Robotic Weed Removal

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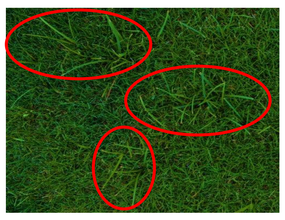
Background & Challenge

➢ Difficulties in Precise Weed Management

- Weed removal has high labor demand for large field
- Due to lack of labor, over-application of herbicides cause environmental damage
- Crops can be easily damaged and weeds are best controlled at seedling stage

➢ Requirements for Weeding Robot

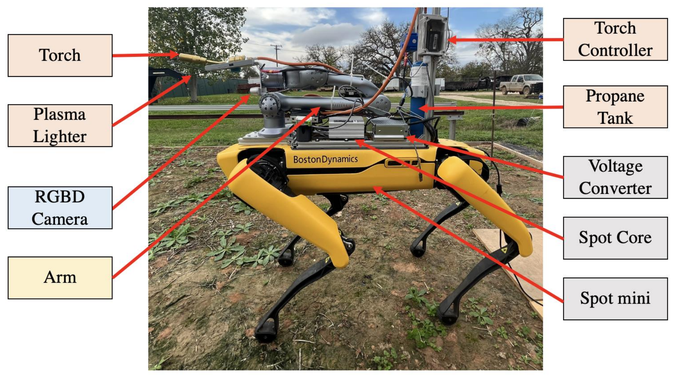
- Identify weed from challenging environment
- Killing weed with high efficiency, low energy consumption
- Precise actuation while conquer the complicated terrain

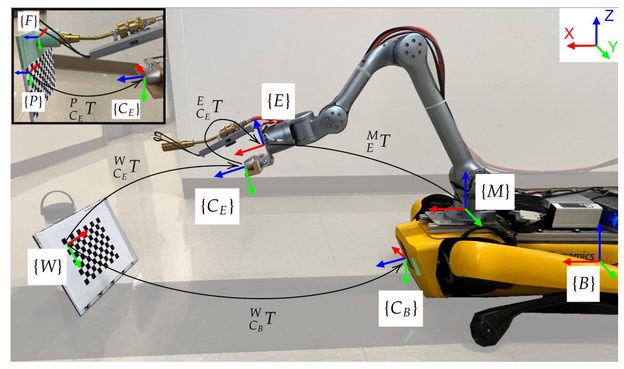


➢ Challenges in Weeding Robot

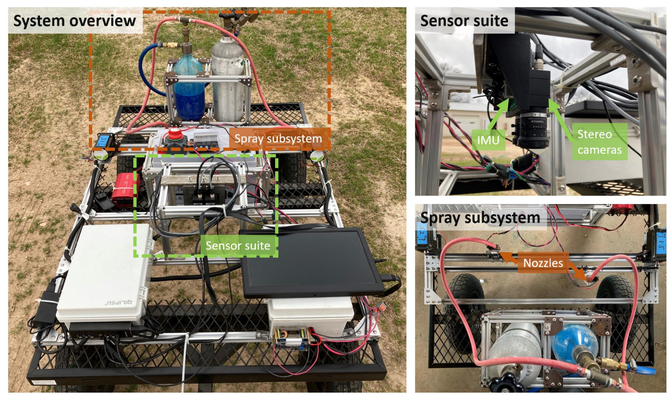
- **Perception:**
  - Weed have different appearance in different grow stage
  - Visual similarly between weed and background
  - Irregular cluster leads to difficult segmentation
  - Detection need to be accurate at centimeter level for
- **Planning & Decision Making**
  - Decision need to made in real time
  - Balance between coverage, distance to crop, energy and efficiency
- **Actuation & Manipulation**
  - Robotic system limitation (kinematics, dynamics)
  - High accuracy actuation

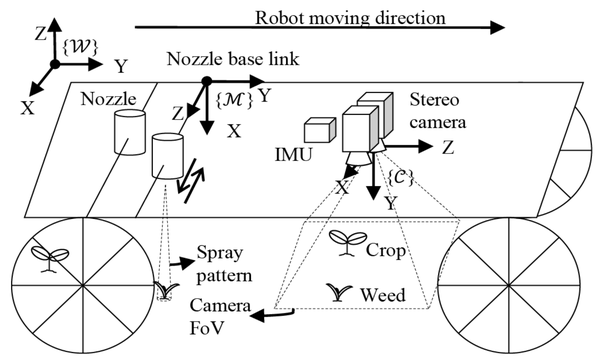
Platforms & Hardware Solutions





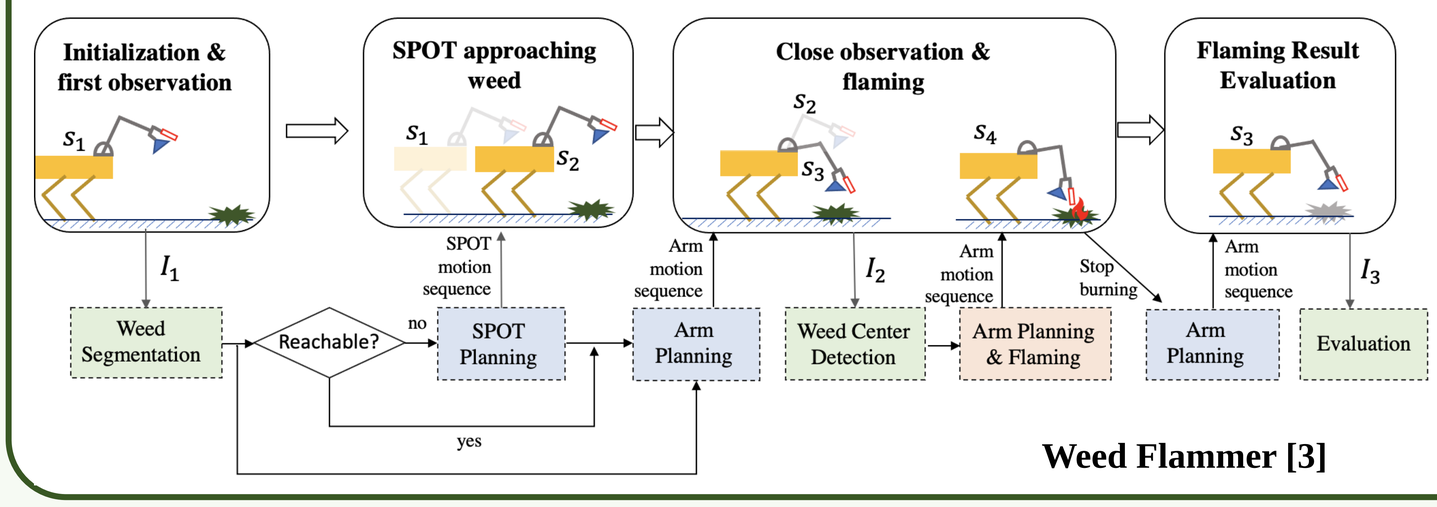
Weed Flammer [3]



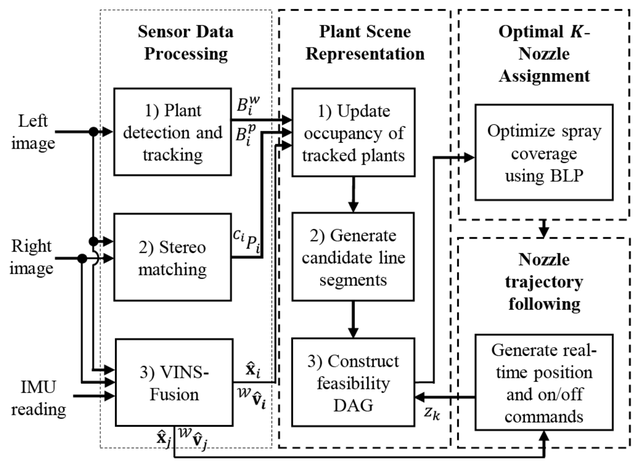


Weed Sprayer [2]

System Pipeline & Design



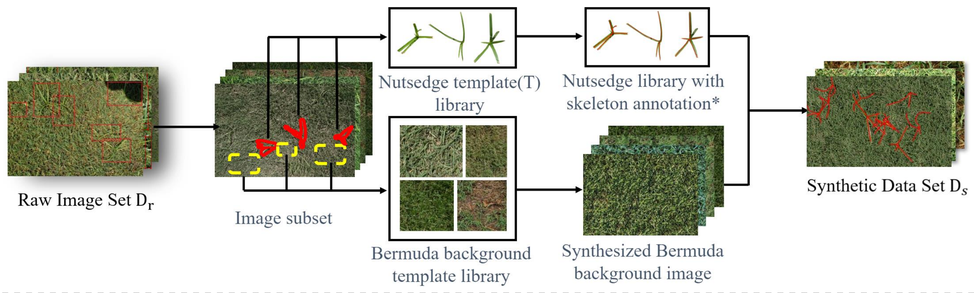
Weed Flammer [3]



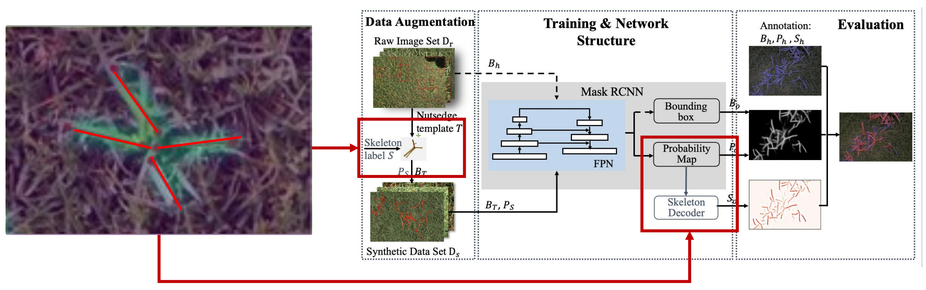
Weed Sprayer [2]

Algorithms For perception and planning

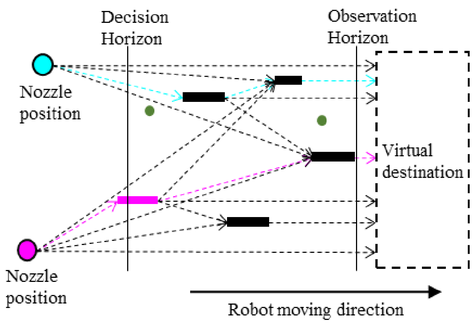
➢ Data augmentation for weed detection [1]



➢ Weed Skeleton Detection and Segmentation [1]



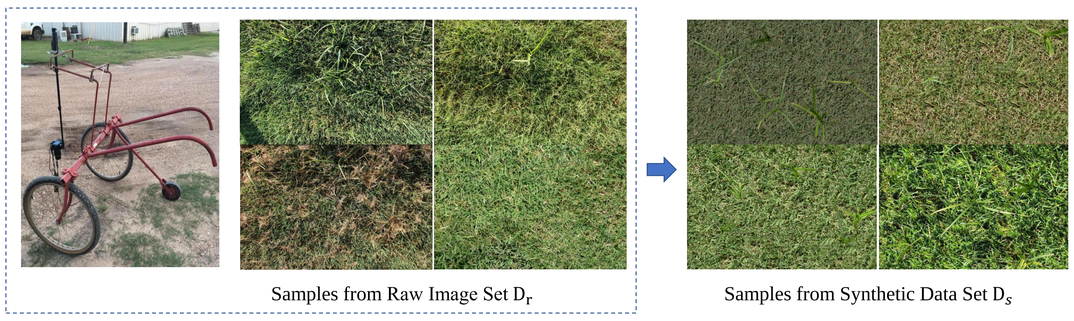
➢ Tri-layer scene representation: directed acyclic graph (DAG) [2]



➢ K-nozzle Assignment [2]

$$\begin{aligned}
\underset{e_{uv}\in\{0,1\}}{\text{maximize}} \quad & \sum_{v\in V_w} r_v e_{uv} - \sum_{v\in V_w} c_{uv} e_{uv} \\
\text{subject to} \quad & \sum_{(u,v)\in\delta^-(v)} e_{uv} \in \{0,1\}, \quad \forall v \in V_w, \\
& \sum_{(u,v)\in\delta^-(v)} e_{uv} = \sum_{(v,k)\in\delta^+(v)} e_{vk}, \quad \forall v \in V_w, \\
& \sum_{(u,v)\in\delta^+(u)} e_{uv} = 1, \quad \forall u \in V_n, \\
& \sum_{(u,v)\in\delta^-(v)} e_{uv} = K, \quad \forall v \in V_d
\end{aligned}$$

Experiment Configuration & Results



Samples from Raw Image Set D_r

Samples from Synthetic Data Set D_s

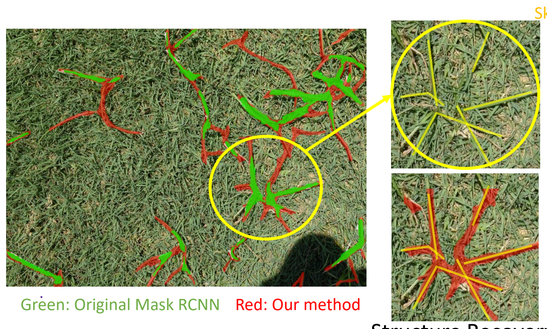
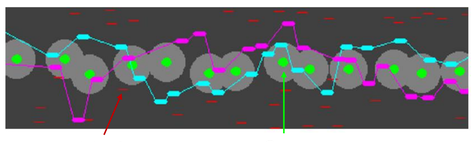


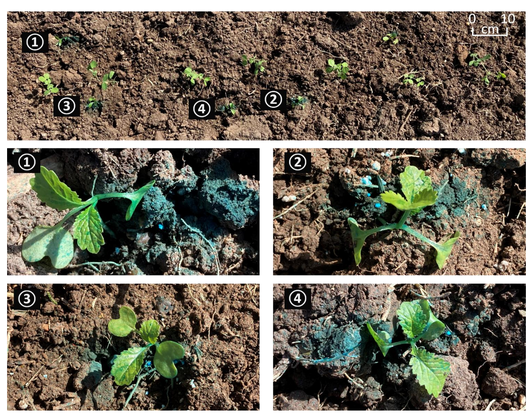
TABLE I
DETECTION COMPARISON.

Training	Testing	Backbone	Loss	$\overline{r}_{IoU}$	$\overline{C}_s$
D_{s_b}	D_{t_S}	R50	CE	0.42	0.75
D_{s_b}	D_{t_S}	R101	CE	0.45	0.77
D_{s_b}	D_{t_S}	R50	KL	0.48	0.81
D_{s_p}	D_{t_S}	R101	KL	0.57	0.88
$D_{s_p} \cup D_r$	D_{t_S}	R101	KL	**0.61**	**0.88**

TABLE II
OVERALL PERFORMANCE COMPARISON

Alg.	Loss	Training set	r_d	r_a	r_{FN}	r_{FP}
a	CE	D_r	3.01	-	-	-
b	CE	D_{s_b}	**22.71**	94.3%	5.0%	**0.2%**
c	KL	D_{s_p}	21.14	96.8%	0.7%	1.7%
d	KL	$D_{s_p} \cup D_r$	18.91	**97.1%**	**0.4%**	4.4%





[1] S. Xie*, C. Hu*, M. Bagavathiannan, and D. Song, ***Toward Robotic Weed Control: Detection of Nutsedge Weed in Bermudagrass Turf Using Inaccurate and Insufficient Training Data***, IEEE Robotics and Automation Letters (RA-L), vol. 6, no. 4, Oct. 2021, pp. 7365 - 7372.
[2]C. Hu*, S. Xie*, D. Song, A. J. Thomasson, R. Hardin IV, and M. Bagavathiannan, ***Algorithm and System for Robotic Micro-dose Herbicide Spray for Precision Weed Management***, IEEE Robotics and Automation Letters (RA-L), vol. 7, no. 4, Oct. 2022, pp. 11633 – 11640.
[3] C. Hu*, D. Wang*, S. Xie*, J. Johnson, H. Ji, Y. Jiang, M. Bagavathiannan, and D. Song, **Active Perception Driven Robotics Weed Flaming Using Spot**
*** Represent co-first author**