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Automated small-scale plant imaging system

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Abstract

For research laboratories, the use of commercial plant phenotyping systems is costly and often do not meet the requirements of the research project. As such, a small-scale plant imaging systems was developed for a biology research group at Washington University in St. Louis. A previous iteration of the device had been prototyped; however, several design requirements were not met, or were not mechanically efficient. Therefore, this paper proposes a second design consisting of a new bridge, trolley and canopy that can be transported easily by the user, and can be made with commercially available parts.

Introduction

Phenotyping plants are an important aspect used in plant agriculture, however, the progress which with the research is able to grow has been limited by the phenotyping techniques available [1,2]. For a laboratory, it is both labor and time consuming to map large population and obtain high throughput data [1,3]. As such, there are currently many systems being developed to tackle this challenge, where most systems include multiple sensing modules to allow for quicker data collection [4, 5, 6, 7]. These systems can also range from large-scale sensing systems that can be placed over a field for remote sensing [8, 9], to proximal sensing methods that can be deployed to a specific plot of land and maneuvered by the user [7, 10]. However, each system has their limitations, and commercially available products are often cost prohibitive to laboratories and institution [11].

Dr. Penczykowski, an assistant professor of Biology at Washington University in St. Louis, observes how the variation in climate affects infectious disease dynamics and pathogen stream diversity. Specifically, she researches the effect of powdery mildew on *Plantago lanceolata*, *Plantago major*, and *Plantago rugelii.* Her current method for collecting data involves manually counting, observing, and measuring plants within a 50 x 50 cm PVC frame quadrat placed on the ground. As such, this paper presents a design for an automated small-scale plant imaging system for Dr. Penczykowski's purposes.

Objectives

An interview with Dr. Penczykowski was conducted, and we attended a field visit to observe the current data collected method and type of environment a new data collection system would encounter. The required resolution of the images was also tested with a Nikon D3400 and macro lens (Nikon Corporation, Tokyo, Japan) to ensure that a researcher could identify the powdery mildew from a photograph.

Based on the interview and field visit, four main design objectives were identified:

(i) It can be moved to different locations by a single user
(ii) It could survey a field size of at least 1 x 1 m automatically
(iii) It maintained consistent lighting conditions between photographs
(iv) It can be disinfected between sampling sites

These objectives were used to guide any design concepts, and to determine if a design was meet adequately enough.

Past Work

A previously study was conducted to create an autonomous plant imaging system [12] as depicted in figure 1.

Figure 1. First prototype of an automated small-scale plant imaging system

The system consisted of a frame made up two aluminum beams (80/20 Inc., Columbia City, Indiana, USA) and two PVC pipes. The aluminum beam had racks attached to the top surface to allow the central bridge to move across the frame on powered gears. Additionally, it had four PVC legs that were detachable from the frame. The center bridge was made from similar aluminum beams (80/20 Inc., Columbia City, Indiana, USA) that supported a box containing all electrical components and a Nikon D3400 camera with a macro lens (Nikon Corporation, Tokyo, Japan). In all, the system could cover an area of 1.5 x 1.5 m, taking a total of thirty 20 x 30 cm images.

The system could be broken down into the individual components and transported as such; however, it required two people to carry the system to different locations. Additionally, the system did not address the lighting requirement, it could not comfortably fit into field vehicles for transportation, and the box which held the camera was not detachable. Due to this, the first prototype did not comply with all the user's needs and a second iteration was designed as described in this paper.

Materials and Methods

The second iteration consist of a foldable frame and legs, a bridge, a camera trolley, a canopy, a controller, and a battery (fig. 2).

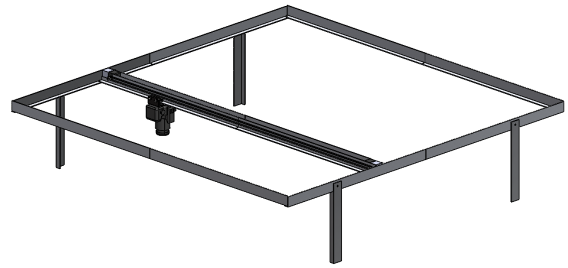

Figure 2. SolidWorks model of the second iteration

Appendix 1 describes the set the setup protocol and use of the system.

Frame and legs

The frame is made out of four PVC and four aluminum L-Beams (McMaster-Carr, Elmhurst, Illinois, USA) that can be folded together via hinge connectors. The legs are also made up of aluminum beams (McMaster-Carr, Elmhurst, Illinois, USA) that are permanently affixed to the frame and can be collapse together with the frame. Due to the need for disinfection after each run, aluminum and PVC are chosen. As described in Appendix 1, the central bridge only rest on the aluminum L-beams of the frames, and as such, PVC L-beams are used for the other two sides as it did not have to support any weight. The profile of the aluminum L-beams is selected based on the strength it provides to minimize deflection that affects the image resolution.

Similarly, the legs are made of aluminum so that they can be disinfected and have the strength needed to support all other components of the system. The legs also elevate the camera to a height approximately 30 cm above the ground, allowing (40) 20 x 30 cm images to be taken at the resolution needed for Dr. Penczykowski's research purposes. Appendix 1 describes how the user can collapse the frame and legs for easier transportation.

Further details on the design process of the frame is described in Appendix 3.

Bridge and Camera trolley

As described in Appendix 1, the frame supports a bridge that spans the entire length of the frame. It is also made from four aluminum beams (McMaster-Carr, Elmhurst, Illinois, USA) that can be folded in half. The bridge can move along the frame via a single motor attached to the bridge, and Spiderwire® () that pulls the bridge along the frame. The bridge also supports a camera trolley that was 3D printed with PLA on a printrbot and includes ball bearings that allows to the bridge to glide on the frame via a gear and pulley system attached to the bridge. A Nikon D60 (Nikon Corporation, Tokyo, Japan) can be attached by a standard mount to the trolley, and an IR LED sends signals to the camera to take photos automatically at preprogrammed time intervals.

All other movements are also pre-programmed and controlled by an Arduino UNO. The motion of the entire system is described in Appendix 2. In all, the camera mimics a 3D printer's x-y motion and stops at specific intervals to capture an image of the plants below.

To note, all electrical components are attached directly to the bridge. This allows the central bridge to be easily lifted off the frame during disassembly without having to disconnect anything.

Further details on the design process of the bridge and camera trolley are described in Appendix 4 and 5 respectively.

Canopy

For this system, the canopy diffuses the sunlight entering, and reduces the amount of shadow created on the plants. This ensures that key features of the focal plant species (e.g., herbivore or pathogen damage) can be seen clearly and evenly in the images.

To achieve this, a 75 x 78 inches canopy made from a Polycarbonate diffused sheet (Menard Inc., Eau Claire, Wisconsin, USA) was added to the second iteration. Acrylic is another option that could be considered as both acrylics and polycarbonates can diffuse harsh LED lights to create a softer and even light distribution. However, twin-walled polycarbonate is a stronger lightweight material and was selected as such.

The canopy can be folded by the user into eight sections as described in Appendix 1, reducing its overall dimensions to 20 x 39 inches for easier transportation.

Further details on the design process of the canopy are described in Appendix 6

Conclusion

Through this project, a second iteration consisting of a new frame, bridge, trolley, and canopy was designed. Several design concepts for each component were made using either wood or foam core, and the final design was built with the required material.

However, due to design challenges, a final design of the frame was not met, and with different design requirement from the users, the original frame was used instead. The redesign of the bridge and trolley continued and a smaller and more compact second iteration was made.

Lastly, a canopy that was previously ignored was added was able to diffuse the sunlight as required.

To further the project, a frame of a different size is needed and the electrical component of the system needs to be tested in the proper setting.

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