Learned Visual Navigation for Under-Canopy Agricultural Robots

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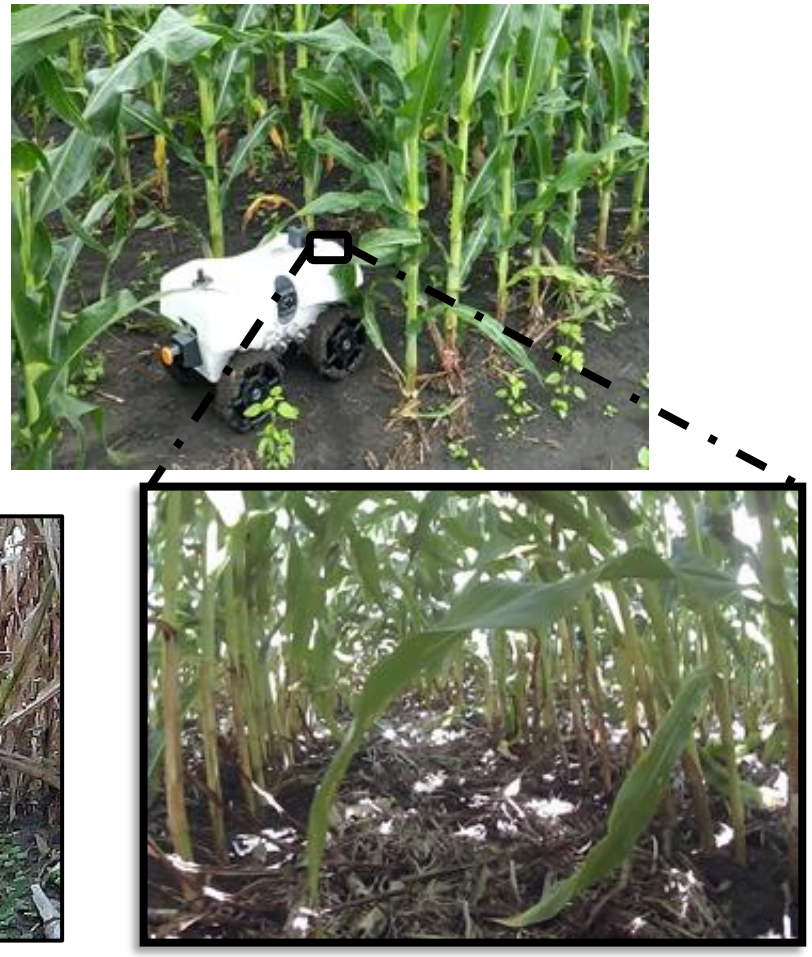
Under-canopy agricultural robots

Under-canopy navigation is challenging

- Unreliable GPS, LiDAR
- Lots of occlusion and clutter
- Large variability in appearance over season and crops
- No large scale under-canopy datasets
- Lack of extensive real world validation

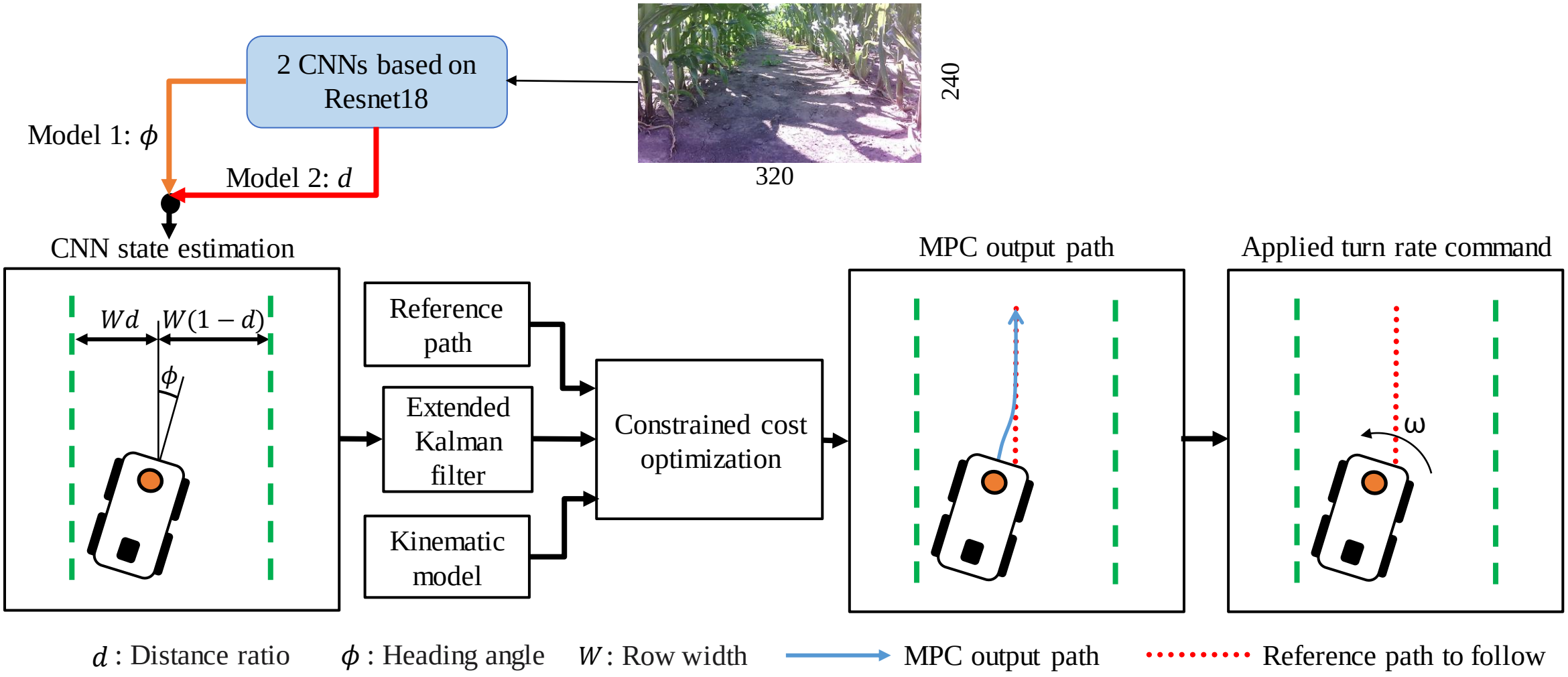


View from on-board camera of the robot

Contributions

- Collected a large and diverse under-canopy corn and soy dataset
- Developed a modular approach that combines
  - Learning based perception
  - Inertial measurement unit (IMU) sensor fusion using extended Kalman filter (EKF)
  - Model predictive controller (MPC)
- Extensively validated the proposed system in the field
  - Over 25km of under-canopy visual autonomy
  - Outperforms LiDAR (distance between intervention of 485 meters vs 286 meters)
  - 50x reduction in cost over LiDAR

CropFollow Overview



Labeled Dataset

- Corn
  - 2.7 hours of data
  - 19 fields
  - 25296 labeled images
    - Early 28%, Late 72%

- Soybean
  - 1.2 hours of data
  - 4 fields
  - 10685 labeled images
    - Early 54%, Mid 46%

Offline and Field validation

- Offline validation of heading and distance ratio model

	Heading (deg)	Distance Ratio
Mean error	1.99	0.04
Median error	1.21	0.03
95 %ile error	4.71	0.19

- Field validation of the proposed system – CropFollow vs LiDAR

Growth Stage	Length (m)	LiDAR w/ IMU	LiDAR w/o IMU	CropFollow w/ IMU	CropFollow w/o IMU
Early	1120	-	-	3	4
Late	3726	13	72	7	8

- CropFollow w/IMU – **485 meters/intervention** compared to LiDAR w/ IMU – 286 meters/intervention

Field validation in diverse environments

Early season

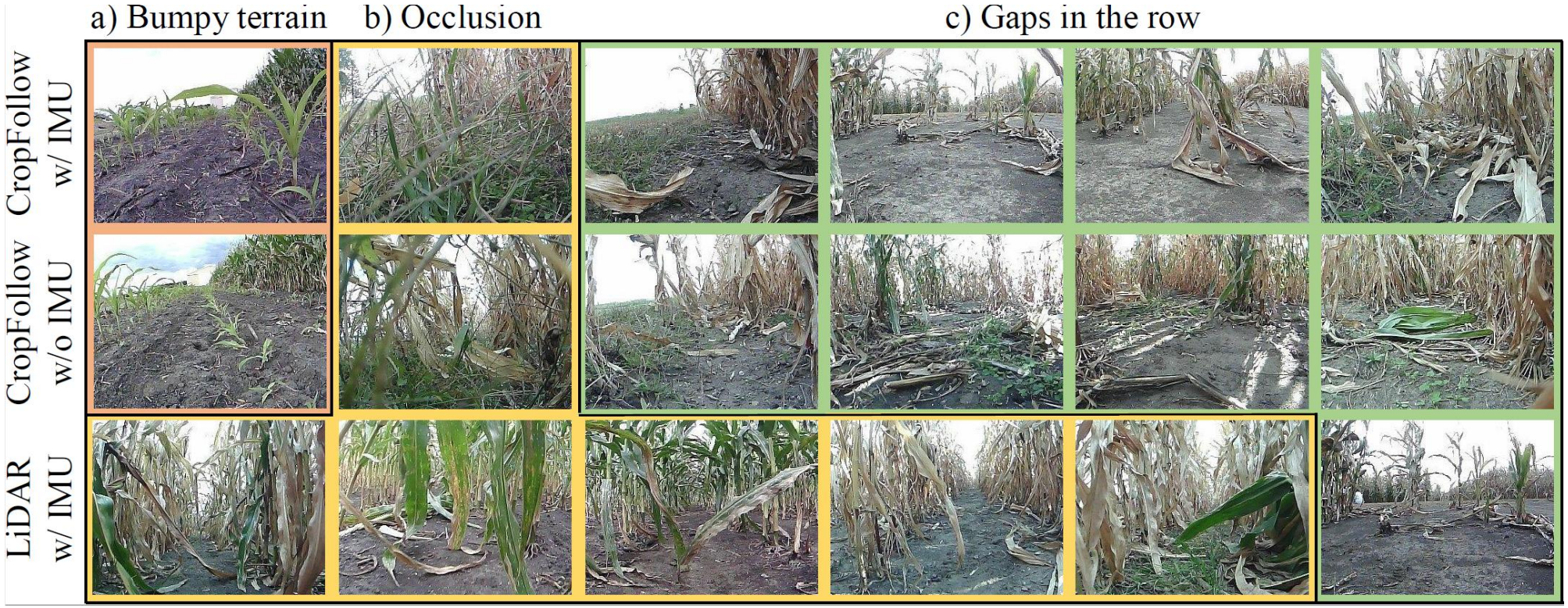
Late season

Navigating through a curve

Navigating through occluding leaves

Videos are at 5x speed

Failure modes of vision vs LiDAR



- Vision - Gaps in the row since no such images in training data
- LiDAR - Occlusions

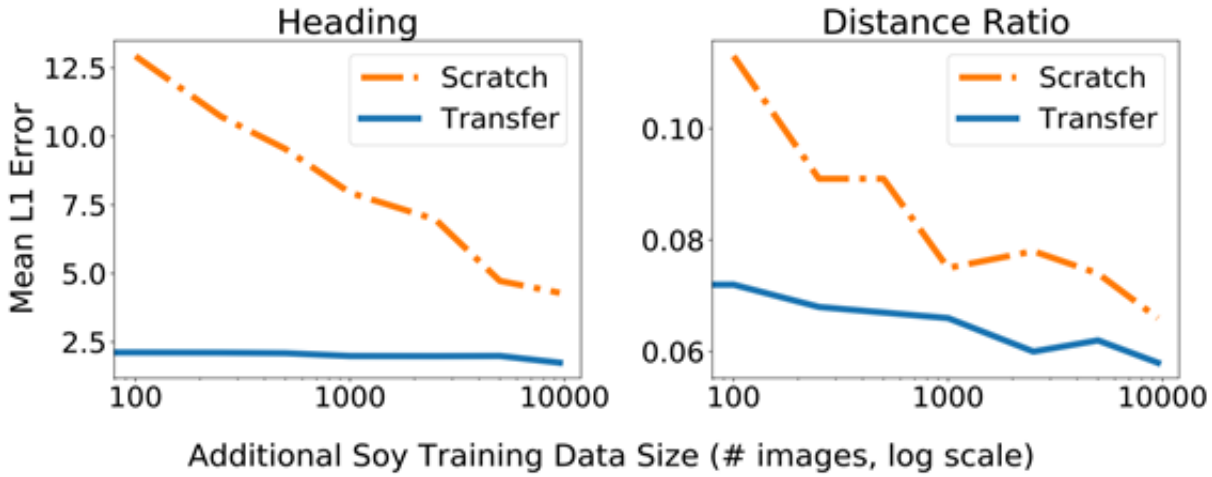
Generalization to Soybean

- Soybean appears very different from corn (shorter and stouter)

Soybean

Corn

- Heading and distance models trained on corn generalizes well without retraining in soybean



Summary

- We have developed a low cost, modular learning based vision navigation approach for under-canopy navigation
- Extensive field validation over 25 km shows the effectiveness of this approach (485 meters/intervention compared to LiDAR's 286 meters/intervention)
- ~1000 labeled images and 24000 unlabeled images from our work are openly accessible to enable further research