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Automatic Phenotyping Systems for Agricultural Research in Different Modes

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Opinion

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Abstract

Automatic controlled environment phenotyping systems for agricultural research have been constructed in both industry and academia in the past 10 years, with diverse capabilities and applications. In this brief opinion article, we introduce different modes of automatic phenotyping, and discuss the advantages and disadvantages of each mode for different research goals.

Keywords: Automatic Greenhouse; Plant Phenotyping; Hyperspectral Imaging; Plant Sensors

Introduction

Plant science worldwide is under pressure to develop new varieties with higher yield and improved nutrition and quality to feed 9 billion people in 2050. The fastest way to test and breed plants is in controlled environments, which allow more consistent growing conditions throughout the seasons, and more generations per year. A breakthrough in data collection has allowed researchers to more quickly select varieties that can impact potential food shortages.

Plant phenotyping is the comprehensive assessment of complex plant traits such as growth, development, tolerance, resistance, physiology, yield, and the measurement of parameters that form the basis for more complex traits. Non-destructive sensor technologies such as 3D imaging, hyperspectral imaging, fluorescent imaging, and X-Ray scanning have become popular over the last decade as they can identify changes in plant physiology hidden to the human eye, allowing the detection of subtle physiological changes that occur during the early stages of plant stress responses, leaving plants intact. Over the last 10 years, agricultural research facilities with automatic plant phenotyping capabilities have been constructed in both industry and academia. Although they share a lot of common features, different modes were implemented for different research goals.

Mode 1: Move Plants to Imaging Stations

The most well-known mode of high-throughput greenhouse phenotyping systems where plants move to imagers were first installed in the US by seed breeding companies such as Monsanto (https://www.youtube.com/watch?v=nyAP1xmgur0) in the late 2000s, when grain prices were at historic highs, and companies were investing heavily in R&D infrastructure. This mode is still popular, and subsequent installations at academic institutions have followed, such as the systems in University of Nebraska-Lincoln and Purdue University [1].

These systems are installed in headhouses, which are sensor workshops adjacent to plant growth facilities. Plants are transferred from growing areas to the headhouse via conveyors to be scanned and handled at a series of phenotyping stations. This popular "grown in greenhouse, scanned in headhouse" model has successfully predicted useful plant traits, reported publicly [1-4].

Moving plants to imaging stations is the predominant mode of operation for a number of reasons. Sensitive imaging equipment is kept in clean, climate- and light-controlled headhouse buildings, rather than hot, humid often less clean plant growth areas. Plants can be kept in multiple independent growing environments and imaged with common equipment for consistency and to maximize use of the expensive sensors. When plants grow on automated conveyor systems, they can be shuffled methodically to randomize their positions.

However, this model has several potential drawbacks. The cost of building the automatic transfer system for moving the plants to the headhouse and back to the growing area is high. The transfer cycle can be complicated and long lasting (often over an hour), which limits the frequency and number of times each plant can be scanned through its lifetime. The transfer of plants through the conveyors causes shaking and may damage the plants (e.g. broken leaves) and can topple plants causing stem leaf and root damage. Light, temperature, and humidity variability and exposure to pest during transfer could cause the plant's biological functions to change before reaching the phenotyping stations, thus yielding imprecise measurement data.

Mode 2: In-Grow Room Imaging

To overcome these challenges of plant movement systems, researchers have shifted paradigms slightly by bringing sensors to the plants in the growing environments. Such imaging systems can contain ruggedized versions of the same cameras (hyperspectral imager, thermal imager, 3D camera, etc) with similar sensitivities as the phenotyping stations in the headhouse. The sensors are suspended from the greenhouse ceiling at a distance appropriate for monitoring the plants below. With this setup, there is no perturbation to the growth and treatment of the plants and the expensive conveyor systems are no longer needed. It also allows 24/7 continuous monitoring of the plants, making it possible for a better understanding of the changes and development of plant stresses in a much finer time resolution. Compared with agricultural remote sensing technologies such as cameras on UAVs, this system also allows better lighting control and camera position control.

Drawbacks to under-Ceiling systems include top-view only imaging angle, limited control of lighting conditions, and a limited volume of plants, which is determined by the size of the growing area they are installed in. Since the plants are not supposed to move in this mode, greenhouse micro-climates remain as issues for the plant uniformity, requiring statistical correction for positional effects. Plant canopies will also overlap at later stages, making the imaging and processing challenging if individual plant resolution is required.

Mode 3: Hybrid Systems

There have been other modes of automatic phenotyping greenhouses developed recently that attempt to exploit strengths and overcome challenges of both the previous systems. In Purdue University's first automatic greenhouse phenotyping system, plants are kept on a continuously rotating conveyor system for the whole growing cycle. The advanced imaging sensors are contained in an enclosed tower within the greenhouse integrated into a section of the conveyor, and they can be scanned every 20 minutes. This hybrid mode reduced plant size variance by 10-15% compared with a traditional greenhouse (unpublished). Although this hybrid solution addresses the microclimate issues of Mode 2, it is still comparatively expensive to build the automated conveyors in the greenhouse, and throughput is limited to the plants in the growth room. The environmental conditions also present a challenge to the sensors in the conveyor loop, which require additional engineering and technology development. A final hybrid system, developed by researchers at Iowa State University, is a robotic conveyance system that carries sensors between multiple growth environments. This "Enviratron" has higher capacity and multiple contained environments.

Conclusion

Automatic controlled environment phenotyping technology has been developing rapidly over the last decade due to collaborative efforts by plant scientists and agricultural engineers. Many such facilities have shown value, but each mode of operation has advantages and disadvantages. Choosing the right mode should depend on the specific research goals, the budget, and local environmental conditions.

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