PhenAI-Bot: Precision 3D Crop Phenotyping of Pepper (*Capsicum annuum* L.) Varieties in Greenhouse

Swarnabha Roy[1,2*], Amee Parmar[1], Rishik Aggarwal[1], Pappu Kumar Yadav[1*], Stavros Kalafatis[2]

[1]Machine Vision and Optical Sensor (MVOS) Lab, Department of Agricultural & Biosystems Engineering, South Dakota State University, Brookings, SD 57006, USA

[2]Performance Computing, XR and Robotics (PXaR) Lab, Department of Electrical & Computer Engineering, Texas A&M University, College Station, TX 77843, USA

*Contact: swarnabha.roy@sdstate.edu, pappu.yadav@sdstate.edu

INTRODUCTION

- Manual phenotyping of pepper plants often relies on human judgment, leading to subjective evaluations that can introduce inconsistencies in data collection (Hong et al., 2020).
- The process of manually phenotyping pepper plants is highly labor-intensive and time-consuming (Ninomiya, 2022).
- Errors in assessing traits like leaf area and height can lead to inaccurate evaluations of plant health and performance, thus compromising the research outcomes in pepper plant studies (Ninomiya, 2022).
- Many manual measurement techniques can be destructive to plants, which limits the number of times measurements can be taken from the same plants (Horgan et al., 2015).

Fig 1. Manual phenotyping of pepper plants

Fig 2. Destructive phenotyping

HYPOTHESIS

PhenAI-Bot can accurately and efficiently measure key phenotypic traits of pepper plants autonomously with measurement accuracy comparable to ground truth data.

OBJECTIVES

- To develop and evaluate PhenAI-Bot, an autonomous robotic system for 3D crop phenotyping of pepper varieties in greenhouse settings.
- To assess the accuracy and efficiency of PhenAI-Bot in measuring five key phenotypic traits (plant height, canopy major and minor diameters, canopy area, and leaf count per plant) across four pepper varieties.

Fig 3. using PhenAI-Bot for 3D phenotyping of pepper plants

MATERIALS AND METHODS

Experimental Setup

- Location: South Dakota State University East Headhouse
- Crop: Chili Pepper (*Capsicum annuum* L.)
- Varieties: Poblano, Thai Hot, Hungarian Hot Wax, Black Hungarian
- Data acquisition: May - July 2024
- Datalogger: Two CR310 dataloggers set up in two rows independently
- Soil moisture sensor: 4 sensors with one in variety of pepper plant.

Fig 4. CR310 datalogger and soil moisture sensor

MATERIALS AND METHODS

PhenAI-Bot specifications

- Robotic Platform: Roboworks Wheeltec
- Sensor: Intel RealSense D435i RGBD camera, Astra S camera, Arducam B0205 2MP camera, Campbell Scientific CR310 datalogger
- Processor: Nvidia Jetson Orin Nano 4GB
- Chassis Controller: STM32
- Max Payload: 35 Kg
- Max Speed: 1.65 m/s
- Battery life: 4 hrs. (no Payload), 2.5 hrs. (max. Payload)

Fig 5. Chili pepper plantation in the greenhouse

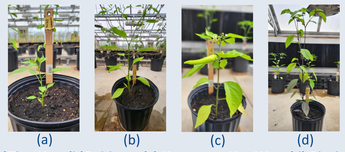

Fig 6. (a)Thai Hot, (b)Poblano, (c) Hungarian Hot Wax, (d) Black Hungarian

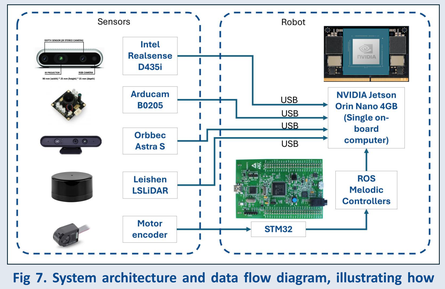

Fig 7. System architecture and data flow diagram, illustrating how data is transferred from the sensors mounted on the robot to the on-board computing systems.

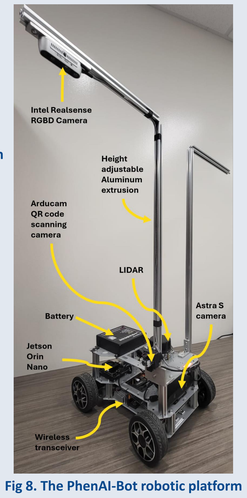

Fig 8. The PhenAI-Bot robotic platform

RESULTS

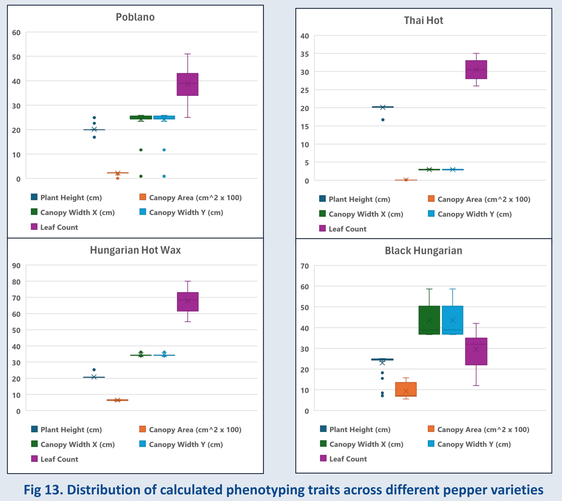

Fig 13. Distribution of calculated phenotyping traits across different pepper varieties

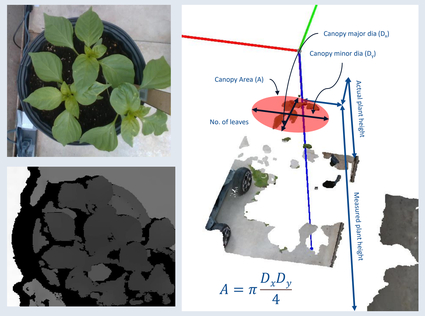

Fig 9. RGB, depth and point cloud images generated by RealSense camera

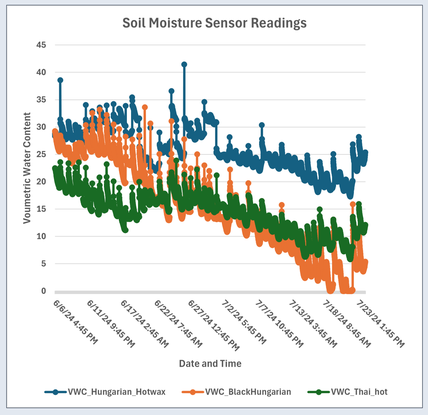

Fig 10. Trends in soil moisture sensor data across different pepper varieties

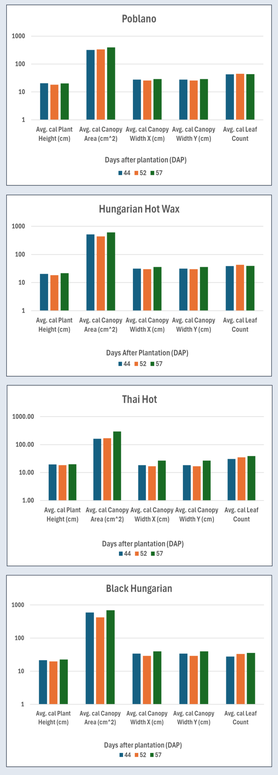

Fig 11. Trends in calculated phenotyping traits across different pepper varieties

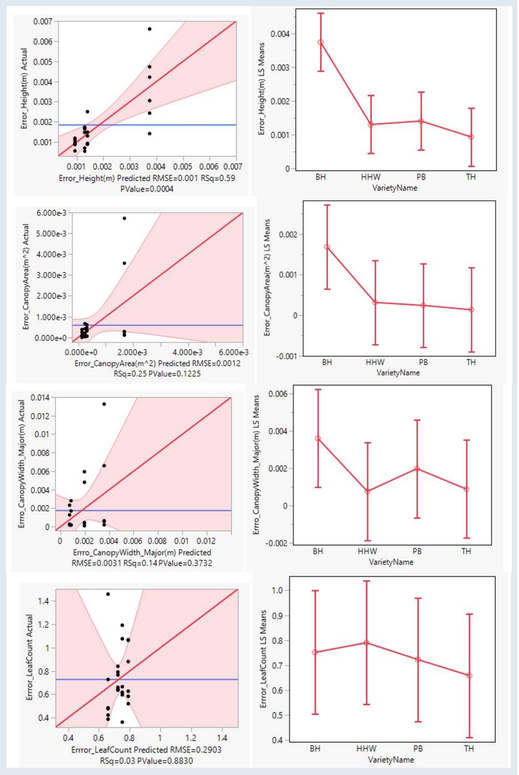

Fig 12. Correlation and errors in measurement accuracy for calculated phenotyping traits across different pepper varieties

DISCUSSION AND CONCLUSIONS

- PhenAI-Bot demonstrates potential as a low-cost, autonomous solution for 3D crop phenotyping.
- The robot can operate at a moving speed of up to 0.2 m/s under standard daytime conditions.
- The system shows varying degrees of accuracy across different pepper varieties:.
- Pearson's correlation coefficient (R^2) values ranged from:
  - As low as 0.015 for Hungarian Hot Wax
  - As high as 0.91 for Poblano
- Mean squared error (MSE) ranged from:
  - As low as 0.004 for Hungarian Hot Wax
  - As high as 0.097 for Thai Hot

FUTURE WORK

- Application of AI algorithms for improving measurements of crop phenotyping traits.
- Expanding the application of PhenAI-Bot to other crops, such as wheat, soybean, corn, and sunflower.
- Autonomous harvesting using ROSMASTER X3 PLUS robot

REFERENCES

- Hong, Ju, et al.. "Genomic Selection for Prediction of Fruit-Related Traits in Pepper (Capsicum Spp.)." Frontiers in Plant Science 11, (2020): 570871.
- Ninomiya, Seishi. "High-throughput Field Crop Phenotyping: Current Status and Challenges." Breeding Science 72, no. 1 (2022): 3-18.
- Horgan GW, et al.. Automated estimation of leaf area development in sweet pepper plants from image analysis. Funct Plant Biol. 2015 May;42(5):486-492.

ACKNOWLEDGEMENTS

We thank Brian Langum, Dr. Todd Trooien, Dr. Young Chang , Mr. Sainath Reddy Gummi and Dr. Ravi Mural for their help. Hatch-Multistate:3AR764

USDA National Institute of Food and Agriculture U.S. DEPARTMENT OF AGRICULTURE