HardwareX (2018) e00029

Contents lists available at ScienceDirect

HardwareX

journal homepage: www.elsevier.com/locate/ohx

Hardware Article

An automatable, field camera track system for phenotyping crop lodging and crop movement

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ARTICLE INFO

Article history:
Received 11 April 2018
Received in revised form 7 May 2018
Accepted 7 May 2018
Available online xxxx

Keywords:
High throughput phenotyping
Image analysis
Plant breeding
Video analysis
360 video

ABSTRACT

High throughput phenotyping systems enable rapid data collection for plant breeders. Some plant traits such as lodging, or the breaking and falling over of plant stems under wind stress, are complex and not easily measured through existing high throughput imaging platforms. We present designs for an automatable camera system that can be used in the quantification of crop lodging and crop movement under field wind conditions. Using a 360FLY 4K hemispherical video camera, industrial curtain track, and a raspberry pi computer, the camera system is capable of capturing aspects of crop lodging and movement unquantifiable by other phenotyping systems, such as unmanned aerial vehicles. The design is versatile and inexpensive relative to commercial camera track systems, and could be employed to quantify a variety of plant traits from detailed images in a field setting.
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Specifications table

Hardware name	Automated camera track
Subject area	Environmental, Planetary and Agricultural Sciences
Hardware type	Imaging tools Field measurements and sensors
Open Source License	CC BY-SA
Approximate Cost of Hardware	*$5550 (USD)*
Source File Repository	*https://github.com/Hortus/CameraTrack*

1. Hardware in context

High throughput phenotyping provides plant breeders detailed and timely information on plant traits. Many of the traits that plant breeders study exhibit quantitative variation, such as lodging resistance (stem breakage or falling over). Some quantitative traits can be measured objectively (eg. grain yield) while others such as lodging are typically measured subjectively using a visual rating scale (1–10) [1]. Though genes associated with lodging can be inferred from these rating scales

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https://doi.org/10.1016/j.ohx.2018.e00029
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[2], the simplification of such complex phenotypes into subjective scales reduces a breeder's ability to estimate precise genetic effects for the trait. Quantitative traits such as lodging are also influenced by environmental conditions (precipitation, breezes, and temperature) over the growing season that affect the plant response to severe wind events. Thus, providing more continuous data on crop lodging and any morphological changes prior to lodging in the field could improve selection for lodging resistance and many other quantitative plant traits.

The hardware presented enables detailed, automatable video imaging of agricultural research plots for capturing continuous variation of crop lodging and plant movement. The camera track system represents one of many new methods of high throughput phenotyping in plant breeding and other agricultural disciplines. Crop lodging severity has been quantified from unmanned aerial vehicle (UAV) images [3], however UAVs may not be operable in the presence of wind gusts that induce plant movement and lodging in situ. Our fixed system can address these limitations because it can operate under the high wind conditions that initiate plant movement and lodging, but prohibit drone flights. Commercial track based phenotyping systems exist, such as the PhenoSpex FieldScan, but the designs we present are open source and are simplified for smaller research plots. Furthermore, the hardware system could serve as the base for other sensors that offer data collection in a 360 degree field of view, and represents an accessible design for breeders looking to obtain large amounts of image and video data on plant traits in an automated fashion. Additionally, the system lends itself to quantifying novel aspects of plant-wind interaction (such as plant movement) from the video data collected.

2. Hardware description

The hardware constitutes an automatable camera system for the video or still imaging of agricultural research plots. The track system comprises commercially available hardware and electronics that allow for automatable high throughput phenotyping of lodging and plant movement. Material costs for the track system approximate the price of a commercial imaging drone. Additionally, the track system can be operated with higher frequency and greater autonomy than commercial imaging drones. The hardware as presented is designed to accommodate 360 degree field of view cameras. The maximum load on the track for the presented configuration is 22.7 kg, which is far greater than the typical mass of a 360 degree field of view camera (~100 g). This opens the possibility of deploying heavier sensing equipment, such as lidar detectors. Movement of the camera along the track is carried out by a motor driven through UNIX commands executed on a Raspberry Pi. This system was built to image crop lodging and plant movement in agricultural research plots, but it could be used to quantify many other aspects of plant growth such as, maturity and/ or nutrient deficiencies through the use of image data. The dimensions of this system are customizable to the research field and crop system under study. For our purposes, the track system is designed to span a 39.6 m (130′) research field, by 36.6 m (120′) in width at 2.7 m (9′) off the ground.

Other possible uses for this hardware include:

- Measuring color changes in plant leaves via RGB imaging that are indicative of plant maturation, nutrient deficiencies, or drought stress
- Capturing time lapse images of agricultural research plots
- Imaging agricultural research plots experiencing extreme weather events (wind, hail).

3. Design files

3.1. Design files summary

Design file name	File type	Open source license	Location of the file
Control Box wiring diagram	**Figure (PNG)**	CC BY-SA	**Available with article (Fig. 1)**
Motor and Pulley Mount Drawing	**Figure (PDF)**	CC BY-SA	**Available with article (Fig. 2)**
End Post Mounting System	STL	CC BY-SA	**Source File Repository**
Motor Box	STL	CC BY-SA	**Source File Repository**
Motor shaft_wood spacer	STL	CC BY-SA	**Source File Repository**
Timing Belt Pulley	STL	CC BY-SA	**Source File Repository**
Motor Post End Assembly	**Figure (PDF)**	CC BY-SA	**Available with article (Fig. 3)**
Motor Post End Assembly	STL	CC BY-SA	**Source File Repository**
Wood Corner Bracket	STL	CC BY-SA	**Source File Repository**
End Post	STL	CC BY-SA	**Source File Repository**
Motor Bearing	STL	CC BY-SA	**Source File Repository**
Oat Lodging Camera System Drawing	**Figure (PDF)**	CC BY-SA	**Available with article (Fig. 4)**

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