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Field Phenotyping Robot Design and Validation for the Crop Breeding

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Abstract: Crop breeding is the focus of global agricultural hi-tech companies and requires phenotypes screening after growing and cultivating. However, rice phenotypic traits are not easily obtained with high-throughput in the field due to the complexity of unstructured environment. This paper presents a design solution of the field robot to construct visual space for measurement of rice traits .The truss system equipped with manipulator modules and vision system locates the object by the position information recorded in the phase of growing seedlings. 3 manipulators including the rice-separating manipulator, the height measuring manipulator and the panicle-expanding manipulator were designed by imitating people's actions such as pushing adjacent rice, expanding the panicle and rubbing rice long in order to reduce the overlap. Combined with them, 3 imaging sensors including the CCD camera, the structured light sensor and the laser sensor were introduced to measure a phenotype quantitatively. The simulations were designed to obtain workspaces of manipulators. The results showed that the volume of reachable space of clapboards of the rice-separating manipulator was 1.6×10^{-3} cubic meters, the effective movement of the height measuring manipulator was 1300mm and the maximum work area of the panicle-expanding manipulator was 32500 square millimeters. The results are consistent with those of manual operations. In conclusion, this paper describes an effective and reliable approach to acquiring phenotypic traits with high-throughput in the field.

Keywords: Field phenotyping robot, Plant phenotype, Plant breeding, High-throughput, Imaging sensors

1. INTRODUCTION

Facing the challenges presented by the rapidly growing human population and the slowly increasing rate of grain yield, seeking the high-production and high-quality potential of rice and exploring innovation of new technology and methods in crop breeding are extremely urgent（Tester, et al., 2010）. Plant phenotyping is a key link in understanding environmental effects and gene function , and plays an important role in crop breeding. Plant phenome is defined as traits that are decided or influenced by genome and environments, and can reflect the plant structures and compositions, or reflect the processes and results of plant growth and development(PAN et al.,2015). Phenotypes screening is required by the genetic breeding, which is connected with the genotype to select high yielding, stress-tolerant plants more rapidly and efficiently (Li et al., 2014). The conventional method for phenotypes screening is still manual, which is not only subjective but also time consuming (Yang et al., 2011). Phenomics, which still lags far behind genomics, has become a new bottleneck in plant biology and crop breeding (Furbank et al., 2009). To relieve this bottleneck, the use of reliable, fast, effective, multifunctional and high-throughput phenomics technologies and methods in plants is the key point (Yang et al. , 2013).

Modern technologies such as machine vision and remote sensing technology, are utilized for automatically acquiring various traits of plants, which are non-invasive and non-destructive. These techniques are often used to quantify complex traits such as growth, architecture, physiology and ecology for plant phenotyping due to the visualization of multi-dimensional and multi-parameter data in high resolution (Arvidsson et al., 2011). However, only imaging technology is not enough to meet the demand of high-throughput screening, automatic transport system is also needed.

At present, automatic, multifunctional, and high-throughput phenotyping platforms based on sensing technologies, automatic control technology and computer technology are

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developed to allow plant physiology and phenomics to better parallel plant genomics (Finkel et al., 2009; Furbank et al., 2011; Neilson et al., 2015). For example, CropDesign (Belgium) developed a high-throughput technology platform, called TraitMill in 2005, which enables large-scale automated analysis of the whole growth period phenotypes of plants. Lemnatec (German) developed another high-throughput technology platform, which is called Scanlyzer 3D system. Combined with image processing techniques, leaf area or biomass can be obtained. The University of Adelaide (Adelaide, Australia) put the Plant Accelerator into use for a throughput of 2400 plants per day in 2010.Besides, Huazhong University of Science and Technology in China developed some platforms for isolated traits (Huang et al., 2013; Yang et al., 2015). Generally speaking, these platforms has focused on the intensive measurement of individual plants by combining robotics and image analysis with controlled environment systems (Golzarian et al., 2011; Hartmann et al., 2011). Testing samples are planted in pots individually, then transmitted to the darkroom by the conveyor belt and taken pictures by imaging sensors. Finally, related traits are obtained by analysis and calculation. Although platforms are fast, high-throughput and non-destructive, there are some shortcomings that cannot be overcame. First, several imaging technologies like visible imaging have to face challenges of the overlap of adjacent leaves, which is difficult in image segmentation. Second, platforms are often used in controlled environmental systems (in growth chambers or in the greenhouse). However, using controlled environments to represent field environments has some well-known limitations. The field plants are under the harsh environment with different soil, solar radiation, wind speed and evaporation rates (White et al., 2012).

In this paper, the field phenotyping robot for the crop breeding was designed. 3 manipulator modules were introduced by imitating people's actions to measure rice parameters in the field in case of overlap. Several imaging sensors were also introduced to meet the requirement of various traits measurements. Manipulator modules were validated by simulations of workspace compared with manual operations. In short, this article present a new idea about the robot for field crop phenotyping.

2. OVERVIEW OF THE ROBOT

2.1 The Structure of the Robot

The robot was designed to be used in the field to realize automatic high-throughput screening for important traits of rice. The robot was consisted of 5 modules such as manipulator modules, vision system, auxiliary modules, control system and data analysis system. Manipulator modules included 3 manipulators which were used to imitate people's actions such pushing adjacent rice, expanding the panicle and rubbing rice long in order to reduce the overlap. Vision system was constituted of the CCD camera, the structured light sensor and the laser sensor. These imaging sensors were used to acquire the visualization of multi-dimensional data for various traits including plant height, leaf area, panicle number, tiller number and so on. Truss system was a main unit in the auxiliary modules, which was set in the field for transport. Control system was built based on direct current (DC) servo motors and EtherCAT bus. Data analysis system was applicable to analyse a large quantity of images and data for phenotypic traits. This paper focus on manipulators design and vision system. As shown in Fig. 1, truss system was built in the field, which could carry manipulator modules and vision system to a specified position by control system. The inspection chamber was fixed on the moving device of truss system and a CCD camera mounted on the top of it to acquire the top view of rice. Apart from it, the other two imaging sensors were fixed on the wall of the inspection chamber, with which they could move up and down under control. As the important part of the robot, manipulator modules were designed to cooperate with truss system to adjust the posture of single rice. Of course, the methods of rice planting were different from the norm. As shown in Fig. 2, precision planting was required so that the position information per plant could be easily obtained in the phase of growing seedlings, which enabled truss system to locate effectively. Important design parameters of the robot are given in Table 1.

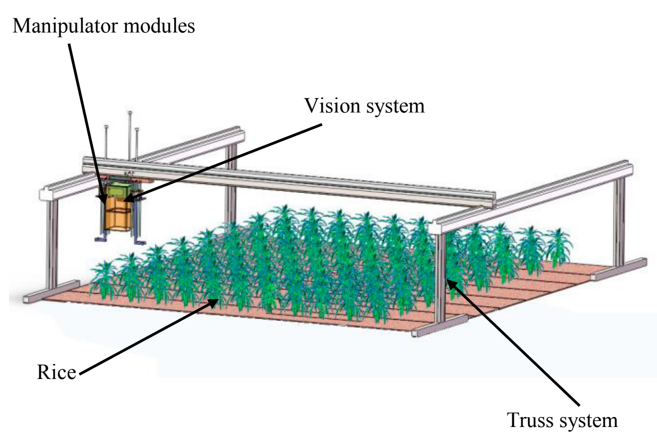

Fig. 1. Integrated field phenotyping robot system for the crop breeding

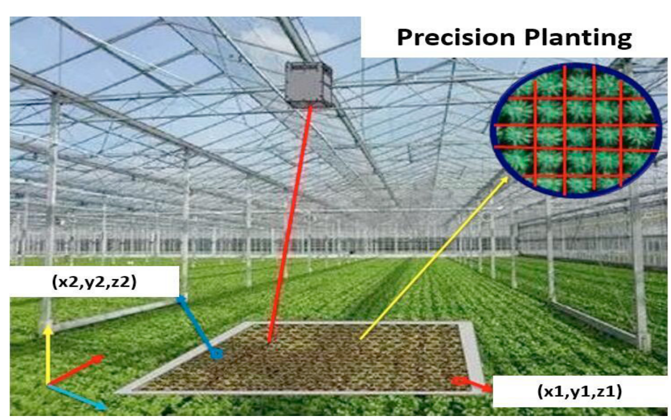

Fig. 2. Precision planting of rice in the field

2.2 The Workflow of the Robot

Acquiring rice phenotypic traits automatically in unstructured environment is not an easy task. Combining manipulators