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Integrated Robotic System for Stress Detection in Greenhouses

Case Study 20

Research goal	To develop an effective, affordable robotic real-time inspection system which will enable early detection of biotic and abiotic stresses in greenhouse environments.
Beneficiaries	Greenhouse Crops Industry, Robotics and Imaging Industry, Phytopathologists.
Activities conducted in order to achieve the objectives	Determination of narrow spectral bands (at wavelengths greater than the visible spectrum) that identify crop disease upon emergence and as it develops (different signatures). Development of AI algorithms to successfully map the plants stress status. Development of Human – Robot interaction protocols Development of network/communication protocols Development of optimal time and location sampling algorithms
Funding	1 BARD award: IS-4886-16; $338,000
Publications	2 journal publications and 4 international conference presentations resulted from this study to date
Students involved	Three Ph.D and 3 M.Sc students, 1 post-doctorate fellow and 3 engineers
Stakeholders' collaboration	Collaboration with phytopathologists
Environmental impact	Application will lead to targeted and reduced application of pesticides that have negative environmental impact.
Social impact	Application will lead to reduced crop waste and loss for the farmers and increased food security for the general population.
Commercial engagement	The researchers from the 3 institutes are preparing a proposal to the Israel Innovation Authority together with a funding industrial partner.
Patents	None
Practical agricultural applications	A human integrated robotic system that will replace manual monitoring for greenhouse crop disease, enabling high resolution, dynamic mapping of the crop area. Early detection will lead to improved crop management (by preventing uncontrolled spreading of stresses causing irreparable damage), reduced crop loss and a decrease in pesticide applications.
Economic impact	The innovation is not yet implemented and a monetary value has not been assigned. Section 6 details the potential benefits and presents the potential magnitude of impact.

Green- Academic information; Yellow - Social and environmental information; Blue - Economic information

1 Objective: Robotic System for Detection of Stress in Greenhouse Crops

The research aimed to develop an effective and affordable high frequency and high resolution human integrated robotic inspection system to detect biotic and abiotic stress in greenhouse environments as soon as they emerge.

2 Research Activities

BARD award IS-4886-16 was granted to Avital Bechar (ARO), Shimon Nof (Purdue University) and Yang Tao (U of Maryland) in 2016 and is currently in its third year of research. See appendix A for details of the award.

Remote sensing methodologies currently available or being developed for robotic inspection of open field crops are unsuitable for protected crops grown in greenhouses (mainly due to light occlusion by the roof of the closed structure and an inability to obtain 3D images of the various plant elements).

The collaborative research aims to develop an HRI (Human-Robot Interaction) system that will improve performance, simplify and reduce costs of a fully autonomous robotic system and will provide the growers with real-time, early detection of plant disease.

The development of the methodology targets detection of Powdery Mildew, Cucumber green mottle mosaic virus (CGMMV) and Tomato Spotted Wilt Virus (TSWV). Future developments will pursue detection of potassium, magnesium and nitrogen levels. Detection of the plant stress is conducted by the integration of multispectral, hyperspectral, RBG (red-blue-green), thermal and 3D imaging technologies into a single robotic mobile platform.

Achievements to date are:

1. Novel hyperspectral image analysis algorithms were developed to enable identification of narrow spectral bands for TSWV detection, leading to successful identification of disease only a few days after disease inoculation. Signal patterns have been determined for different stages of disease progression.
2. Studies have been conducted to optimize the sampling resolution to achieve greater than 95% true positive (and <2% false positive) identification of TSWV.
3. The robotic cart platform has been successfully deployed in laboratory and greenhouse conditions. The cart incorporates location, orientation and depth sensors for successful spatial fusion, enabling unprecedented spatial and temporal resolutions of the crop elements. 3D mapping and spatial imaging of the greenhouse crop rows has been accomplished.
4. Work has begun on the development of the robotic arm that will act as the platform for the optimized imaging and measuring instrumentation. The arm will

access all relevant plant elements (e.g. top and bottom foliage, stem, variable heights and depth).

5. Human integrated algorithms have been developed and simulations are ongoing to evaluate the operation of a remotely-based sampling manipulator. The workflow of the integrated agricultural greenhouse stress management is within the framework of a MDR – CPS (Monitoring, detecting and responding– cyber physical system).

2.1 Publications

To date, 2 peer-reviewed publications have emerged from this study, as well as it being presented at 4 international conferences and meetings.

2.2 Capacity Building

Three Ph.D and 3 M.Sc students, 1 post-doctorate fellow and 3 engineers are involved in the research.

3 Stakeholder's Collaboration

The ARO group have worked closely with phytopathologists, collaborating on plant disease inoculation and visual identification of disease.

4 Commercial Engagement

The researchers from the 3 institutes together with a funding industrial partner are preparing a proposal to be submitted later this year to the "Magneton"[1] program of the Israel Innovation Authority.

5 Practical Agricultural Applications

Monitoring of greenhouse crops for bacterial, fungal and viral diseases are currently conducted by manual inspection. Performance is inadequate due to limited spatial (20 points per hectare) and temporal (7-10 days) resolution. By the time stress conditions are detected in a greenhouse environment it is often too late to undertake remedial steps and damage can be irreparable. Additionally, remedial steps that are taken can often lead to over implementation of pesticides, nutrients and water.

As disease (biotic stress) usually emerges from a few infected plants early detection is imperative in reducing the secondary spread of the disease.

The Human-Robot Integrated (HRI) system under development has many advantages. Identification of the specific narrow spectral bands in which a disease can be identified at

[1] https://innovationisrael.org.il/en/program/technology-transfer-magneton

its very early stages will enable the mounting of low cost multispectral cameras for disease detection at high temporal and spatial resolution. The technique enables the detection of the disease at 5 days post disease transmission rather than the 12-14 days post disease transmission by visual examination. The AI of the robotic system together with the human integrated element enables an appropriate response to the dynamic greenhouse environment. The system incorporates historic data, current conditions, unique aspects of each disease (spreading rates, seasonality, location on plant etc.) and will conduct repeated measurements when the real-time analysis indicates the need to perform additional targeted sampling.

Successful development and implementation of the system can lead to attainment or exceedance of crop yields and quality targets and is expected to lead to a reduction of approximately 80% in pesticide application in the greenhouse environment[2]. The human robot collaborations will effectively utilize the available resources to achieve the required tasks in less time, with less errors and less effort.

6 Environmental Impact

Application will lead to targeted and reduced application of pesticides that have negative environmental impact.

7 Social Impact

The innovative automatic system technology can solve practical problems of labor for farmers. Today, a single inspector is able to cover only 80 hectare per season per year.

Application will lead to reduced crop waste and loss at the farmers level and increased food security for the general population.

8 Economic Impact

8.1 Investment Cost

BARD contributed $338,000 in research funds between 2016-2020.

8.2 Benefits

8.2.1 Direct Benefits

To date, the robotic system focuses on detection of Tomato spotted wilt virus (TSWV) and Cucumber green mottle mosaic virus (CGMMV). TSWV causes crop losses in a wide variety of greenhouse-grown vegetable and ornamental plants across Canada and the United States. In particular, tomato, pepper and gloxinia crops have been devastated

[2] Personal communication with researchers

by spotted wilt. CGMMV has a narrow host range and is primarily limited to cucurbit species, including watermelon, melon, cucumber, pumpkin, squash, gourds, etc. The damage CGMMV causes to greenhouse cucumber crops can be extensive. Effects can result in substantial yield losses and a product with a comparatively low market value because of fruit abnormalities[3].

Once established and proven at the commercial scale, the expansion of the HRI system to additional common pathogens of greenhouse crops is a straightforward path. Globally, the total greenhouse crop area for vegetables and herbs was estimated at 500,000 hectares (of which 180,000 hectares are in Asia)[4]. Implementation even on 10% of this area would lead to an immense reduction in crop loss providing economic benefit to the farmer and augmented food security for the global population. Pesticide applications on cucumber and tomato greenhouse crops are documented as ~ 14 kg annually a hectare in Northern America and Turkey[4,5] with an annual cost of ~ $1500 per hectare in Turkey[5] and ~$11,000 in Mississippi[6] which is between 5 ~ 10% of the variable production costs[4,5] in both countries. A rough calculation assuming application of the innovation in 10% of Turkeys 40,000 and North and Central Americas 23,000 hectares of greenhouses respectively would mean reduced annual usage of ~ 8 tons of fungicides and annual savings of ~$3 million. Crop loss is expected to be reduced multifold (say from 10% loss to 1% loss)[7] which ultimately means the new technology could increase greenhouse yields by 10%. Taking the same presumed 10% adoption rate of the innovation for the greenhouse vegetable market in the US and EU (100 million tonnes in 2017[3]), this implies increased production of 1 million tonnes of greenhouse vegetables.

8.2.2 Indirect benefits

1. The new hyperspectral image analysis tool (OR-AC-GAN) developed as part of this research was shown to be advantageous in comparison to classic spectrum band selection methods and likely can be applied to additional imaging purposes in the agricultural or alternative sectors and can accelerate the in-field applications of hyperspectral imaging technology.

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[3] Agri-facts, Emerging Virus and Viroid Disease Risks on Greenhouse Crops, April 2018 https://open.alberta.ca/dataset/20f25b60-cd74-47d6-be5d-e8592f1b0097/resource/7be71cf3-2f32-4704-b7fa-15326c1b69d2/download/200-630-1.pdf

[4] RaboResearch, Food and Agribusiness, World Vegetable Report, 2018; far.rabobank.com

[5] (a) Economic analysis of pesticide use on greenhouse cucumber growing: A case study for Turkey; Journal of Plant Diseases and Protection, S. Engindeniz & D. Yücel Engindeniz , 113, **2006**, (b) An Economic Analysis of Growing Conventional Greenhouse Tomatoes in Turkey, S. Engindeniz; Practical Hydroponics and Greenhouses, 69, **2003,** 63-66.

[6] Greenhouse Tomato Budgets for Mississippi, Extension Service of Mississippi State University, Publication 2766 (POD-02-14), **2017**

[7] Personal communication with researchers

2. This first and unique 3D mapping of the full greenhouse crop area can likely be utilized for many additional purposes other than disease detection, some examples being real-time monitoring of fruit quantity, quality and ripening stages.

9 Economic benefit

As the innovation has not yet been fully developed and implemented, a monetary value was not assigned. Although section 6 describes specific potential benefits, the extent and significance of the innovation is likely to be in many additional realms.

Automated and robotic systems have been and are being developed for various agricultural labor intensive tasks (sowing, weed control, harvesting etc.) and use of sensors and imaging has been introduced into crop monitoring techniques. However, this robotic system is truly unique. This arises from its suitability for greenhouse environments, its high temporal and spatial resolution, its multi-sensor fusion systems and the HRI component that increases system performance and reliability and ensures a low-cost to the system.

10 Appendix A: BARD Awards

Table 1: The BARD award

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
I-4886-**16**	Development of a Robotic Inspection System for Early Identification and Locating of Biotic and Abiotic Stresses in Greenhouse Crops				
	Avital Bechar Shimon Nof Yang Tao	ARO Purdue U U. Maryland	$338,000	3 years	2016

11 Appendix B: Information providers: Personal communication

Avital Bechar – PI of BARD grant, Agricultural Engineering, ARO