle filters false positives in intercept keypoints



Offline Evaluation

Validation Dataset	Model	L1 Heading Error (deg)		L1 Distance Ratio Error	
		Mean	Median	Mean	Median
Entire Dataset (4873 images)	CropFollow	1.27	1.12	**0.042**	0.035
	CropFollow++	**1.2**	**0.66**	0.044	**0.026**
Zigzag trajectories (1576 images)	CropFollow	1.41	1.37	0.042	0.037
	CropFollow++	**0.72**	**0.45**	**0.026**	**0.018**
Uneven terrain (213 images)	CropFollow	1.9	1.85	0.041	0.035
	CropFollow++	**0.36**	**0.29**	**0.025**	**0.02**

Field Evaluation

CropFollow++ (CF++)
CropFollow (CF)

	Length (m)	Number of collisions		Max distance without collisions (m)		Total time in autonomous mode (s)	
		CF	CF++	CF	CF++	CF	CF++
Run 1	420	2	**2**	310	**412**	**494.2**	500.1
Run 2	420	8	**5**	115	**262**	417.8	**415.0**
Run 3	420	10	**2**	165	**366**	416.2	**412.6**
Run 4	180	7	**1**	74	**170**	199.0	**193.6**
Run 5	420	6	**3**	260	**390**	422.2	**413.0**

Demo: Deployment on Cover Crop Planting Robots

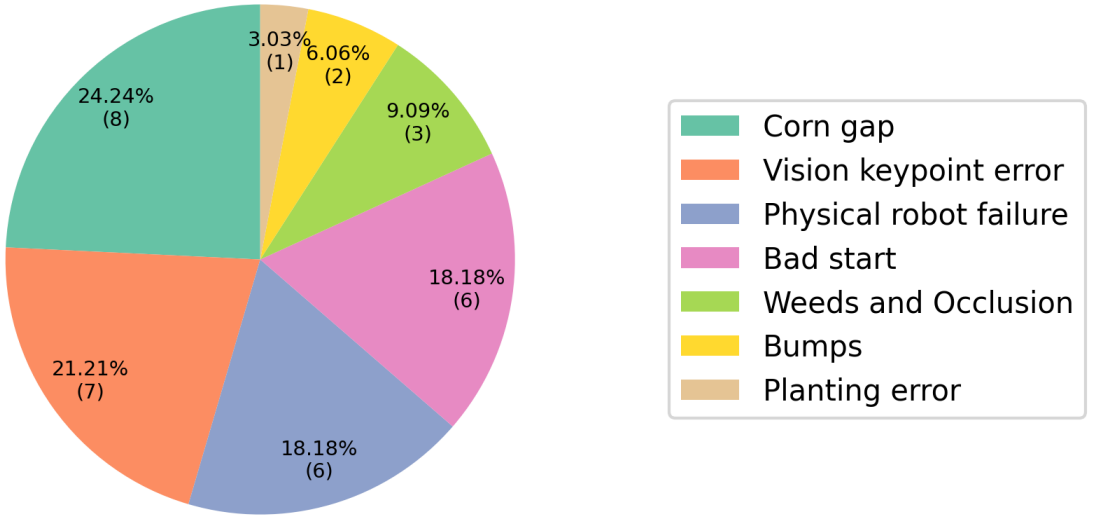
1x

Demo: Autonomous Failure Recovery

1x

Deployment in Cover Crop Planting Robots

Length of tests	25.3 km
No. of collisions	109
No. of autonomous recovery	76
No. of irrecoverable collisions	33
Longest run without irrecoverable collisions	3.57 km



Failure modes of irrecoverable collisions

Failure Modes Visualization

Corn gap

Weeds and Occlusion

2x

Thanks!

Questions?

av7@illinois.edu