Early-Stage Detection and Control of Leaf Diseases in Tomato Transplant Production

Xuemei Missi Zhang [1], Shadab Haque[1], Abhisesh Silwal[3], Jacob Neice[2], Thomas Hadlock[2], Boris Vinatzer[1], Song Li[1], Chang Lu[2,] and George Kantor[3].

1. The School of Plant and Environmental Sciences, Virginia Tech. 2. The Department of Chemical Engineering, Virginia Tech.

3. CMU Robotics Institute, Carnegie Mellon University

Project Website: https://lilabatvt.github.io/research/DiseaseDetection/

Introduction. The goal of this project is to develop an integrated CPS for early plant disease detection and control based on precise pathogen identification in transplant greenhouses. The system consists of three components:

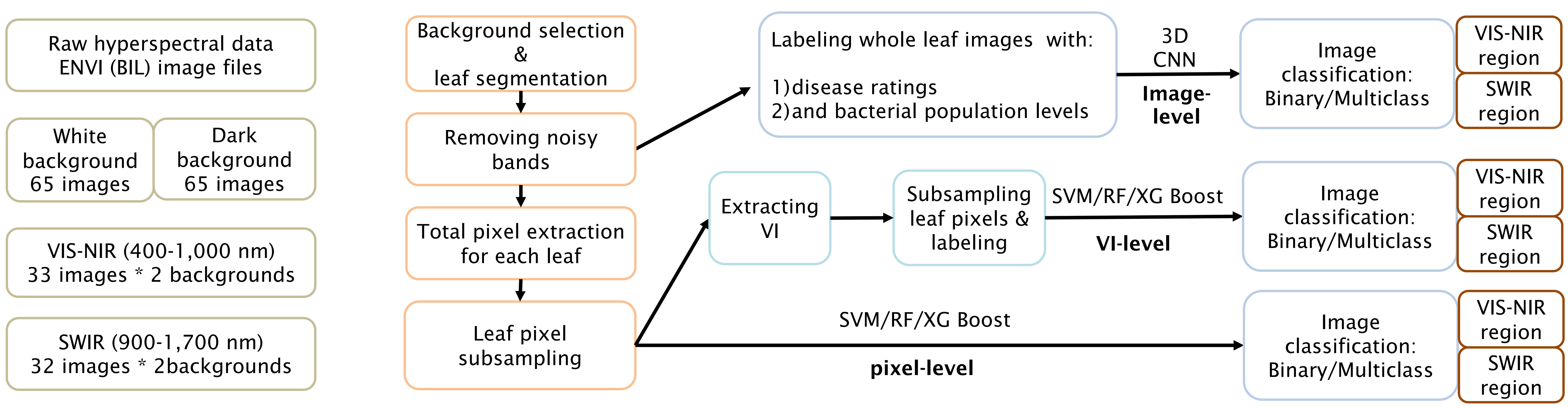
1. a robotic platform to collect images and leaf DNA samples with possible pathogen infection (Figure 1).
2. a microfluidic device for on-board DNA sample extraction of all microbes, including the putative pathogens, and identification of pathogen by nanopore sequencing in near real-time (Figure 2).
3. A method of detection of disease spread using imaging and sequencing data, and to determine optimal control strategies (Figure 3).

Experimental Design for Imaging and Sequencing Based Disease Detection:

Run1: 8 experimental units (2 plants/unit). Unit 1,2,5 & 6: uninoculated. Unit 3,4,7 & 8: inoculated

Run2: 10 experimental units (2 plants/unit). Unit 1-5: uninoculated. Unit 6-10: inoculated

Data collection (9 times): visual observation (disease rating) -> hyperspectral imaging -> bacterial growth -> Nanopore sequencing.



Key problem to be addressed: The objective is to reduce plant loss due to disease while minimizing sensing cost with sequencing.

Major innovations: First, a novel robotic platform, T-REX, was developed to perform 3D perception and modeling of plant shape. An end-effector was designed to collect plant and microbial DNA samples using microneedle for biosensing. Second, traditional methods of image-based plant disease detection (hyperspectral and RGB imaging) were combined of state-of-the-art biosensing technology including nanopore sequencing and CRISPR-lateral flow assays. These bio-sensing technologies have the potential to enable near real time decision making for plant diseases with high specificity and at the molecular level. Both innovations can be applied to other Ag-CPS systems where robotic-plant interactions and bio-sensing are required for the control of an agricultural production system.

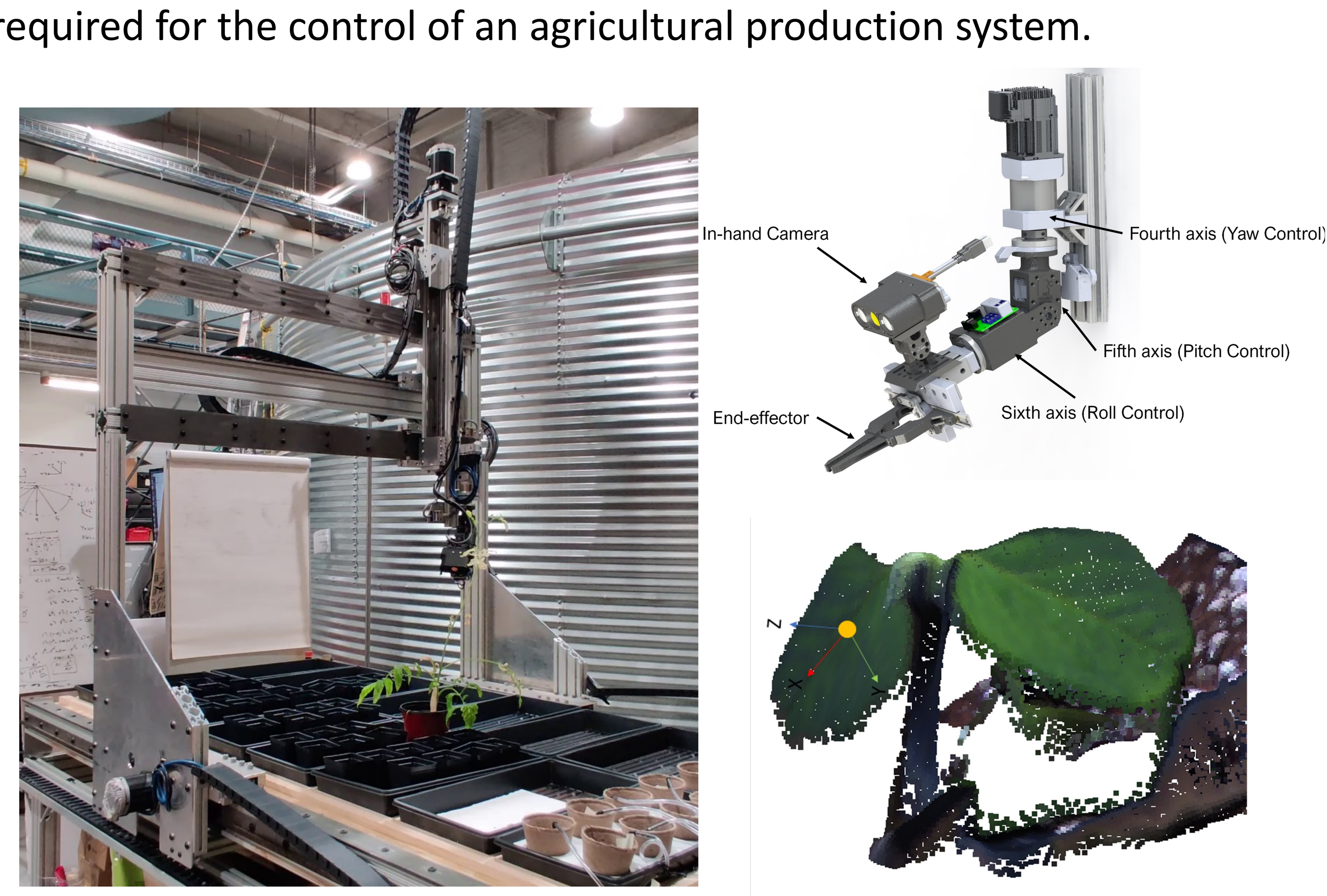


Figure 1. (A) a 3-axis robotic system, tomato gantry TREX designed for tomato leaf sample collection. Reachable workspace: 1.75 m x 0.75 m. Speed: 0.25-0.5 m/s. (B) This system is equipped with active light stereo color cameras and an end-effector for using microneedle to collect plant DNA. (C) 3D point cloud constructed from living plant to guide robotic-plant interaction.

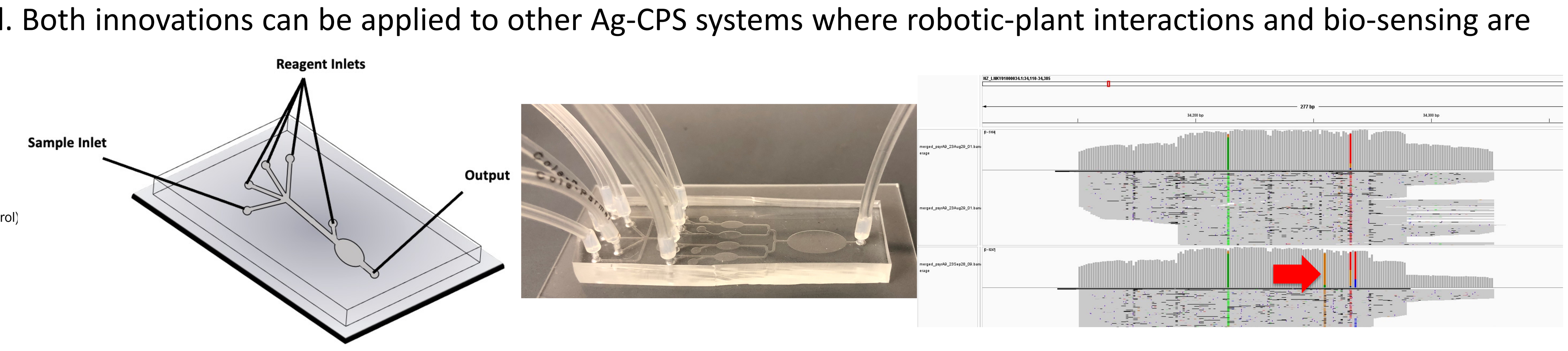


Figure 2. (A) 3D model of the microfluidic device. (B) Photo of a working prototype. (C) Nanopore sequencing result of healthy (top) and diseased (down) samples. Red arrow indicates a single nucleotide difference detected by the sequencing experiment that is only found in pathogenic bacteria.

Av. Heights_Healthy =19.2cm Av. Heights_Stressed = 17.8cm

Figure 3. (A) and (B) Foundation models (SAM, and Grounding DINO) were finetuned to capture plant responses to stresses. (C) Plant height as an indicator of plant stresses. Stressed plants can be removed by T-REX platform

Project Title: Collaborative Research: CPS: Medium: Early stage plant disease detection via robotic sampling and on site metagenomic sequencing

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