Real-time Measurement, Computing and Visualization of Plant Structure

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Abstract. A method and software tool for measuring and reconstructing small plant in real time was presented. The key of this method lies in the feature points measuring with 3D digitizer and organ templates-based details 3D reconstructing. Firstly, several feature points were selected and measured by using a digitizer from the targeted plant. Then the morphological parameters of this plant could be calculated from these feature points, with its skeleton model was reconstructed in the process of measuring. For a details 3D reconstruction of the plant structure, organ’s 3D template was used, which was created by using 3D point cloud data measured from real plant organs, or created with interactive designing. This method has been tested in many plants, including crops and small fruit trees. The experiment results indicated that the proposed method is suitable for real-time measurement and multi-scale structural modeling of small plants.

1. Introduction

The rapid and automatic measurement and reconstruction of plant structure has a long history both in area of agronomy research and computer science [1, 2]. Recently, with the successful applications of various measurement devices in industry, more and more people reproduce 3D plant models from measured data. The calculation of morphological parameters and reconstruction from measured data is presently considered to be the most accurate approach to quantitatively represent the 3D architecture of a plant, because the actual features of plant geometry are taken into account.

Early in 1980s electromagnetic digitizers were used to measure the spatial position and orientation of stems and leaves from plant both for accurate reconstructing structure and giving a quantitative assessment to the plant geometry [3-5]. This kind hand-held device is robust for capturing the spatial characteristics of objects as such it is still a good choice for crop reconstruction to many people [6, 7]. However, it is a tedious and time-consuming job to digitize a plant with complex branch structure and crowned leaves, or canopy of plant population with crowded organs [8], and often not enough for accurately capturing the detailed organ geometry, e.g. measuring the detail leaf surface [9]. Several species of crops (such as maize, grain sorghum, cotton and so on) has been measured by using a
digitizer for analyzing their morphological architecture. However, the time and labor costs for measuring data still maintain a question for considering.

In recent years, with the wide applications of 3D laser scanner, measurement and reconstruction plant structure from laser scanned point clouds has been used more frequently [10-12]. Laser scanners enable us to rapid quantify the surface of an object as a dense set of points. This may be very useful for the rough measurement and reconstruction of big plant with sparse branches and leaves in their canopies. However, how to obtain the morphological parameters (such as the length, width and incidence angle of an organ) automatically from laser scanned 3D point cloud is hard to be addressed, especially for small plant. Because of limited scanning resolution and occlusion from other organs of other plants, parts of organs would be missed in the scanned point cloud. The missing information can be estimated by using existing or statistical knowledge about the morphological structure of plants [13]. However, automatic segmentation of different individual organs from 3D point cloud and then accurate calculation of morphological parameters still not an easy task [14].

Image-based method or computer vision is a more directed and low-cost solution for measuring morphological parameters. Many work have been done in this field under the rising requirement from plant phenotyping [15-17]. Multidisciplinary collaboration among the biological, engineering, and computer sciences are expected and also needed for a more automatic and accurate calculation of plant phenotyping.

This study presented a method and software tool for real-time measuring, computing and visualizing of small plant structure with low costs of time and manual labor. Our method used spatial characteristics points measured from plant with 3D digitizer as the input. These spatial characteristics points were then used to calculate morphological parameters, reconstruct skeleton model and details 3D model of the plant.

2. Data Measurement

A 3D digitizer Patriot (Polhemus Inc., Colchester, VT, USA) was used to collect data from target plant. We can describe the structure of plant with less complex structure by a small number of feature points. As such several feature points is enough for each internode on a branch of a plant. In this case, 6 points were selected from each internode, as Figure 1 shows. In which p1 is the crossing point of the stem and the petiole, p2 is the crossing point of the petiole and the leaf blade, others located on the margin of the leaf blade. Generally point p4 is the tip of the leaf blade, while p3 and p5 were digitized at the widest points of each leaf blade. While p0 means the root of the plant. The digitizing order was from root to top for each stands.

![Figure 1. Diagram of the selection of Feature Points](image-url)
Three extra points (from $e_0$ to $e_2$ in Figure 1) were also picked before measuring the feature points from the plant. These extra points are auxiliary and necessary for calculating azimuth angle and inclination angle of each leaf in the plant. All the extra points were selected near the root of the plant. In which $e_0e_1$ represents the northern direction. Triangle $\Delta e_0e_1e_2$ represents the ground.

3. Real-time Visualization and Parameters Calculation

Since all the feature points mentioned at Section 2 were picked by digitizer one by one. We can show the picked points on the screen and also calculate the morphological parameters of the measured plant while digitizing.

3.1. Display the Feature Points

OpenGL, an open source 3D graphics API, was used to display the feature points measured by digitizer. Each feature point was input as a vertex. The contiguous two points from a same internode were connected by a straight line. While the stem was displayed by connecting the first point of all internodes. As Figure 2 shows, the three points on the bottom of the black area are the extra points, as such the brown triangle represents the ground. This figure shows that one and half of an internode had been measured.

![Figure 2. Visualization of feature Points and Calculation Results](image)

By this way, the process of digitizing feature points from a plant were visualized (see Figure 3). This would give users a more intuitive experience, and tell him how many organs had been digitized, whether the picked feature points are right.

![Figure 3. Visualizing the process of digitizing a plant](image)

3.2. Morphological Parameters Calculation

Base on the digitized feature points, several morphological parameters of the plant could be calculated easily. For example, the length of leafblade is the distance between point $p_2$ and $p_4$; the width of...
leafblade is the distance between point \( p_3 \) and \( p_5 \). The length of internode can be calculated from point \( p_0 \) and \( p_4 \). To calculating the azimuth angle and inclination angle of each leaf in the plant, the three extra points were used as reference, in which the direction from point \( e_0 \) to \( e_1 \) represents the northern direction of the earth. And the triangle consisting of these three points represents the ground. The calculation results were displayed immediately on the screen of our software. Once a feature point was measured, the morphological parameters were then calculated and shown, as Figure 2 shows. In other words, this calculation was real-time.

4. Structure Reconstruction

When all the selected feature points of a plant were measured, the skeleton structure of this plant was also reconstructed. However, in some case a skeleton model is too simple. For example, this skeleton model didn’t produce the leaf area of the plant.

4.1. Simple Reconstruction

The simple reconstruction of a plant is to generate a 3D mesh model directly from these feature points measured from this plant. The key processes includes two tasks, one is the reconstruction of stem, another is the meshing of leafblade. The 3D model of the stem can be generated by using a sweep algorithm. The 3D model of the petiole can be also generated with the same way. We can see, from Figure 1, that four feature points were measured from a leafblade. To generate a 3D mesh from the four feature points of a leafblade, firstly B-spline curve was used to represent the edge of the leafblade, then Delaunay triangulation method was used to generation a mesh from the closed B-spline curve. As such a simple 3D model of the plant was reconstructed (see Figure 4a).

4.2. High-precision Reconstruction

The surface of a leafblade in real plant is often irregularity. The leafblade mesh used in the simple model was still not very accurate, and should reach incorrect area calculation. To give a more precise mesh model of a plant (see Figure 4b), we can use a more detail leafblade mesh to replace the mesh generated by using just four feature points. This kind detail leafblade mesh (see Figure 5) could be generated from 3D point cloud scanned from real plant leaves.
5. System Implementation and Results

5.1. System Implementation

With the regulation of data measurement, a software system has been implemented by using C++, and combing Polhemus Tracker SDK. This system firstly connect to Patriot 3D digitizer, then the measured feature points were detected and displayed in the interface. And the morphological parameters of the plant were calculated synchronously, as Figure 6 shows.

This system also provides several useful functions, including simple 3D reconstruction of plant, high-precision reconstruction, population generation, data exporting, and so on. This provides users a flexible tool for measuring and analysing plant structure.

5.2. Case of Applications

Our software has been used for morphological measuring of several plants, from seedling to maturity of the targeted plant.

Figure 7 gives an example for measuring a cucumber population. In this case 16 stands of cucumber were selected to collect spatial feature points by using Patriot 3D digitizer. It has been mentioned in section 2 that only 5 feature points were selected from each internode, as such points needed to be digitized from a plant was few. About fifteen minutes was used for the digitizing of a stand. The 3D model of each digitized plant was generated rapidly, with the morphological parameters.
6. Conclusion

The problem of measuring the morphological parameters and reconstructing its 3D model of plant was put forwarded in this paper, with considering low time and labor consuming. A method for measuring feature points and software tool for real-time computing and visualizing was presented. This method used spatial characteristics points measured from plant by using a 3D digitizer as the input. These spatial characteristics points were then used to calculate morphological parameters, reconstruct skeleton model and details 3D model of the plant. Currently the presented method is suitable for small plants. However, we know that this method is not enough for big plant which have more complex morphological structure. To this kind plant, computer vision-based or 3D scanned point cloud-based method should be better. Automatic, rapid, and non-destructive measurement and 3D reconstruction of plant is of great significance to plant phenotyping. And this is presently still an open problem because of complex natural conditions in real field. The key challenge roots not only in the complication of the plant canopy, but also the measuring method. All these problems are expected to be furthered and maintain the measurement of plants canopy a challenging topic.

Acknowledgments

This work is supported by Natural Science Foundation of China (No. 61762013), basic ability improvement project for young and middle-aged teachers in universities of Guangxi province (No 2018KY0078 and 2017KY0075), Scientific Research Foundation of Guangxi Normal University (No. 2017BQ018 ), and Guangxi Scholarship Fund of Guangxi Education Department. The authors also thanks the support from the Foundation for University 1000 Young Key Teachers by Guangxi Province.

References

[1] T. Watanabe, J. S. Hanan, P.M. Room. Rice Morphogenesis and Plant Architecture: Measurement, Specification and the Reconstruction of Structural Development by 3D Architectural Modelling, Ann. Bot. 95, 7: 1131-1143(2005)
[2] G. Sonohat,H. Sinoquet, V. Kulandaivelu, D. Combes, F. Lescourret. Three-dimensional reconstruction of partially 3D-digitized peach tree canopies. Tree Physiol. 26,3: 337–351(2006)
[3] P. Kaitaniemi, P. Room, J. Hanan. Architecture and morphogenesis of grain sorghum, Sorghum bicolor (L.) Moench. Field Crop. Res. 61: 51-60(1999).
[4] R. P. de MorasFrasson and W.F. Krajewski. Three-dimensional digital model of a maize plant. Arg. Forest Meteor. 150, 3:478-488(2010)
[5] J. L. Drouet, R. Bonhomme. Do variations in local leaf irradiance explain changes to leaf nitrogen within row maize canopies? Ann. Bot. 84: 61-69(1999)
[6] C. Fournier, C. Pradal. A Plastic, Dynamic and Reducible 3D Geometric Model for Simulating Gramineous Leaves. International Symposium on Plant Growth Modeling, Simulation,
Visualization and Applications (Shanghai, China, 2012).

[7] J. Wu, Y. Guo. An integrated method for quantifying root architecture of field-grown maize. Ann. Bot. 114: 841-851 (2014)

[8] M. Rakocevic, H. Sinoquet, C. Christophe. Varlet-Grancher. Assessing the Geometric Structure of a White Clover (Trifolium repens L.) Canopy using 3-D Digitizing. Ann. Bot. 86: 519-526 (2000)

[9] B. Loch, J. Belwar, J. Hanan. Application of surface fitting techniques for the representation of leaf surfaces. International Congress on Modelling and Simulation (Melbourne: MODSIM Press, 2005)

[10] E. Kaminuma, N. Heida, Y. Tsumoto, N. Yamamoto, N. Goto. Automatic quantification of morphological traits via three-dimensional measurement of Arabidopsis. Plant J. 38: 358-365 (2004)

[11] T. Dornbusch, P. Wernecke, W. Diepenbrock. A method to extract morphological traits of plant organs from 3D point clouds as a database for an architectural plant model. Ecol. Model 200: 119-129 (2007)

[12] G. Louarn, S. Carré, F. Boudon. Characterization of whole plant leaf area properties using laser scanner point clouds. Fourth International Symposium on Plant Growth Modeling, Visualization and Application s (Shanghai, China, 2012)

[13] D. Sylvain, J. Christian, R. Pascal. PypeTree: A Tool for Reconstructing Tree Perennial Tissues from Point Clouds. Sensors, 14: 4271-4289 (2014)

[14] A. K. Aijazi, P. Checchin, L. Malaterre and L. Trassoudaine. Automatic Detection and Parameter Estimation of Trees for Forest Inventory Applications Using 3D Terrestrial LiDAR. Remote Sens. 9, 946: 1-24 (2017)

[15] D. Rousseau, H. Dee, T. Pridmore. Imaging methods for phenotyping of plant traits. Phenomics in Crop Plants: Trends, Options and Limitations. Springer, New Delhi (2015)

[16] H. Scharr, H. Dee, A.P. French. Special issue on computer vision and image analysis in plant phenotyping. Mach. Vis. Appl. 27, 607-609 (2016)

[17] S. A. Tsafaritis, M. Minervini, H. Scharr. Machine Learning for Plant Phenotyping Needs Image Processing. Trends Plant Sci. 21, 12: 989-991 (2016)