Three dimensional digitisation of plant leaves

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Abstract

Realistic plant models are important for leaf area and plant volume estimation, reconstruction of growth canopies, structure generation of the plant, reconstruction of leaf surfaces and agrichemical spray droplet modelling. This article investigates several different scanning devices for obtaining a three dimensional digitisation of plant leaves with a point cloud resolution of 200–500 µm. The devices tested were a Roland MDX-20, Microsoft Kinect, Roland LPX-250, Picoscan and Artec S. The applicability of each of these devices for scanning plant leaves is discussed. The most suitable tested digitisation device for scanning plant leaves is the Artec S scanner.

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Contents

1 Introduction

Accurate digital scanning and subsequent generation of 3D foliage models are important for realistic reconstruction of entire plants. The characteristics of the leaves affect agrichemical spray droplet impaction, retention and deposited droplet behaviour [3, 4, 5, 12, 19]. We discuss the capture of leaf surface geometry at a scale of 200–500 μm for the purposes of accurately modelling the movement of droplets on leaves.

A number of techniques are available for collecting a point cloud of a plant, including 3D scanning [8, 2, 17, 10, 9], photograph extraction [15, 13, 20, 14, 18, 1] and electron scanning microscopy [6, 11, 7]. Current research that uses 3D plant data includes estimating the leaf area and volume of the plant [9], reconstructing plant canopies [10, 14, 17], estimating wax growth [6] and analysing chlorophyll fluorescence on a single leaf [11], structure generation of the plant [1, 13, 20] and reconstruction of leaf surfaces [3, 4, 5, 12, 19].

Several different scanning devices, including the Roland MDX-20, Microsoft Kinect, Roland LPX-250 and Artec S, were used for data collection, and are discussed with their respective strengths and weaknesses for scanning plant leaves. We show that of these three scanners, the Artec S is the most versatile for scanning the plant species of interest; cotton, chenopodium and wheat. This work is a crucial component in the construction of virtual plant models [4].

2 3D digitisation hardware

A number of difficulties associated with scanning plants must be considered in the choice of digitisation hardware for plant leaves. The standard issues of accurately scanning 'sharp' edges is prevalent due to the thinness of leaves, as well as the lack of control over commercial post processing software which is bundled with the devices. Other difficulties associated with plant leaf scanning include environmental conditions and leaf obstruction, where plant leaves obstruct each other.

Environmental conditions, such as light and wind, have a significant impact on the geometry of the chenopodium and wheat plants. Chenopodium is very sensitive to light conditions [16], to the extent that the leaves change orientation minutes after light conditions are changed to perform the scan of the plant. Wheat is very sensitive to wind conditions due to the grassy nature of the species.

The nature of plant growth frequently leads to leaves being fully or partially obscured by other leaves when viewed from a direction perpendicular to the leaf surface. As the scanners used are most effective when operated from this position, care has to be taken when scanning these particular leaves.

Table 1: Summary of the scanner hardware tested for scanning plant leaves.

Scanner	Technique	Resolution	Cost
Roland MDX-20	contact scanner	50 µm	AU$7 000
Microsoft Kinect	IR depth scanner	1000 µm	US$149
Roland LPX-250 scanner	red laser scanner	200 µm	AU$10 000
Picoscan	structured light	500 µm	€1 999
Artec S scanner	structured light	200 µm	AU$15 000

The 3D scanners considered are a Roland MDX-20, Microsoft Kinect, Roland LPX-250, Picoscan and Artec S. These were chosen as they employ different scanning techniques and produce scans with a range of resolutions. Table 1 details each of the scanners tested for scanning plant leaves.

2.1 Roland MD20 contact scanner

The contact scanner provides the highest resolution point clouds at 50 µm resolution. This device works by extending a needle at the given resolution until it contacts the object's surface. Its method of scanning is unsuitable for plant leaves due to their soft and penetrable nature.

2.2 Microsoft Kinect scanner

The Microsoft Kinect scanner (Figure 1(a)) uses an infrared (IR) emitter and IR depth sensor to produce scans of the plants, but they are not sufficiently detailed for our use. The device's low resolution was not able to capture surface features at the required detail and further use of this device was ceased. This scanner was tested due to its low purchase cost, widespread availability and portability.

(a) Microsoft Kinect

(b) Roland LPX-250

(c) Picoscan

(d) Artec S scanner

Figure 1: Images of the scanning hardware tested on plant leaves.

2.3 Roland LPX-250 scanner

The Roland LPX-250 scanner (Figure 1(b)) uses a red laser scanner which moves in conjunction with a turntable to produce a 3D point cloud of the plant. This scanner has an advantage over the other scanners in that the entire plant is scanned at once and the automated movement of the device allows the software to correctly position all points at the resolution requested. Some disadvantages are that the movement of the turntable caused the chenopodium and wheat plants to move, producing incorrect scans of the plant. Also, as the direction of the laser beam is fixed, this caused horizontal and obstructed leaves to not be scanned. This scanner is not portable, making it unsuitable in a field situation, as well as having limited capacity.

2.4 Picoscan

Picoscan (Figure 1(c)) uses structured light and a standard camera to perform a planar scan of the plant. This requires the plant to be rotated manually a number of times to scan all directions. This is followed by an alignment procedure to ensure all planar scans are in the same orientation. This scanner requires a detailed calibration each time the distance between the object and camera changes to ensure an accurate scanning process. Picoscan also requires careful setup of the camera sensing properties, such as aperture, shutter speed and white balance, to ensure that the structured light pattern is reliably captured by the camera.

2.5 Artec S scanner

The Artec S scanner (Figure 1(d)) is the most expensive of the scanners tested and uses structured light to capture the geometry of the plant. This scanner captures points at the same resolution as the Roland LPX-250, but moves freely as it is a handheld device. This overcomes the difficulties associated with the Roland LPX-250 as the Artec S can be positioned to ensure that all leaves are scanned and is able to be transported to the location of the plant. The major difficulty associated with scanning plants using this device is ensuring that there is enough of the surface visible in the device's field of vision, due to large regions of empty space around the plant leaves. This scanner was most effective when performing a number of smaller individual scans, which were then aligned and incorporated into the point cloud.

3 Leaf surface scanning

During the project, individual scanners were available at different times. Hence, a direct comparison of the scanners on the same plant at the growth stage is not available. Therefore, only a comparison of large leaf feature scanning is feasible. Thus the ability of the individual scanners to capture the stem, petiole and leaf portions of the respective plants is not reported here.

3.1 Cotton leaf scanning

The cotton plant leaves were the most simple to scan. This is due to their large leaf area and geometrical shape. The scanners had difficulty accurately capturing the petioles due to their thin size and obstruction by the leaf to which they are attached. This was consistent across all scanners, with the exception of the Roland LPX-250, which also had difficulty scanning the horizontal leaves. The Artec S was able to produce the most consistent 3D representation of the leaves due to the handheld nature of the device, allowing it to be positioned appropriately to obtain the best quality data. A 3D interactive scan of a cotton plant obtained with the Artec S scanner is viewable in Figure 2 with Adobe Reader.

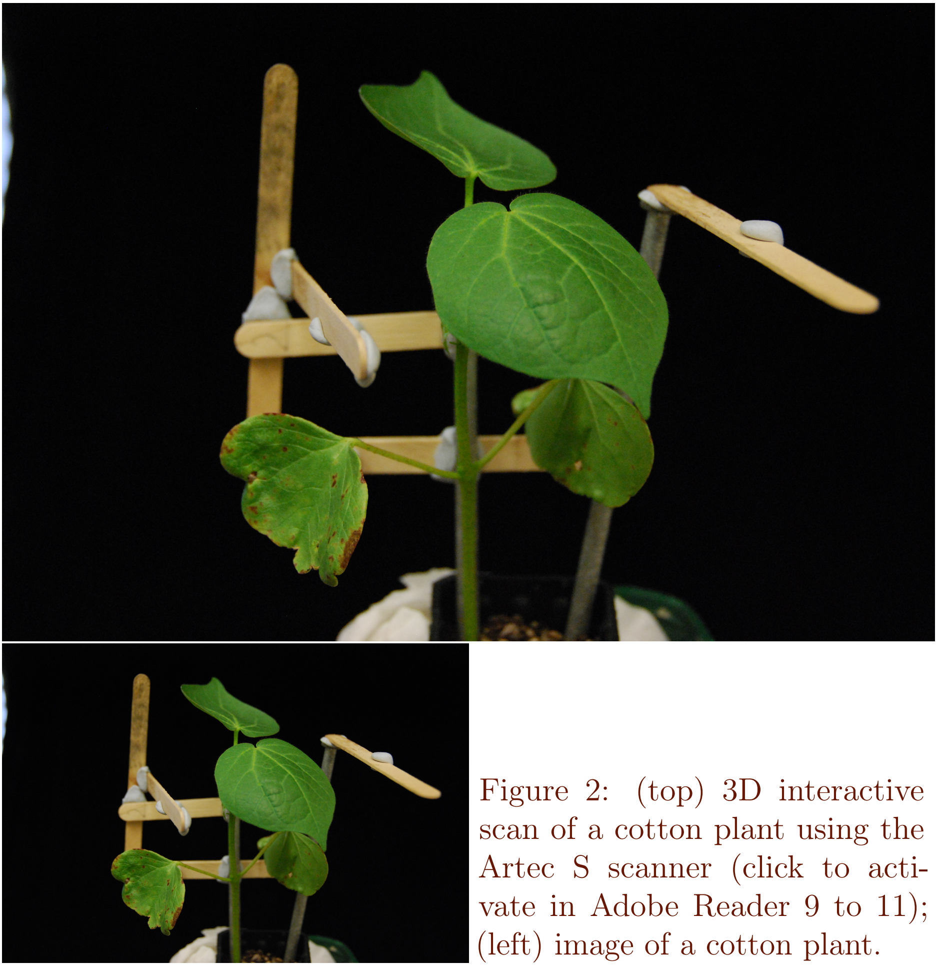

Figure 2: (top) 3D interactive scan of a cotton plant using the Artec S scanner (click to activate in Adobe Reader 9 to 11); (left) image of a cotton plant.

3.2 Chenopodium leaf scanning

The chenopodium plants were unable to be accurately scanned using the Roland LPX-250 due to the flexible nature of the main stem, which moved the plant with the torsion of the turntable. Difficulties in scanning these plants are further compounded by the jagged edges of the leaves. The petioles were also very difficult to capture accurately. The Artec S was the most consistent scanning device for chenopodium, and was able to accurately capture the shape of the large and small leaves, with minor errors at the tips of the irregular edge. A 3D interactive scan of a chenopodium plant obtained using the Artec S scanner is viewable in Figure 3 with Adobe Reader.

3.3 Wheat leaf scanning

Wheat plants are the most difficult of the three species to scan, as changes in wind conditions alter the shape of the plant. Due to this restriction, the Roland LPX-250 was unsuitable. The difficulty in scanning this plant type is further compounded by the thin leaves and restrictions within the provided commercial software to determine between real and artifact points. The Artec S software was the most configurable in this manner, but was still largely unsuitable. This scanner again produced the most consistent scans of the plants. A 3D interactive scan of a wheat plant obtained using the Artec S scanner is viewable in Figure 4 with Adobe Reader.

4 Conclusion

This article discussed the scanning of three plant species and the difficulties associated with the accurate determination of their leaf geometry to a resolution of 200–500μm. For scanning cotton, chenopodium and wheat plants, the Artec S scanner is the most versatile and consistent of the 3D scanners

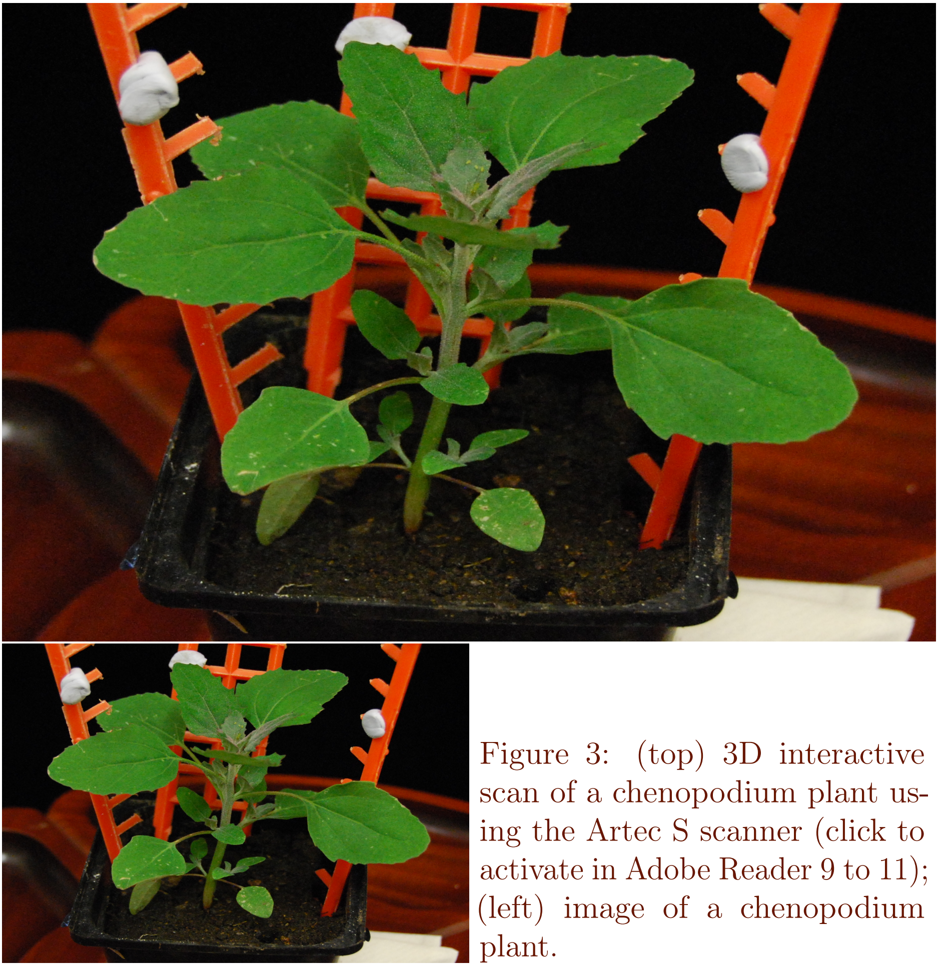

Figure 3: (top) 3D interactive scan of a chenopodium plant using the Artec S scanner (click to activate in Adobe Reader 9 to 11); (left) image of a chenopodium plant.

Figure 4: (top) 3D interactive scan of a wheat plant using the Artec S scanner (click to activate in Adobe Reader 9 to 11); (left) image of a wheat plant. The interactive 3D scan is viewable in Adobe Reader 9.0 or later (click the image to activate the interactive video).

discussed. This is due to the versatility of its handheld operation and the resolution achievable by the device.

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