BARD project summary report Year 1: Development of a Robotic Inspection System for Early Identification and Locating of Biotic and Abiotic Stresses in Greenhouse Crops

I. Hyperspectral disease detection

One of the main issues in hyperspectral (HS) imaging for plant disease detection are the selection of specific bands which contain the information about the symptoms of the disease.

Problem definition: This task involves integration and collaborative effort of development of early detection algorithms, optimal wavelengths selection methods developed by the PRISM, UMD and ARL teams.

Methodology: experimental system (Fig 1) and apparatus was developed to acquire hyperspectral images of powdery mildew and CGMMV diseases in cucumber in the lab and in greenhouse.

Figure 1: hyperspectral disease detection experimental system.

A Specim hyperspectral camera was connected with an high-resolution, high-speed image acquisition device (NI PCIe-1427) installed on an i7-4770 CPU PC. The computer was equipped with the Specim data recording application for hyper spectral image (HSI): Lumo Scanner. This application can control HSI and scanner, and store the data into the computer hard drive. The HS camera was mounted on Motoman MH5L, a 6 degree of freedom robotic manipulator and were physically integrated by a custom-made end-effector. To control the desired motion to acquire the HS image with the manipulator, an application was specially designed and developed in Matlab (fig. 2).

Two experiments were conducted. One to detect powdery mildew (PM) on five plants and the second with 100 plants to detect CGMMV. After the inoculation of the plants four classes were selected for the CGMMV: healthy young leaves (HY), diseased symptomatic young leaves (DY), healthy old leaves (HO), diseased symptomatic old leaves (DO). In conformity with the development of the disease in the healthy classes we do not have any color variation or shape deformation. In contrast diseased classes are strictly connected with color variation and shape deformation especially DY class. In DO the main symptoms regards color variation. A database of HS images (HSI) was created. The database consists HSI of PM disease in cucumber and tomatoes and CGMMV in cucumber. The database was transfer to PRISM and UMD for analysis and development of detection algorithms.

A schematic description of the analysis procedure and the various analyses conducted is presented in figure 3. In the channels combinations procedure, 84 specific channels were reduced from total 840 channels at equal spectral interval. all combinations of 2, 3 and 4 different channels were generated (3486, 95284 and 1929501 combinations respectively) of the selected 84 channels. Each channel combination was used as input for PCA and LDA. The developed methodologies parts refer to the methodologies developed for optimal wavelength selection. The deep spectral analysis refer to the evaluation of the discriminant capability of each one of the 840 channels (fig. 4).

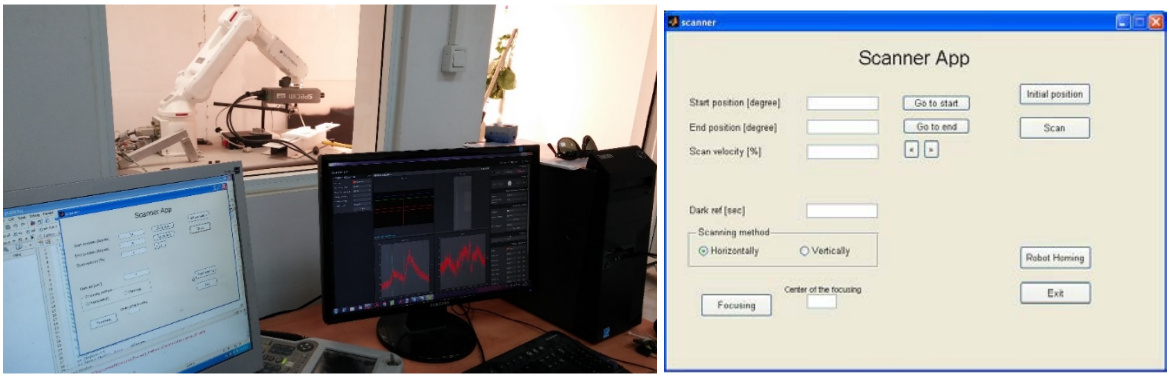

Figure 2: the application to control the robotic manipulator to acquire the hyperspectral image.

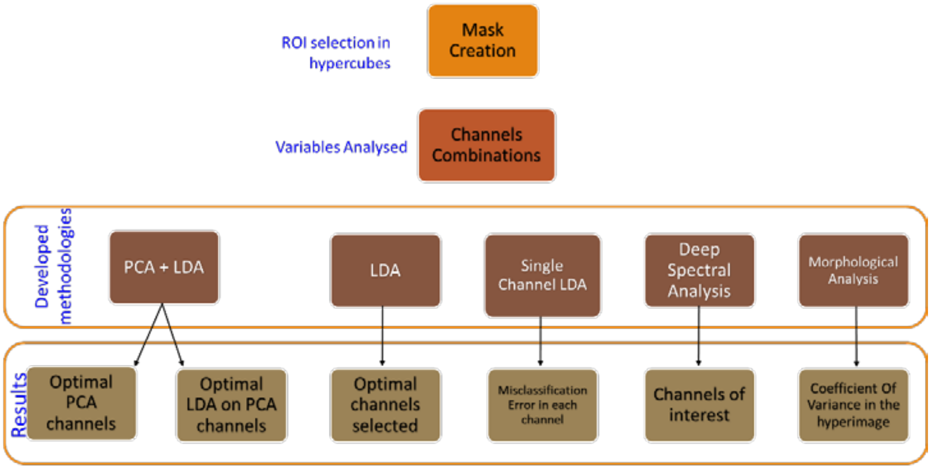

Figure 3: A schematic description of the analysis procedure.

For the CGMMV analysis we developed a CV analysis. The evaluation of the CV mask is made for 5 channels found by the wavelength selection method described above (466 nm, 546 nm, 612 nm, 711 nm, 839 nm) with five different window sizes (10 , 20 , 50 , 70 , 100 px) for each resized region.

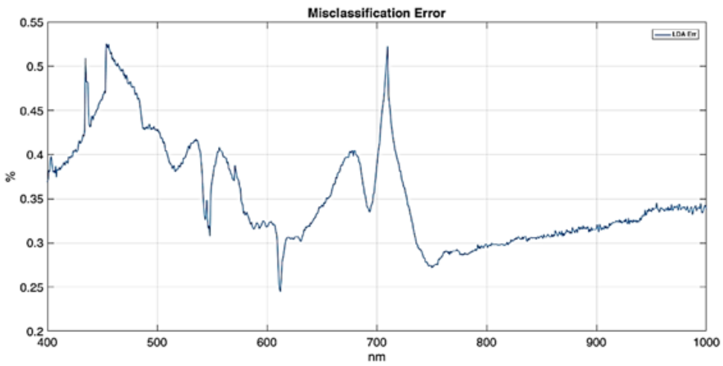

Figure 4: misclassification error of a single channel.

<u>Results and discussion</u>: Best results were found with the LDA for the combinations of 2, 3 and 4 wavelengths (table 1).

Looking at the disposition of the target wavelengths founded on figure 4, which represents the linear discriminant capability of each single channel, it is possible to see how the best discrimination not always corresponds with the combination of channels with the minimum misclassification error. We assume that the interaction among the wavelengths are important more than the single discriminant capability.

Table 1: LDA target channels for powdery mildew detection

Combinations	Misclassification	Channels [nm]			
2	13.5%	543	871		
3	11.0%	612	869	874	
4	10.8%	542	613	750	923

The two methods discussed and applied to the CGMMV detection showed a great potentiality in plant disease detection. The reduction of the wavelengths is very important for the determination of the target channels thanks to which it is possible to develop a specific sensor for a defined disease. For the identification of CGMMV symptoms in young leaves, three channels were selected with a linear misclassification error of 11%. The application of the first methodology comparing healthy old leaves with infected old leaves resulted with three optimal channels with a linear classification error of 12%.

The developed methodology of CV is very promising for the measurement of the leaf-light interaction. CGMMV causes different symptoms like shape deformations, color mottling (green and yellow), bubbling tissue. It was demonstrated that specific wavelengths succeed in differentiating the symptoms both by a visual inspection and by the CV analysis of a region of interest took inside the symptomatic leaf.

II. Development of Adaptive Routing algorithms

Problem definition: How to develop the routing and searching process for the ARS in a greenhouse so that stressed plants are detected as early as possible?

Scientific challenges addressed: (1) Applying Collaborative Control Theory (CCT) to the new field of agriculture is a challenging and promising contribution. Beyond understanding the new challenges, it is necessary to adopt and adapt existing techniques to the new requirements.
(2) Online adaptation for the routing and searching: The adaptation of the route by integrating searching algorithm to find all existing stressed or infected items (plants) will improve the overall performance, in theory and in experiments.

Methodology: The initial route can be mapped via CCT-based CRP-I (Collaboration requirement Planning) in the planning phase. The requirements are generated from Collaboration Requirement Metrix (CRM). CRP-II, the execution phase, obtains the plan from CRP-I. When more information is obtained during the monitoring process, the CRP-I plan can be adjusted, forming the basis for real-time adaptation to redefine the route and parameters to be measured by particular sensors. The plan will: re- route the robot; schedule the locations to be visited; order the information to obtain from each location; assign the sensors to measure and detect. Genetic algorithm is used for creating the route, and adaptive searching protocol will capture the plant behavior and stress status.
Experiments and planned tasks: The algorithm and policy have been defined, developed, refined, and included in several experimental simulations. For the next period, it is necessary to perform more complex and comprehensive experiments, **applying stress and disease scientific information from the UMD and ARL teams**. The plan is to develop the simulation experiments to validate and test the algorithm. After obtaining the proper search policy which will indicate the location to be more emphasized, the searching protocol and plan will be more effective and further refined by these experiments.

III. Fault Tolerant Interface design

Problem definition: How to develop an effective Error Detection and Conflict Prevention model in an Agricultural Robotic System establishment?

Scientific challenges addressed: In a multi-sensor framework of ARS (Agricultural Robotic System), interfacing and combining data from different sensors is a challenging issue – conflicts and errors must be prevented and reduced or they might inflate as the number of interactions between sensors and monitored objects increases.

Methodology: A mathematical model has been developed to increase the fault tolerance mechanism within the ARS. The model incorporates a weighting mechanism that gives a numerical weight for each sensor to increase the prediction accuracy when all the sensor data are combined. The weight is modeled as sensor-specific and time-specific, meaning that as time progresses and more data are gathered, the adaptive algorithm keeps updating the relative weight for each sensor. The model has further been developed into two different algorithms: Adaptive Learning Algorithm (ALA) and Cumulative Learning Algorithm (CLA). The difference between the two is the span of data-mining activity: ALA only considers the observed and actual data from one-step iteration ago, while CLA mines those two data types cumulatively since the beginning of the first iteration. It is found that CLA has a better performance of using observed data to approximate the actual data; meanwhile, ALA gives acceptable prediction while requiring less memory and runtime.

Experiments and planned tasks: The model has been tested on a small number of sensors, five sensors or less – which is a reasonable number of sensors to be put on the ARS robot; it performed satisfactorily. Furthermore, the model could still perform well even when the amount of actual data is limited to as low as 10% of the observed data. The experiment will continue testing the limitation of the model by accommodating a larger number of sensors in the model and varying values of error rate and conflict rate.

IV. Collaboration requirements algorithms/protocols

Problem definition: The research aims to facilitate the use of CCT in handling uncertainties in agriculture and design a CCT-based CPS (Cyber-Physical Systems) collaboration platform for prevention, detection and response system, targeting the stress situations and stress conditions in greenhouses.

Scientific challenges addressed: The premise is that for the ARS to be effective, this systems design needs to integrate and model the collaboration of humans, sensors, and robots.

Methodology and planned tasks: Cyber-Physical System oriented framework and workflow for agricultural greenhouse stress management has been developed and will be implemented and tested. The system has been designed to focus on monitoring, detecting and responding to various types of stress. Collaborative control theory is applied to deploy CRP (Collaborative Requirements Planning), address CEs (Conflicts and Errors) and enable a collaborative architecture for better CPS interactions. Analytic studies and computational experiments have been and will be conducted to compare our scheme with three other (non-CPS) schemes for greenhouse stress management.

V. Testbed Design

Problem definition: This task involves integration of other research tasks developed by the UMD and ARL teams for simulation and testing.

Scientific challenges addressed: The testbed, specifically designed for greenhouses, requires collaborative simulation and testing of a human-robot system for greenhouses based on continuous inputs and feedback from prototypes in three different, remote locations.

Methodology: During the 1st year of this project a graduate student from PRISM was working for two month at ARL on designing and developing the testbed. He created i) a realistic simulation of a robot in the greenhouse with automated navigation, and that also can be controlled by teleoperation (keyboard, joystick control). ii) Creating 3D models of robots in ROS, and making the robots moveable and adding physical and collision properties. iii) Creating automated movement of the actual physical robot in the lab, and keyboard control of the same using python programming. Using ROS to give commands to the Arduino software in the robot. An electric robotic cart is under development (fig. 5) and designed to carry the sensory system and operate in different HRI modes (collaboration levels). The cart is able to carry about 100 Kg and operate for several hours.

Figure 5: the electric robotic cart.

A real time environment mapping application was developed using the robot sensors while it moves in the environment and generate a 3D model of the environment (fig. 6). The mapping algorithm uses a stereoscopic cameras or a time of flight camera (RGBD).

Figure 6: A real time environment mapping application.

A collaborative simulator application was prepared at PRISM and ARL that includes a Robot with Time of Flight camera, capable of autonomous navigation and obstacle detection. Other features that have been created for the simulator include the ability for the robotic system to map its surroundings based on sensor data, greenhouse layout and plant models, and the option for a human operator to give on-line navigation commands to the robot. ROS robotics middleware and Gazebo simulation software have been used to accomplish these tasks. The above tasks were originated by ARL researchers and have been integrated with PRISM researchers.

Experiments and planned tasks: Preliminary tests on the collaborative simulator have been conducted between PRISM and ARL, were, the control station was located at PRISM and the robot simulator located at ARL. The robot simulator was controlled successfully from PRISM.

Upcoming tasks for the testbed would include experiment for controlling the Robot with Time of Flight camera, located at ARL or ARL greenhouse from the control station at PRISM; integrating the collaborative fault-tolerance interface and routing algorithms/protocols (described above), and inclusion of multiple sensors for stress detection, and sensor fusion of the same, also including researchers from UMD.