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Phenotype-based Robotic Screening Platform for Leafy Plant Breeding

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Abstract: Automatically measuring the dynamics of plant phenotype is fundamental to the enhancement of our ability to dissect the agriculturally important traits and the understanding of plant development processes. This paper describes a high-throughput, automatic phenotyping platform to trace the phenotype of leafy plant and complete the screening function. First, a binocular stereo vision system is introduced to acquire images and transfer them to a host computer which processes, analyses and obtains some certain morphological parameters, such as leaf area and height. Second, according to the parameters obtained at different time points, a quantitative phenotype database and a prediction model of growth are established. Third, based on the models, a robotic arm executes the transplanting instructions to screen the plant with undesirable characteristics. The experiment results of leaf area show the measurement accuracy is higher than 90%, and this method can be applied in accurate measurement of plant phenotypic parameters. This work demonstrates how a high-throughput phenotyping equipment can construct an evaluation index system of plant growth during its whole cultivation period with high spatial and temporal resolution by machine vision, and offers an automated approach to the screening in plant breeding.

Keywords: Automated agriculture, Plant phenotype, High-throughput, Binocular stereo vision, Robotic arm, Screening, Plant breeding

1. INTRODUCTION

Global agricultural demand is expanding rapidly and agriculture faces tremendous challenges for crop production in the coming decades (Furbank et al., 2009). Plant phenotyping is the comprehensive assessment of complex plant traits such as growth, architecture, physiology, ecology, and the basic measurement of individual quantitative parameters that form the basis for more complex traits. So there is a necessity for quantitative analyses of plant phenotype to accelerate the screening of crops that have desirable characteristics to improve yields. By connecting the genotype to the phenotype, high yielding, stress-tolerant plants can be selected far more rapidly and efficiently than is currently possible (Phillips, 2010). Given the rapid development of plant genomic technologies, a lack of access to plant phenotyping capabilities limits our ability to dissect the genetics of quantitative traits (Li et al., 2014). At present, the use of high-throughput phenomics technologies in plants is a key element to improve the production of the crops with genotypically desired agricultural traits (McMullen et al., 2009).

Worldwide, the automated high-throughput phenotypic technologies emerge as a dominant position in plant breeding. Advances in high-throughput genotyping have paved the way for the development of large mapping populations and diversity panels of thousands of recombinant inbred lines for phenotyping (Neilson et al., 2015). High-throughput automated photogrammetry is now the ideal tool for phenotyping, and is becoming more advanced and popular, with the capacity to measure multiple morphological and physiological traits for an individual plant (Finkel, 2009). The fundamental task of photogrammetry is to rigorously establish the geometric relationship between the image and the object, as it existed at the time of the imaging event. Once this relationship is correctly recovered, one can then derive information about the object strictly from its imagery. This paper presents a binocular stereo vision system, a importnt kind of photogrammetry, defined as the process of deriving morphological information about an object through two parallel cameras (Mikhail, 2001), for gauging applications of plant's phenotypical parameters.

In the past decades, plant phenotyping relied largely on visual sorting, which was time-consuming and can generate inevitable bias. To meet the needs of current research, automatic and high-throughput phenotyping platforms have been developed (Hartmann et al., 2011). Multiple studies in phenomics highlight findings, such as time and background variation, relationships between traits, plant growth behavior

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as well as reproduction in various conditions (Furbank and Tester, 2011; Yang et a., 2013; Brown et al., 2014). Current phenotyping platforms include a variety of imaging methodologies to obtain high-throughput non-destructive phenotype data for quantitative studies of complex traits (Chen et al., 2014). At present, prestigious universities and research institutes have acquired these technologies such as the CT scanning laboratory for agricultural and environmental phenotypeing research and the McGill Plant Phenomics Platform (MP3) at McGill University (Canada), the Australian Plant Phenomics Facility at the University of Adelaide (Australia) and the Arkansas Center for Plant-Powered Production at Arkansas University (Vello et al., 2014). However, they have limitations such as structure complexity, costly equipment and unitary function. This paper presents the phenotype-based robotic screening platform which has accurate and fast measurement, and can achieve both functions of high-throughput phenotyping and screening simultaneously.

2. ROBOTIC AUTOMATION

The platform mainly consists of following items, a control cabinet, a binocular stereo vision system, a turntable, and a robotic screening arm. An Industrial Personal Computer (IPC), connected to a S7-200 PLC, is fixed inside the control cabinet and constructs the control system. The binocular stereo vision is installed in a dark enclosed room, a space that is equivalent to a camera obscura with two movable doors controled by photoelectric switch, which is disigned to prevent the effects of natural light. The turntable, a fixture to hold the potted leafy plant, consists of one zero position and 7 operation positions. Two cameras with the same intrinsic parameters, placed in parallel, are loaded onto the zero position vertically. Fig. 1 and Fig. 2 show the three-dimensional model of the platform and the material object separately.

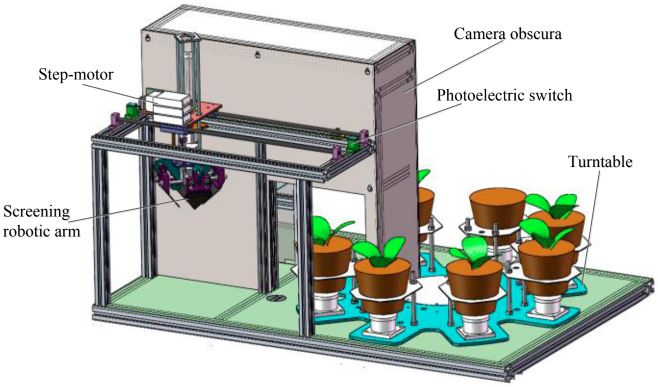

Fig. 1. Three-dimensional model of platform's mechanical structure

2.1 Automated High-throughput Phenotyping

The IPC is configured with the Intel Atom processor D2550, and Intel ® NM10 Chipset. The programming environment is VC++ 6.0 with Open Source Computer Vision Library (OpenCV). The implementation of the automated high-throughput phenotyping is shown as a flow chart in Fig. 3. After safety inspections, the doors move to a specified. position to turn the photoelectric switch on. The PLC connected to photoelectric switch can issue a series of pulses to step-motor to drive the rotary of turntable to next operation position until all the positions are measured. The cameras connected to the IPC are used to obtain images from the perpendicular position for phenotyping. The IPC allows the user to control the flash and image acquisition. The task of gathering images of the morphology is separated into 3 parts, leaf inclination angle, leaf projection area, and height, which are all captured by perpendicular binocular cameras.

Fig. 2. Photograph of phenotyping platform

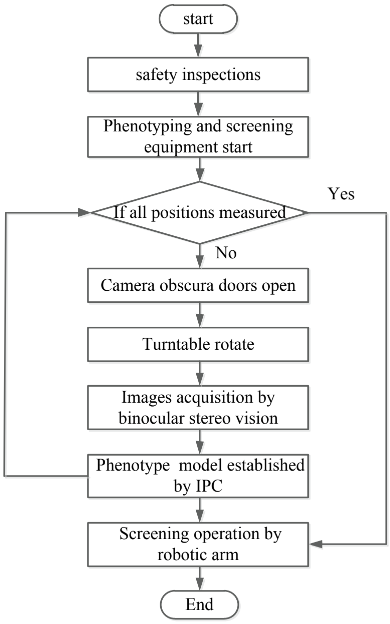

Fig. 3. The operation flow chart

2.2 Automated Screening

The robotic screening arm, constructed with a 3 degrees-of-motion, is shown in Fig. 4 (a). A quantitative phenotype database and a prediction model of growth are established in IPC according to the morphological parameters obtained at different time points. Based on the evaluation models, the robotic arm automatically executed the transplanting