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Professor: A motorized field-based phenotyping cart

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A B S T R A C T

An easy-to-customize, low-cost, low disturbance, motorized, and adjustable proximal sensing cart for field-based high-throughput phenotyping is described. General dimensions, motor specifications, and a remote operation application are given. The cart, named Professor, supports mounting multiple proximal sensors and cameras for characterizing plant traits grown under field conditions. Professor easily adapts to multiple sensor configurations supporting detection of multiple target traits and has two axes of adjustable clearance by design. Professor is useful as a field-based phenotyping platform and offers a framework for customized development and application.

Specification	
Hardware name	Professor
Subject area	Environmental, Planetary and Agricultural Sciences
Hardware type	Field measurements and sensors
Open Source License	U.S. Public Domain
Cost of Hardware	$4000 (Without sensors or cameras)
Source File Repository [11]	http://dx.doi.org/10.15482/USDA.ADC/1431007

1. Introduction

Improving crop yield to meet the demands of a growing population is one of the biggest challenges faced by agriculture today [1]. The estimated increase of the world's population to 9 billion by 2050 will necessitate a >70% increase in agricultural production worldwide to meet growing demands in food, fiber, and bioenergy [2]. One of the biggest bottlenecks to crop improvement is the ability to rapidly phenotype large numbers of field grown plants at regular intervals throughout the crops growth cycle [3]. Current manual techniques are labor intensive and time consuming, and often introduce variation

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in the collected data [4]. To improve crop yields and quality, novel phenotyping approaches are needed to rapidly capture plant traits in the field.

Field-based high-throughput phenotyping (FB-HTP) is a novel approach to rapidly characterize (>1 m plot transect/second) plant traits using proximal and remote sensing or imaging. Current proximal sensing platforms include unmanned aerial systems (UAS), high-clearance tractors or other field implements, field scanners, and field carts [5]. Field carts for proximal sensing are typically low-cost, narrow-wheeled, lightweight platforms that have low soil disturbance, are easy to maneuver and transport, and can be designed to accommodate specific crop height and row spacing's, while deploying multiple sensors [6–8]. This enables users to deploy the cart and collect multiple plant traits across an extended duration and location range, as compared to UAS sensor payload and duration, and high-clearance tractors location range. Limitations of manually operated field carts include soil interface z-plane displacement anomalies (bumps), operator fatigue, and inconsistent collection speeds, all of which can affect data quality. Commercial field carts have been developed with drive-assisted technology to alleviate some of these limitations [7], but these are typically not fully customizable or openly available. Open source, low-cost cart options are needed by the scientific community to support research programs with limited budgets and/or with varied agronomic applications.

This paper presents Professor, an adaptable, low-cost, electric, motorized, remote-controlled, and adjustable field cart platform suitable for proximal sensing and imaging in a wide range of agricultural and environmental settings. This system utilizes readily available products for the frame, drive train, and remote control to alleviate the limitations of previous cart models. Professor is fully customizable to accommodate different crops, field designs, and proximal sensing arrays. The design presented in this paper was produced in full cooperation with local high school students, to educate and develop math and mechanical engineering awareness and skillsets, and to provide simple mechanical solutions that support solving complex field phenotyping problems.

2. Materials

All of the components needed for the assembly of Professor are listed in S. File 1. These standardized components are easy to obtain and relatively inexpensive, which enables replication or customization of Professor, based on program goals and available resources. How to build Professor is described in detail below.

3. Methods

The cart is comprised of a frame, wheel assembly, drive train, controller, battery, and the proximal sensing array(s). The sensing array(s) and data recording system (i.e. laptop or data logger) are mounted to the inner frame (Fig. 1)

Design Files Summary

Design file name	File type	Open source license	Location of file
S. File 1	XLSX	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 2	PDF	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 3	PDF	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 4	PDF	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 5	PDF	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 6	PDF	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007
S. File 7	XLSX	U.S. Public Domain	http://dx.doi.org/10.15482/USDA.ADC/1431007

Nomenclature key:

Height = h; Width = w; Length = l; Thickness = t; Inner diameter = id; Outer diameter = od.

3.1. Cart frame

3.1.1. Dimensions and structure

The cart is constructed primarily from 40 × 40 mm extruded aluminum T-Slot, framing members, and hardware (80/20 Inc., Columbia City, IN) (S. File 1). The cart consists of two frames, the outer frame and the inner frame, which are fully adjustable. The outer frame can increase/decrease in width to accommodate different row-spacing configurations and the inner frame can increase/decrease in height to accommodate different crop canopy architectures. The outer frame is approximately 200.0 × 207.2 × 190.0 cm (h × w × l), which supports the inner frame and is attached to the wheel assemblies. The inner frame is clamped inside the outer frame and is approximately 33.0 × 208.0 × 170.0 cm (h × w × l) (Fig. 2). The brackets that connect the inner frame to the outer frame, made from the same aluminum T-slot, are 16.0 × 25.0 × 4.0 cm (Fig. 2). The top and bottom of each bracket are attached to the inner frame by two flat aluminum plates, 16.0 × 10.16 × 0.64 cm. The plates hold the inner frame away from the bracket by 1.4 cm. A slider piece is bolted to the bracket and the vertical outer frame support bars move through the slider by loosening the wing nuts, allowing for vertical movement of