Design of Crop Leaf Area Measurement using Webcam and Raspberry Pi

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Abstract

This paper describes an electronic system for measuring the number of leaves and the total leaf area. This system is built to make it easier for users to compute several leaves and measure leaf area electronically. The number of leaves and leaf area are used to determine the level of fertility of a plant. Several important factors in measuring leaf area are the accuracy and the speed of measurement. The stages conducted in this research consist of needs analysis, design, implementation and testing. The system built uses a mini PC Raspberry Pi as the data processor and a webcam to capture images. Moreover, the image is processed using Binary threshold and Otsu threshold methods. The results showed that the designed system was functioning properly with an error rate of 0% for the number of leaves calculation and a 0.39% error rate in the of leaf area measurement.

Keywords: image processing, leaf area measurement, raspberry Pi, binary threshold, Otsu threshold

1. Introduction

In agricultural and biological studies of plants, leaf area of crop plant is one of the important parameters in understanding photosynthesis, light interception, water and nutrient use and crop growth [1]–[4]. It is a notable index in plant growth study of crop. The leaf area of any crop is a determinant factor in mechanisms such as radiation interception and water and energy exchange. Consequently, leaf area measurement is almost an essential aspect in agricultural and biological studies in order to observe the growth of plant[5].

The leaf area can be measured by direct and indirect methods. Firstly, on indirect methods (destructive methods), leaves are stripped from the crop and measured using leaf area meter, such as expensive tool digital Leaf Area Meter. This method is useful for small plant populations, such as the plants grown in pots. Secondly, the non-destructive method, measurement is conducted based on linear measurements of plant. In general, the indirect method is carried out using a digital leaf area meter which is very expensive. Therefore, a lot of research is conducted by researchers to measure leaf area of plants with a sample and inexpensive tools but the results are similar or close to the actual results, as conducted by Sing et. al. [6] and Pandey and Sing [7].

Several studies about leaf area measurement using sensor or image capture were conducted by researchers. The study by Igatinathane et. al [8] used Photovoltaic (PV) panel to design a simple and practical leaf area meter. They used several components namely a PV panel as sensor, a wooden cabinet as enclosure, a flashlight as light source, and a digital multimeter for voltage measurement. A Study in [9] presented the development of simple and practical leaf area meter based on a solar cell. The system was constructed with 6 series-connected solar cells, a light source, and a parabolic reflector with opal glass for diffusing the light. In principle, both these studies conducted measurement by utilizing the resulting voltage and current measurements via a voltage and current measuring unit. Finally, the leaf area measurements were confirmed by comparing the results with measurements of grid counting method [9]. Another study in [10], the single leaf area could be computed easily based on the counting of the leaf pixels in digital leaf image. They claimed that analysis and experimental results had shown that the proposed method was an efficient and precise method for single leaf or leaf-like object area measurement. Another research with similar method was study in [11]. Our study proposed a device consist of a mini computer (Raspberry Pi) and a webcam that could compute leaves area based on the pixel count in highly accurate via image processing using Otsu algorithm [12]–[14] and binary threshold for getting threshold of image. In addition, the device could detect number of leaves using edge detection technique [15], [16].

2.   Materials and Methods

2.1.   Hardware design

The leaf measuring device used in the test is illustrated in Figure 1. The device is composed of a webcam, pure white plate (size A4) and Raspberry Pi. The webcam is used to capture leaves image from pure white plate. The pure white plate is used to for placing leaves and The Raspberry Pi is used to process picture data from the webcam and calculate area leaves overall. In general, Raspberry Pi is used for monitoring and controlling systems [17]–[21]. This research uses Raspberry Pi 3 Model B which is built using Broadcom processor 3837 ARMv8 64bit.
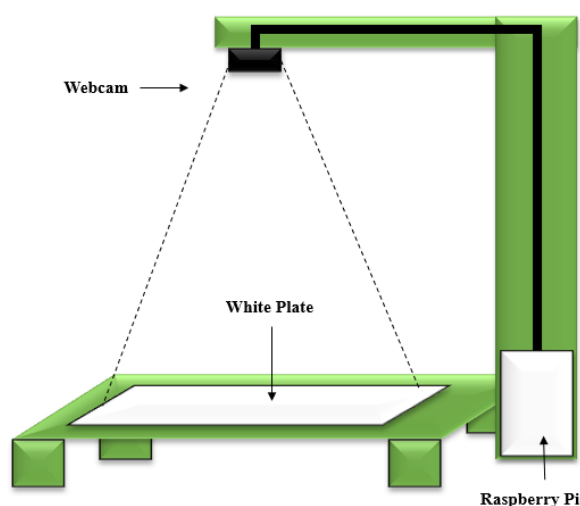

Figure 1. Leaf measuring device design

2.2. Software design

A software design describes the data processing flow of leaf area measurement. It will be run on the Raspberry Pi 3 using Python programming and stored data in the database. The software design flow diagram for the system is shown in Figure 2.
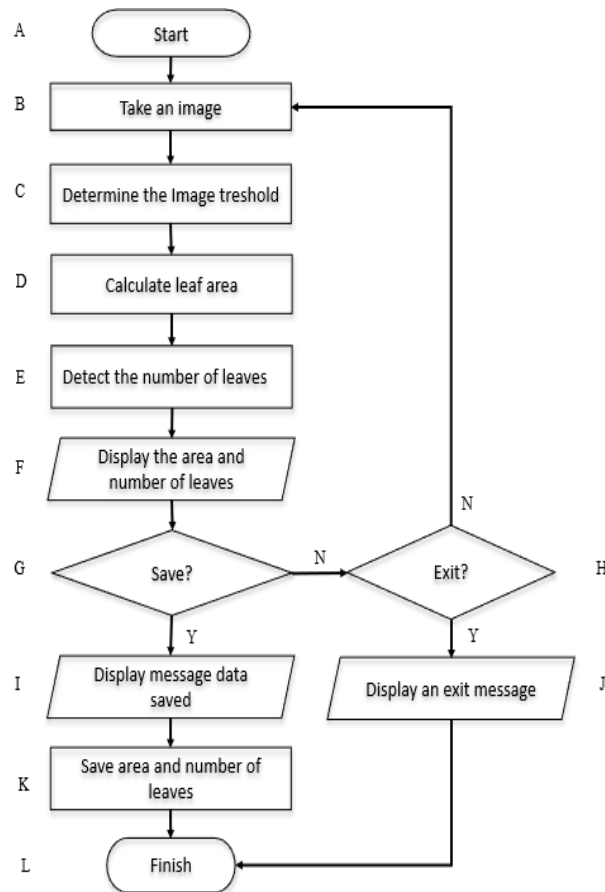

Figure 2. Overall system flowchart

The following is an explanation of the flow diagram in Figure 2: (A) the program is started by initializing all variables; (B) then, the program will activate webcam and take a picture on a white plate board; (C) after that, the captured image will be converted into a black-and-white image using binary threshold and Otsu method; (D) then, the system will calculate the area of the image (leaf); (E) next, the system will count the number of leaf objects using edge detection method; (F) furthermore, the system will display the leaf area and number of leaves; (G) the next stage, the system will ask the user for saving the results; (H) if the results will not be saved then the system will ask user for exiting program; (I) if yes, the results will be saved to memory, then the system will show the message that data has been saved; (A) if yes for exiting, the system will display a message that user has left the system; (K) Finally, the system will store the number of leaves and leaf area to a database; (L) and the program has finished.

The software would activate the camera to capture an image, and save it to directory of the memory card. After acquiring the image, the system would be run automatically image processing. The specific steps were as follows: changing the color image into a grayscale image by Otsu threshold method and converting the images into binary image.

Thereafter, the image calculation step was conducted to find the object area to be calculated. The image from threshold result would be proceed to calculation of the image area (leaves) stage. The leaf area would calculate using formula (1):

$$area \leftarrow (a / r) * n \tag{1}$$

where a is background area, r is camera resolution, and n is number of white pixel. Then, the calculation results will be stored in the database. Another calculation was counting the leaves number on the captured image. Another task was to count the number of leaf objects in the image. Detection of objects was conducted by detecting the edge of the object and creating a square to the object. After that, the system would count the number of squares in the image. The pseudocode for measuring leaf area is shown in Figure 3.

```
_, frame ← camera.retrieve()
frame ← frame[10:700, 90:1000] # Restrict the a ROI
frame ← cv2.medianBlur(frame, 15)
framebw ← cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
# Thresholding
_, framet ← cv2.threshold(framebw, 125, 255, cv2.THRESH_BINARY_INV
|
                          cv2.THRESH_OTSU)
# Deleting noise
framet ← cv2.morphologyEx(framet, cv2.MORPH_OPEN, (5, 5))
# Stop count if lost object
bgs ← mog.apply(framet, learningRate=0.05)
im_out ← framet
cv2.countNonZero(im_out)
n ← cv2.countNonZero(im_out)
a ← 451.5;
r ← 251576;
area ← (a / r) * n #formula (1)
```

Figure 3. The pseudocode for measuring leaf area

In addition, a pseudocode for counting the number of leaves is shown in Figure 4.

```
# Count object
frame2 ← framet.copy()
c, h ← cv2.findContours(frame2, cv2.RETR_TREE,
cv2.CHAIN_APPROX_NONE)
totalContours ← 0
# only square object is counted
for i in xrange(len(c)):
    if h[0][i][3] == ROOT_NODE and cv2.contourArea(c[i]) > 50:
        totalContours ← totalContours + 1
```

Figure 4. The pseudocode for counting the number of leaves

2.3. Measurement of the leaf

Measurements were conducted on seven leaf types, including jackfruit leaves, water guava leaves, lime leaves, Indonesian bay leaves, mango leaves, guava leaves, and galangal

leaves. Each type was measured three times in three different positions, accordingly horizontal, diagonal and vertical. In addition, one type of leaves was measured with different amounts of leaves in every its measurement. Finally, the system was tested to add up the total area of the total leaves number that had been measured.

3. Result and Discussion

3.1. Software testing

The program display is shown in Figure 5. The program will display the frame continuously and wait for the save or exit button to be pressed. Meanwhile, the program display for calculating the area and number of leaves is shown in Figure 6. The program will display the area and number of objects continuously and wait for the save or exit button to be pressed.
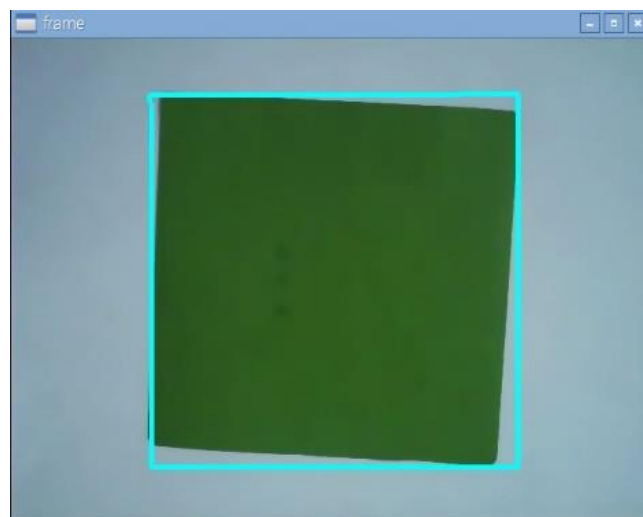
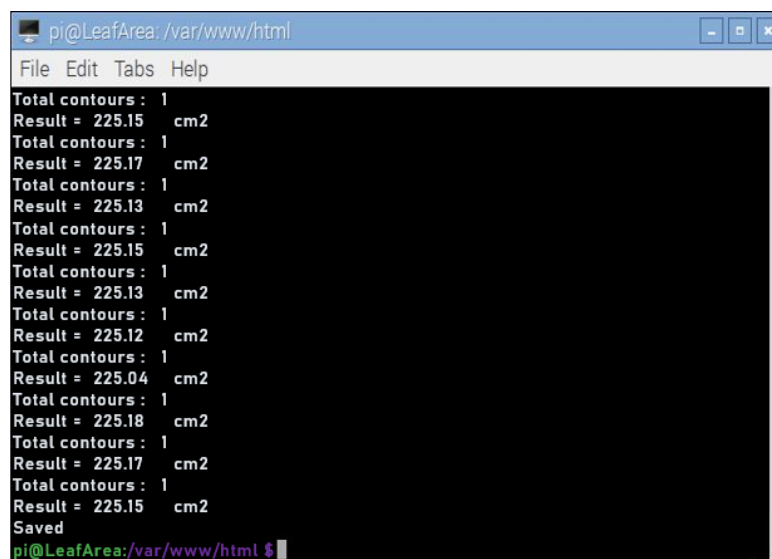Figure 5. Display of a frame camera leaf area meter

Figure 6. Display of the program results for calculating the area and number of leaves

3.2 Measurement of leaves area

In this test, six types of leaves were used to measure their area and compared with manual measurements using millimeter block paper. In addition, testing was carried out on one kind of leaf with a large number. This test was conducted to determine the system's ability to calculate the total number of leaves and the total leaf area from continuous measurements. The images result of the automatic measurement of jackfruit leaf measurements are shown in Figure 7. Figure 7a, Figure 7b, and Figure 7c show the automatic measurement of the area of two jackfruit leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 8d. Leaf area and number of leaves result is shown in Table 1.

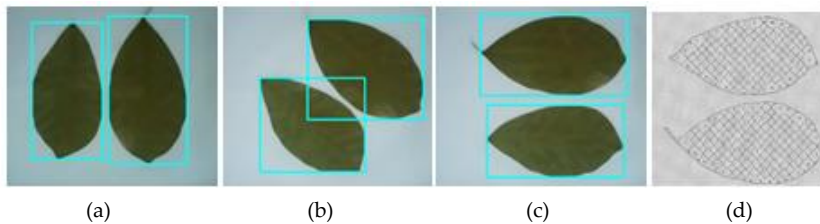(a)   (b)   (c)   (d)

Figure 7. Display of jackfruit leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

The images result of the automatic measurement of guava leaf measurements are shown in Figure 8. Figure 8a, Figure 8b, and Figure 8c show the automatic measurement of the area of two guava leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 9d. Leaf area and number of leaves result is shown in Table 1.

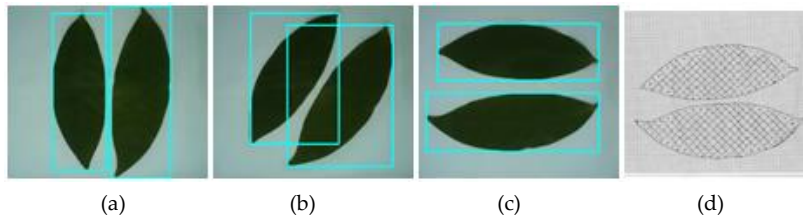(a)   (b)   (c)   (d)

Figure 8. Display of guava leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

The images result of the automatic measurement of lime leaf measurements are shown in Figure 9. Figure 9a, Figure 9b, and Figure 9c show the automatic measurement of the area of four lime leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 10d. Leaf area and number of leaves result is shown in Table 1.

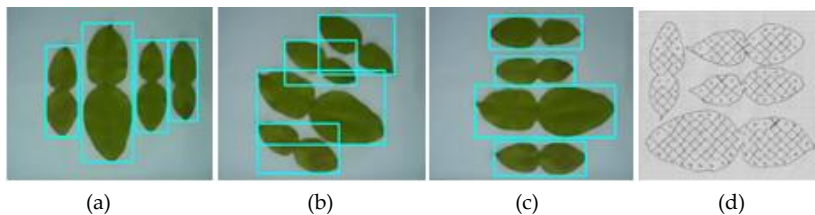(a)   (b)   (c)   (d)

Figure 9. Display of lime leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

The images result of the automatic measurement of Indonesian bay leaf measurements are shown in Figure 10. Figure 10a, Figure 10b, and Figure 10c show the automatic measurement of the area of three Indonesian bay leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 11d. Leaf area and number of leaves result is shown in Table 1.

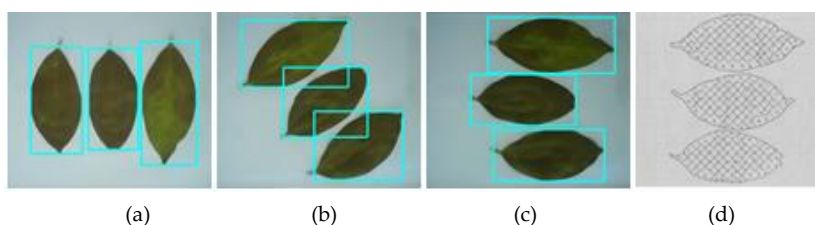|			
(a)	(b)	(c)	(d)

Figure 10. Display of Indonesian bay leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

The images result of the automatic measurement of mango leaf measurements are shown in Figure 11. Figure 11a, Figure 11b, and Figure 11c show the automatic measurement of the area of two mango leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 12d. Leaf area and number of leaves result is shown in Table 1.

(a)	(b)	(c)	(d)

Figure 11. Display of mango leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

The images result of the automatic measurement of galangal leaf measurements are shown in Figure 12. Figure 12a, Figure 12b, and Figure 12c show the automatic measurement of the area of three galangal leaves in various positions, vertically, diagonally, and horizontally, respectively. Manual measurement was conducted using millimeter block paper as shown in Figure 12d. Leaf area and number of leaves result is shown in Table 1.
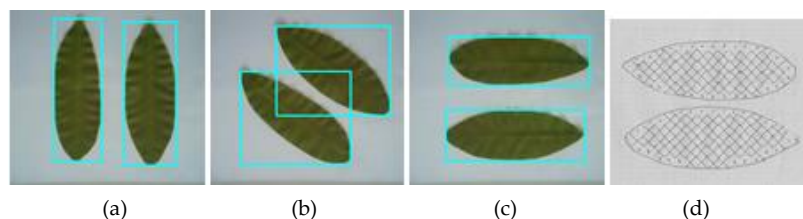

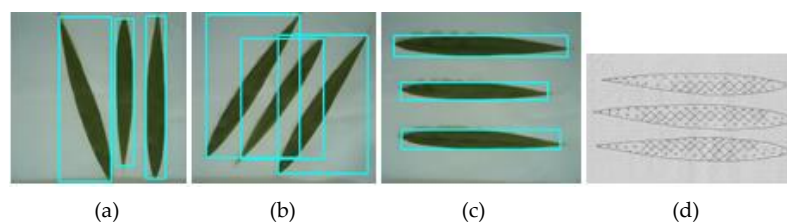|			
(a)	(b)	(c)	(d)

Figure 12. Display of galangal leaf measurement in three positions, a) Vertical position, b) Diagonal position, c) Horizontal position, and d) Manual measurement

All test results for measuring the number and area of leaves are shown in Table 1. Overall the system is able to count the number of leaves correctly. However, in the measurement of leaf area there is a difference. The highest difference, which is greater than

the results of manual measurements, occurs in the measurement of the area of Indonesian bay leaves, which is 3.36 cm² in a vertical position. While the highest difference, which is smaller than the manual measurement results, occurs in the measurement of the area of orange leaves in the horizontal position, which is -2.97 cm².

Table 1. Result of jackfruit leaf measurement

Leaf	Position	Measurement					
		Number of leaves			Leaf area (cm²)		
		Manual	System	difference	Manual	System	Difference
Jackfruit	Vertical	2	2	0	177.93	176.88	1.05
	Diagonal	2	2	0	177.93	178.83	-0.9
	Horizontal	2	2	0	177.93	179.19	-1.26
Guava	Vertical	2	2	0	166.73	166.04	0.69
	Diagonal	2	2	0	166.73	166.64	0.09
	Horizontal	2	2	0	166.73	166.76	-0.03
Lime	Vertical	4	4	0	131.45	133.28	-1.83
	Diagonal	4	4	0	131.45	134.01	-2.56
	Horizontal	4	4	0	131.45	134.42	-2.97
Indonesian bay-leaf	Vertical	3	3	0	151.48	148.12	3.36
	Diagonal	3	3	0	151.48	149.90	1.58
	Horizontal	3	3	0	151.48	151.45	0.03
Mango	Vertical	2	2	0	129.29	129.25	0.04
	Diagonal	2	2	0	129.29	129.77	-0.48
	Horizontal	2	2	0	129.29	129.76	-0.47
galangal	Vertical	3	3	0	86.8	87.47	-0.67
	Diagonal	3	3	0	86.8	88.08	-1.28
	Horizontal	3	3	0	86.8	88.20	-1.4
Average difference			0				-0.39

3.3 Continuous leaf measurement

Tests were carried out to determine the number of leaves and the total leaf area captured by the camera and the results were displayed on a temporary website. In continuous testing, measurements are made on a number of leaves continuously. The leaves measured in this test are guava leaves. Measurements were carried out ten times. Each measurement was carried out on a different number of leaves. Figure 13 shows ten guava leaves displays measured by the system. The ten measurement results can be seen in Figure 14.
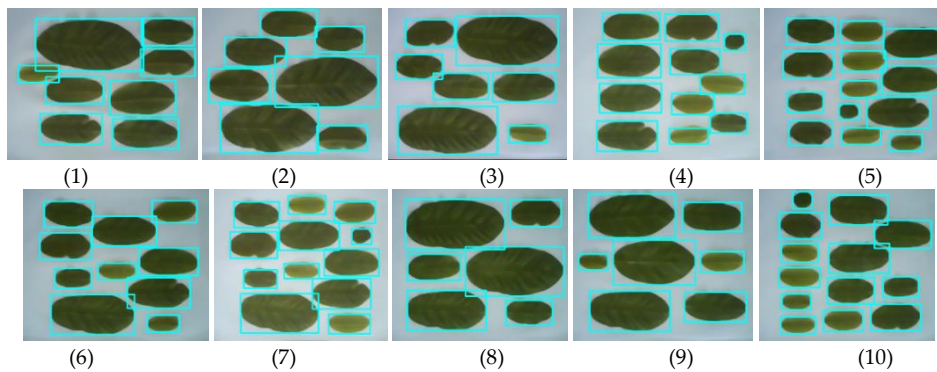

Figure 13. Ten guava leaves displays measured by the system

Temporary data of Leaf Area Meter

Select all	Number	Leaves area	Leaves number
☐	1	198.80	8
☐	2	225.04	7
☐	3	210.87	7
☐	4	165.99	11
☐	5	169.35	13
☐	6	176.14	10
☐	7	191.46	12
☐	8	223.08	6
☐	9	199.24	7
☐	10	167.87	13

For deleting leaves data | Total

	Leaves area	Leaves number
0 Selected	1,927.83	94

Delete

Figure 14. Display of ten measurement results by the system

Data on the total leaf area and number of leaves can be saved into the main web as shown in Figure 15.

Temporary data   **Main data**

Data of Leaf Area Meter

Select all	Number	Name of leaf	Area	Total
☐	1	Guava	1,927.83	94

0 Selected   **Delete**

Figure 15. Display of measurement results in main web

4.   Conclusion

Based on the research results, the design of leaf area measurement device could be concluded to have functioned properly. Every area of leaves could be calculated accurately. In addition, the device could be compute the scan results that performed continuously. The experiment results show error percentage for counting the number of leaves is 0% and the error percentage in measuring leaf area is 0.8%. The results of measurements and computations of the number and area of leaves can be stored in a database and can be viewed on the website display. Future research is to implement a system that uses Internet of Things technology so that measurements can be conducted anywhere and data can be stored in the cloud. Another addition is to include machine learning methods to predict plant growth based on leaf measurements and anticipate plants not thriving.

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