Plant Placement using Natural Language Grounding

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Thrust 1
Natural Language Communication, Knowledge Acquisition, and Reasoning for Ag Robots

Achieved Objectives

- Integrate **LLMs with Ag robots** for NL assisted control.
- Utilize FarmBot's state info to **resolve command ambiguities**.
- **Ground NL commands** using robot's state.
- Fine-tune CodeT5-small[1] to **generate valid plant locations** from {NL constraints, Robot state}.
- Create a unique dataset for **plant placement task** with diverse NL commands and robot state info at every timestep.
- **Improve accuracy** for the task of plant placement using NL.

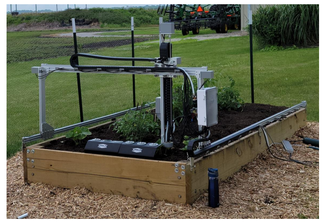

Figure 1: FarmBot at Illinois Autonomous Farm

LLMs for Spatial Reasoning

- LLM pre-trained for text-to-code **learns syntactic and semantic rules** of programming languages. [2]
- Fine-tuning on **{NL+State, Code} pairs** helps LLM **map natural language and robot state to code** that contains semantically correct plant locations in its function calls.

Dataset Generation

- Data Collection for FarmBot:

a) ***Automated Script Execution:*** *Direct command execution*
b) ***State-Dependent Command Generation:*** *Script produces relative commands based on plant descriptions.*

- Sampling Details:

a) 30 locations uniformly sampled for every Plant 1 to model the allowed area for Plant 2 placement.

- Benefits:

a) Enhances model's understanding of spatial constraints.
b) Improves attention mechanism's ability to ***correlate natural language words with constraints for location generation****.*

NL Command	Paraphrases	Constraint
Above Plant1	(North of, on top of, higher than)	$(y > y_{plant1})$ & $(D_{P1P2}>D_{min})$
Below Plant1	(South of, under, beneath, lower than)	$(y < y_{plant1})$ & $(D_{P1P2}>D_{min})$
Right of Plant 1	(East of, to the right of, higher along long side)	$(x > x_{plant1})$ & $(D_{P1P2}>D_{min})$
Left of Plant 1	(West of, to the left of, lower along long side)	$(x < x_{plant1})$ & $(D_{P1P2}>D_{min})$
Next to Plant 1	(Besides, close to, adjacent to)	$D_{max}>D_{P1P2}>D_{min}$
Far away from Plant 1	(Distant from, Not close to, far apart)	$D_{max}>D_{P1P2}>D_{min}$

System Overview

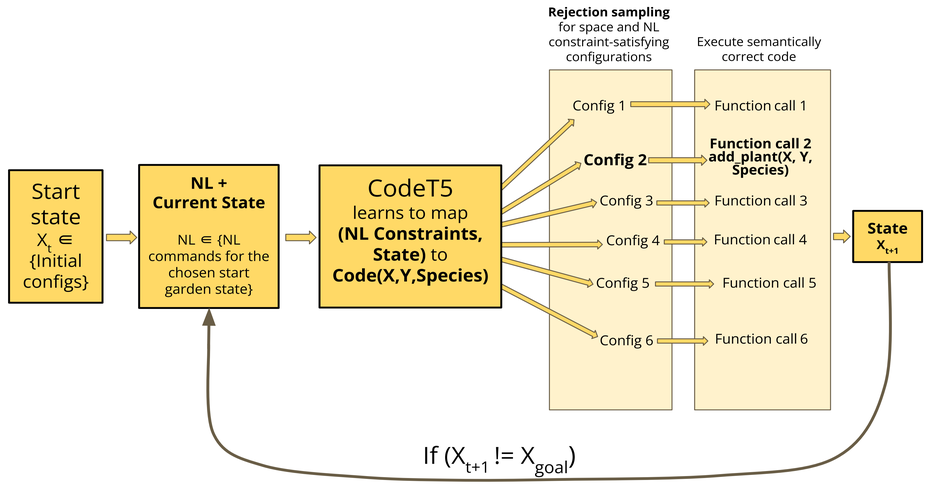

Figure 2: Flow diagram for plant placement using NL grounding

- Single relative description NL commands achieve higher accuracy due to a higher sampling area.
- Uniform rejection sampling ensured number of data points were proportional to areas that satisfied constraints.
- CodeT5-Large, with 770 million parameters, performed similarly to CodeT5-Small's 61 million parameters in Scenario 5, indicating a need for a more diverse dataset.

Scenario	Model Training Size	Near Distance Range	Far Distance Range	Maxdist Correct Range
Scenario 1	2.4M	[0.9*(R1+R2), 1.8*(R1+R2)]	[3*(R1+R2), Xmax]	Xmax
Scenario 2	725K	[0.9*(R1+R2), 1.8*(R1+R2)]	[3*(R1+R2), Xmax]	[3*(R1+R2), Xmax]
Scenario 3	725K	[0.9*(R1+R2), 1.8*(R1+R2)]	[3*(R1+R2), Xmax]	[3*(R1+R2), 8*(R1+R2)]
Scenario 4	2.4M	[0.9*(R1+R2), 1.8*(R1+R2)]	[3*(R1+R2), Xmax]	[3*(R1+R2), Xmax]
Scenario 5	2.24M	[0.9*(R1+R2), 1.8*(R1+R2)]	[2*(R1+R2), Xmax]	[3*(R1+R2), Xmax]

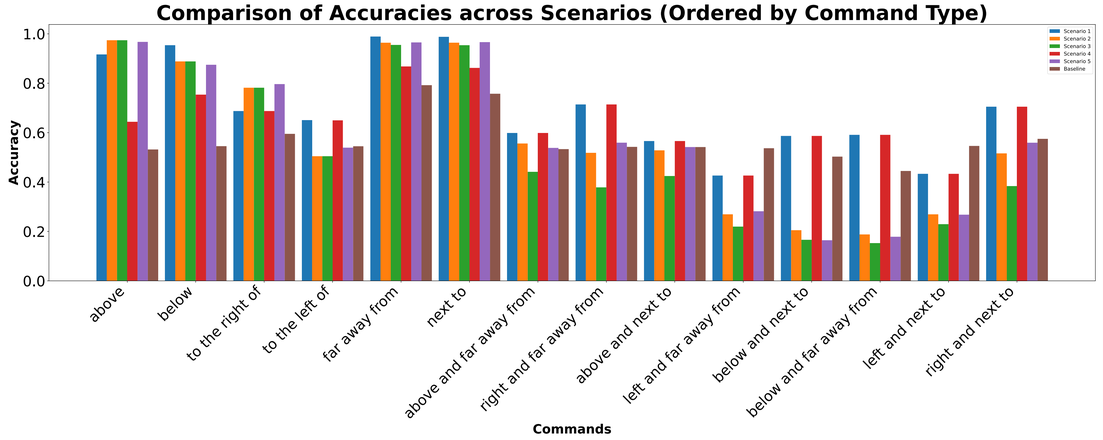

Figure 3: Comparison of accuracies for each type of relative spatial description NL command.

Limitations

- **Communication is unidirectional:** from user to FarmBot. No bidirectional interaction or clarifications.
- Focuses on relative spatial descriptions in commands: **Does not cater to Natural Language abstractions** like rows, columns, grids, or complex tasks with multiple sub-tasks.

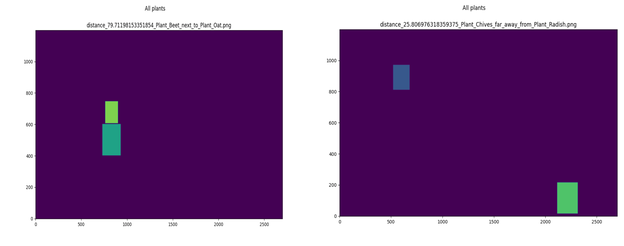

Figure 4: Occupancy plots showing the area occupied by the plants for different NL commands.

Conclusion

- Natural language assisted control helps **remove ambiguity** and **increases the accuracy** for **plant placement**.
- Fine-tuned CodeT5 can use the robot state information to **interpret and generate plant locations** that **satisfy constraints.**
- Generated a **unique dataset** with a **variety of NL commands and their combinations** and robot state information. The dataset assists in **grounding the NL commands** with respect to the robot's state.

References

[1] Shafiq Joty Steven C.H. Hoi Yue Wang, Weishi Wang. 2021. Codet5: Identifier-aware unified pre-trained encoder-decoder models for code understanding and generation. In Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing, EMNLP 2021.

[2] Royi Lachmy, Valentina Pyatkin, Avshalom Manevich, and Reut Tsarfaty. 2022. Draw me a flower: Processing and grounding abstraction in natural language.

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ACKNOWLEDGEMENTS: This work is supported by Agriculture and Food Research Initiative (AFRI) grant no. 2020-67021-32799/project accession no.1024178 from the USDA National Institute of Food and Agriculture.

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