Journal of Signal Processing, Vol.26, No.4, pp.123-126, July 2022

SELECTED PAPER AT NCSP'22

Measurement of Tomato Leaf Area Using Depth Camera

Nozomi Maeda, Hiroshi Suzuki, Takahiro Kitajima,
Akinobu Kuwahara and Takashi Yasuno

Graduate School of Sciences and Technology for Innovation, Tokushima University
2-1 Minami-Josanjima, Tokushima 770-8506, Japan
E-mail: maeda-n@ee.tokushima-u.ac.jp
{ suzuki.hiroshi, yasuno.takashi}@tokushima-u.ac.jp

Abstract

We describe a leaf region detection and leaf area calculation algorithm for estimating the growing conditions of small tomatoes. In leaf region detection, a color image taken by a depth camera is analyzed by image processing. The leaf region is divided into more than one hundred quadrangle meshs, and the spatial coordinates of the vertices of the mesh are calculated from the depth information obtained by the depth camera. To reduce the effect of measurement noise, an approximate surface expressed by a two-variable quadratic function is obtained, and the leaf area is calculated as the sum of the area of the meshs on the approximate surface. In the experiment, the algorithm will be evaluated using leaf measurements of small tomatoes in a greenhouse.

1. Introduction

In recent years, the number of people engaged in agriculture has been decreasing in Japan and became about 1.68 million in 2021[1]. The percentage of elderly people has increased to about 70%, and the shortage of the labor force has become a serious problem. Therefore, smart agriculture using robot technology and information and communication technology (ICT) have been attracting attention. Work automation and environmental control are expected to save labor and reduce the workload. In addition, the accumulation and transfer of cultivation techniques will lead to improved quality and yield.

In this study, we focused on the automatic gathering of crop growth data using sensors. This is expected to improve productivity by optimizing management operations on the basis of the gathered data. In addition, passing on cultivation techniques will be easy using the accumulated data, which is also expected to increase the number of new farmers.

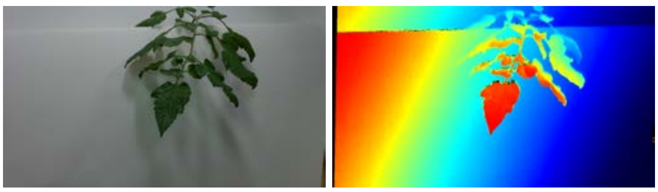
We focused on small tomatoes, which account for about 80% the horticulture production, because they are not affected by weather conditions and the introduction of agricultural robots is easy[2]. In this paper, we propose an algorithm for measuring the leaf area of small tomatoes using a depth camera. The leaf region is detected by using RGB images and the spatial coordinates are calculated by using depth information. After that, the leaf area is divided into a mesh and the approximation curve of the spatial coordinates is obtained. The area of the leaf is calculated as an integration of each mesh area from the approximated curved surface. The accuracy of the leaf area calculation results is investigated through comparison with the area of harvested leaves.

2. Leaf Area Measurement Algorithm

The leaf area is calculated from the leaf region in an RGB image and the depth information of each pixel, which is observed with a depth camera, Realsense L515. The specifications of the depth camera are shown in Table 1. Figures 1(a) and 1(b) show examples of RGB and depth images taken by the depth camera, respectively. The depth image is colored on the basis of the depth information: red means nearby objects, blue means distant objects, and black means undetectable.

Table 1: Realsense L515 specifications

RGB frame resolution	1920 × 1080 pixel
Depth output resolution	1024 × 768 pixel
Depth ideal range	0.25 to 9 m
Depth technology	LiDAR
Use environment	Indoor



(a) RGB image (b) Depth image

Figure 1: Images observed by depth camera

Since the depth camera measures the depth information using an infrared ray, sunlight causes strong noise in the depth information. Therefore, all images in this study were taken at night under LED lighting.

Figure 2 shows the flow chart of the leaf area measurement algorithm. First, a leaf region is detected from the RGB image by image processing in process 1. Next, the leaf region is divided into a mesh in process 2. Finally, the leaf area is calculated using the spatial coordinates of the vertexes of the mesh in process 3.

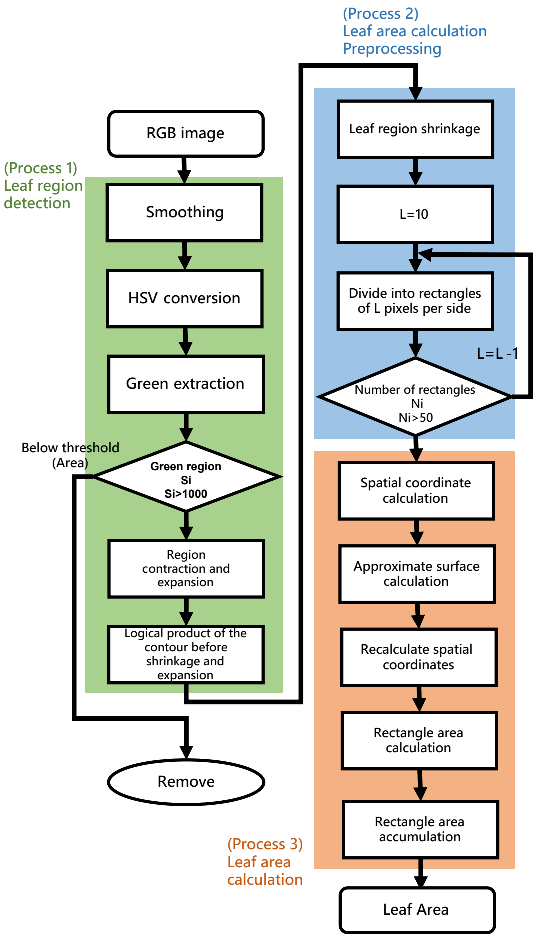


Figure 2: Flow chart of proposed algorithm

2.1 Leaf region detection

In process 1, image processing is performed on RGB images to detect leaf regions. First, the image is smoothed using a Gaussian filter to remove the noise. Next, the RGB image is converted to an HSV color space, which is represented by hue, saturation, and value, to extract the green region. In actual use, it is necessary to set the saturation and brightness thresholds in accordance with the light source, and in this study, the thresholds are also changed in accordance with the input image. Since the image contains green objects other than the leaf of tomato plants, such as trees outside the greenhouse, regions with an area less than the threshold 7500 pixels are removed.

To separate the leaf region from the stem region, region contraction and expansion are performed. In those processes, the fine details of the leaves disappear. Therefore, the region is expanded again and masked with the region before contraction.

The results of green extraction and leaf region detection are shown in Figs. 3(a) and 3(b), respectively. To obtain the leaf region , inside of outermost contour of the green region in Fig. 3(a) is filled. However,the space between the stem and leaves may also be filled depending on a overlapping of the leaves. In Fig. 3(b), the lower leaf region is correctly obtained but the space between the stem and leaves in the upper left part is filled.

(a) Green region (b) Leaf region

Figure 3: Results of leaf region detection

2.2 Preprocessing of leaf area calculation

Since a leaf has a curved surface in 3D, the leaf region is divided into more than one hundred quadrangle meshs, as shown in Fig. 4(a), so that the area of the curved surface can be obtained by the integration of small areas. At this time, the length of a side of the mesh is adjusted so that the leaf regionis divided into more than one hundred regions. Figure 4(b) shows an enlarged image of the leaf region within the red frame in Fig. 4(a).

(a) Square region (b) Magnified image of square region in (a)

Figure 4: Results of leaf area detection

2.3 Leaf area calculation

Leaf area calculation uses the depth information measured by the depth camera and yields the spatial coordinates of the vertices of the mesh. Since there is noise in the depth information, the approximate surface described as Eq.(1) is calculated from the spatial coordinates (x, y, z) to reduce the effect of noise.

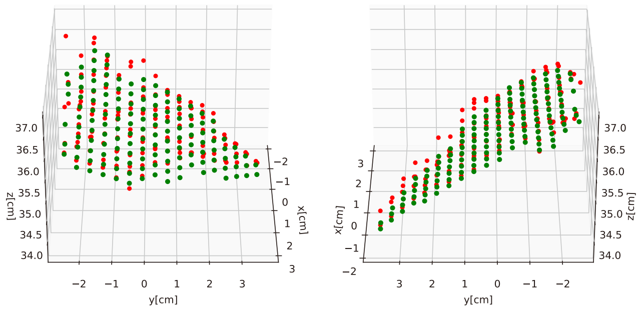
$$z = ax^2 + by^2 + cx + dy + e \tag{1}$$

Here, a, b, c, d, and e are constant coefficients determined by the least-squares method.

The spatial coordinates of the vertices are found again using the approximate surface formula. Figures 5(a) and 5(b) show the spatial coordinates of the vertices of the mesh. Red points are obtained from the depth information, and the green points are obtained from the approximate formula. The origin of the coordinate system is the position of the camera. The area of mesh-i, (S_i), is calculated by summing the areas of two triangles, as shown in Fig. 6; the area of the triangle can be calculated from the lengths of two sides and their angles θ_1 and θ_2, as follows.

$$S_i = \frac{1}{2}|\mathbf{ab}||\mathbf{bd}|\sin\theta_1 + \frac{1}{2}|\mathbf{ac}||\mathbf{cd}|\sin\theta_2 \tag{2}$$

Since there are excluded areas outside the region in the dividing process, the calculated leaf area will be smaller than the actual area. Therefore, the leaf area is expanded using the area ratio of the divided mesh and the remaining area.



(a) Spatial coordinates (0°)　(b) Spatial coordinates (180°)

Figure 5: Area calculation

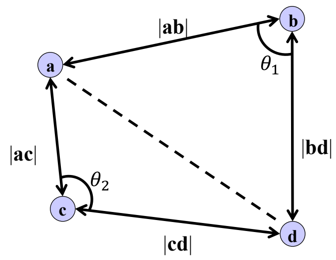
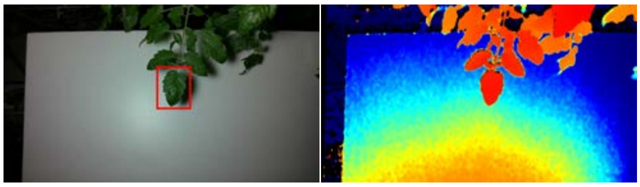


Figure 6: Angle between two sides and three points

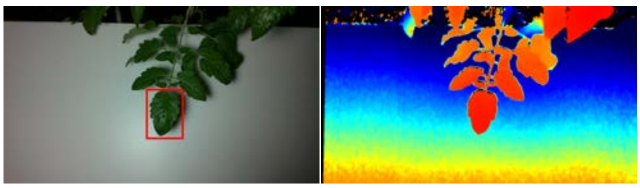
3. Experimented Results

The leaf area measurement experiments were conducted in a plastic greenhouse where small tomatoes are grown. In the experiment, white cardboard was placed behind the plant being observed to prevent overlapping with the background. The leaf images were taken from three directions: perpendicular to the front and looking up and looking down the leaf. The looking up, front, and looking down directions were 27°, 42°, and 53° respectively, from the horizontal plane. Figures 7, 8, and 9 show the images used for the verification. From these figures, it was confirmed that target leaves surrounded by red frame, are detected correctly.



(a) RGB image　(b) Depth image

Figure 7: Verification results for looking down direction



(a) RGB image　(b) Depth image

Figure 8: Verification results for front

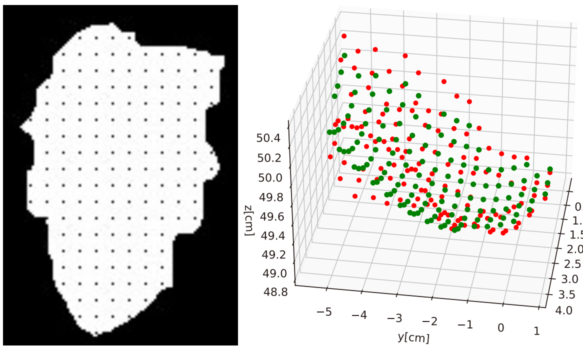
(a) RGB image　(b) Depth image

Figure 9: Verification results for looking up direction

Figures 10 to 12 show the detected leaf region and spatial coordinates of the leaf region, and Table 2 shows the validation results. To compare the true value of the leaf area, the harvested leaf is scanned and the area is measured using the image processing software ImageJ. In this study, the accuracy of correcting the approximate curve is verified by comparing the error of the leaf area calculated using the spatial coordinates before correction with that obtained after correction.

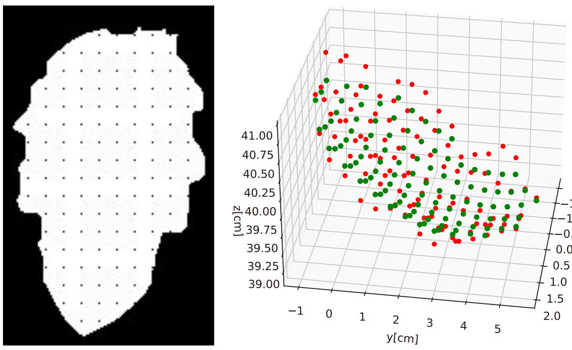
Table 2: Experimental results obtained using proposed leaf area measurement algorithm

Camara angle		looking down	front	looking up
A	Pixels of detected leaf region [px]	10497	16280	21264
B	Pixels of divided mesh [px]	6468	10700	14600
C	Area calculated from total number of pixels in (B) [cm^2]	21.4	23.7	25.2
D	Leaf area estimated from approximate surface [cm^2]	20.6	22.1	24.3
E	Correct (C) by the ratio (A) / (B) [cm^2]	34.7	36.1	36.7
F	Correct (D) by the ratio (A) / (B) [cm^2]	33.4	33.6	35.4
G	True leaf area [cm^2]		30.9	
H	Error in (E) relative to (G) [%]	+12.3	+16.7	+18.8
I	Error in (F) relative to (G) [%]	+8.0	+8.8	+14.6



(a) Green region (b) Spatial coordinates

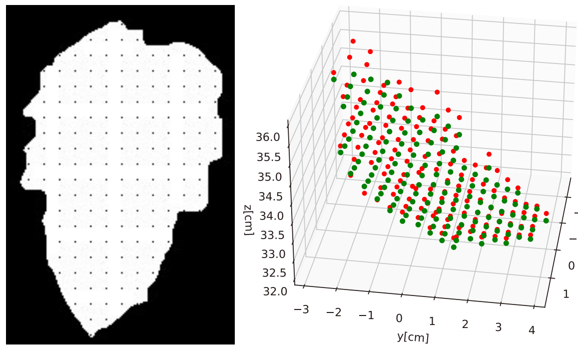
Figure 10: Detection region observed from looking down direction



(a) Green region (b) Spatial coordinates

Figure 11: Detection region observed from front

From the results, it was confirmed that leaves could be detected from images taking at night under LED lighting. From the result (I) in Table 2, the error is seen to be smaller when the image was taken from the looking down direction, while the error was larger when the image was taken from the looking up direction. The error of the leaf area calculated using the spatial coordinates obtained from the approximation curve was the smallest for all patterns, indicating that the use of the approximation curve enabled us to reduce noise. The accuracy of the area calculation tended to vary depending on the orientation of the leaf relative to the camera. When actually photographing leaves, it is recommended to position the camera perpendicular to the leaf.



(a) Green region (b) Spatial coordinates

Figure 12: Detection region observed from looking up direction

4. Conclusions

We proposed a leaf area measurement algorithm and tested it for small tomatoes grown in a plastic greenhouse. The approximate surface of the leaf was calculated using the spatial coordinates obtained from the RGB and depth images, and the noise in depth data was reduced. For leaf area calculation, it is confirmed that using the image taken from the looking down direction results in the smallest error.

Future tasks are to consider appropriate methods of obtaining images for overlapped leaves and a leaf separation method.

References

[1] Ministry of Agriculture, Forestry and Fisheries: Results of a survey on the dynamics of agricultural structure, Management Statistics by Commodity, Government Statistical Office (e-Stat), 2019.

[2] Ministry of Agriculture, Forestry and Fisheries: Large tomatoes management of institutional vegetable crops, Management Statistics by Commodity, Government Statistical Office (e-Stat), 2007.