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Development of Plant Growth Monitoring in Hydroponic using Image Processing

Nor Maizatul Mona Husin[1,*], Norazlin Ibrahim[2], Hanisah Salam[1]

[1] Department of Electrical Engineering, Politeknik Merlimau,77300 Merlimau, Melaka, Malaysia
[2] Department of Electrical Electronics, UniKL Malaysian France Institute, Bangi, Malaysia

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ABSTRACT

Hydroponics is a growing trend in agriculture in Asian countries. Ensure that the plant receives the proper concentration of nutrients solution, air temperature, light, and humidity for healthy plant grow. Lack of one of these factors may cause plants to be stunted and the production of crops to fail. The experiment conducted at two different places for environmental manipulation thus the plant growth observed. Direct measurement of plant growth usually destructive and can cause partial or whole plant damage. Image processing can be used to create an automated system for monitoring plant growth in height changes. The primary objective of this project is to develop a monitoring system for plant growth in hydroponic plants that located at two different places and to access data derived from images to observe plant height. The experiment was setup and plant images were captured for 19 days then run in PyCharm software to get the plant heights. The analysis tool were Minitab and Orange software. The results show the image processing method was strongly correlated with manual measurement having an R2 value of 0.914. Image processing method can replace the manual and outdoor plants give better growth.

1. Introduction

Plants are the main source of living things in this world to enable us to survive well. In this new era of modern technology, the plant can be grown using an efficient and easier method which is a hydroponic method. Ngadimon *et al.,* [3] said environmental factors such as surrounding humidity, temperature, lighting quality, water, pH condition and concentration of nutrients solution are very important for a plant to grow. These parameters should be provided to a hydroponic plant in a sufficient amount to ensure the plants grow healthily. If one of these parameters is below the ideal limit, it will impact the growth of the plants. Plant growth can be observed through its geometric traits like height, width, leaf colour, fruits quality and etc. In-plant research, direct measurement of plant growth, for example, on the plant height measurement, is usually destructive. Direct measurement causes partial or whole plant damage. This is one of the reasons for using image

* *Corresponding author.*
E-mail address: normaizatul@pmm.edu.my

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processing techniques in agricultural research. In image processing techniques, data is obtained only from the image of the object, so this method is non-destructive and does not damage the plant [4]. Due to these major challenges, the main purpose of doing this project is to develop growth monitoring of plants in hydroponics using image processing. By doing this project, the problems of plant stunting and plant damage can be avoided. Thus, the problem of spending much time on manual measurement can be reduced. This can be done through the development of a plant growth monitoring system in the hydroponic using image processing. This project aims at reducing plant stunting that is caused by an insufficient amount of plant needs and plant damage by the indirect method of plant growth measurement. This is done by constantly monitoring the plants using a camera that will capture images of the plants at regular intervals. The images captured will be processed to recognize the various growth changes occurring due to different environmental factors.

The terms hydroponic refer to a planting method that requires no soil but relies on nutrient solutions. Hydroponic planting is complicated for farmers who do not have much information about the hydroponic process from the beginning. The probability of crop failure is high if they did not have patience and do not constantly monitor the plants' growth. Nutrient solution concentration greatly impacts the plant if the supply amount is over the limit or below the limit of the standard according to the type of plant. Various methods include magnetic switches and sensors, video cameras, webcams in a box at different locations and image capturing. Some of them used MATLAB software for the algorithm platform. ANN, edge detection method k means used for prediction and object detection. Environmental factors such as temperature, humidity and lighting exposure give plants the energy and strength to grow healthier [4]. After the observation period, the length and width of the controlled system plant's leaf were 2.5 cm and 2.5 cm, respectively. Whereas the uncontrolled system plant's leaf length and width were 2.0 cm and 1.9 cm, respectively [4].

2. Methodology

In this project, there are four steps need to be done to achieve the objectives which are to develop algorithms for the development of an image processing algorithm for the measurement of Pak Choy plant height, compare the accuracy of Pak Choy plant height measurement using the image processing approach with real measurement and analyse the relationship between environmental factors and plant growth whether indoor or outdoor can give better plant growth. The steps begin with research procedure and experimental design, followed by data gathering and image processing development, and end with program testing and troubleshooting. The experimental design, data gathering, detection and measurement of height using image processing will involve the following process shown in Figure 1.

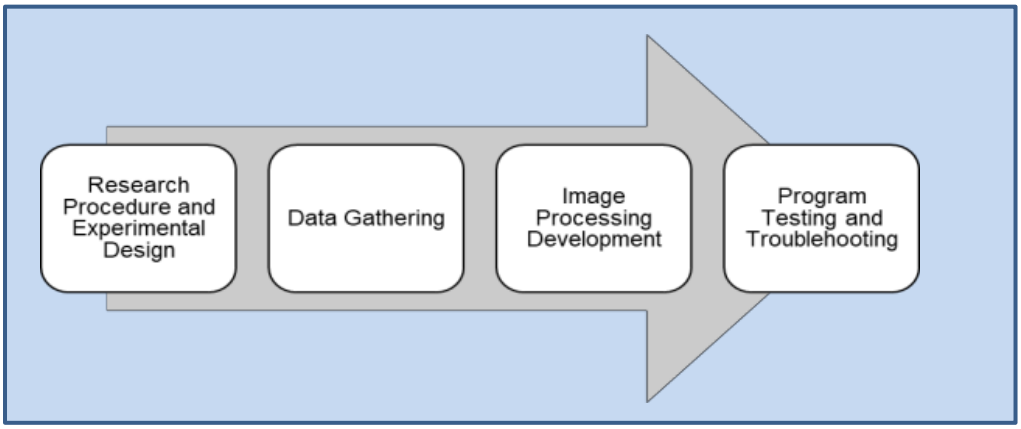

Fig. 1. Project process flow

2.1 Research Procedure and Experimental Design

This research was conducted at Kampung Beta, Pohon Buluh, Pasir Mas, Kelantan. The parameters measured were the number of leaves, plant height, the highest temperature of that day and the lowest humidity on that day. The plant tools and hydroponic media used were basins, net pots, wick clothes, tray seedlings, rock wools, TDS and EC (hold) meter, Temperature Humidity meter, water, Pak Coy seeds and AB mix fertilizer. The measurement tools by manual and image were a ruler and the smartphone Oppo A37fw respectively. Pak Coy seeds are sown using tray seedlings, then when the plants begin to grow, measurement starts. When the plant has 2-3 leaves, all six Pak Coy plants moved to two different hydroponic kits, three located indoors and the other three located outdoor. Hydroponic plants placed outdoor will receive direct sunlight and hydroponic plants placed indoor will receive a limited amount of sunlight. The hydroponic system used in this study is DWC (Deep Water Culture) system. Manual height measurements and image capture are made every day until the Pak Choy is harvested. The results of the study were then analysed using descriptive analysis to obtain a systematic, factual, and accurate description.

2.2 Data Gathering

The data to be gathered for this research are images of Pak Choy plants, manual plant height measurement using a ruler, temperature and humidity from day 1 till day 19 to see their growth. Figure 2, there is one camera of the smartphone Oppo A37fw elevated at a specific height which is 18 cm, and a specific distance which is 28 cm from the plant subject to capture images. The hydroponic pot will be moved in front of the camera without changing its distance. The steps were repeated until all the 6 images of Pak Choy were captured each day. Each day would represent the stages of the growth of Pak Choy that would be used in the analysis. The image is captured for 19 days and a total of 114 Pak Choy images are gathered and stored on a laptop.

Besides the images, the measurement of plant height using a ruler was taken from day 1 till day 19 to see the plant growth by manual method. All the measurement was recorded manually in a worksheet in Excel. The height measurement was taken from the upper part of the white net pot to the top of the highest leaf of the plant. The measurement was not taken from the lowest part of the plant because it was tedious to take out the plant from the net pot every time the measurement took place. It can damage the roots and plants as well. The temperature and humidity were also recorded from the temperature humidity meter placed near the plant.

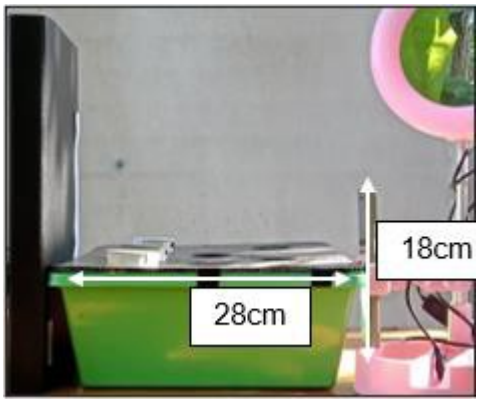

Fig. 2. Camera setup

2.3 Image Processing Development

The features of the Pak Choy plant were identified, such as the physical appearance, colour and height of the plant, which is used for the development of an application program interface (API) for identification. An algorithm was developed using an open-source computer vision library (OpenCV) and Python 3.9 language using PyCharm 2021.2 as an integrated development environment (IDE) to measure the Pak Choy plant height and width. The flow chart for processing images acquired by the camera to determine the height of the Pak Choy plant is shown in Figure 3.

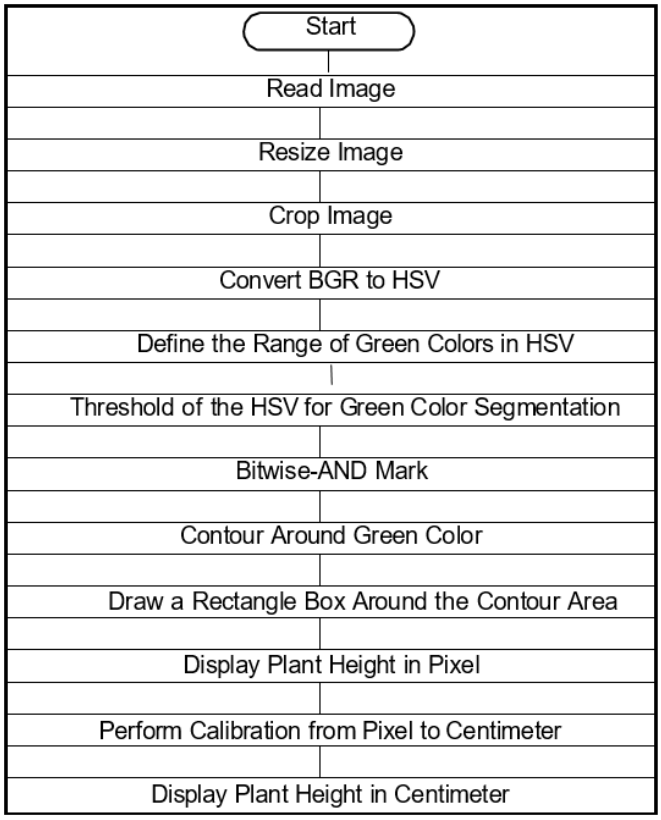

Fig. 3. Flow chart of plant height measurement system

Step 1: Read, resize and crop

All of the images captured before were transferred into a file name 'IMAGES' in the PyCharm IDE program file. The function of cv2.imread (file) is used to read an image in the file. The image is placed in the absolute path. A total of 114 plant images will be read accordingly and will be displayed using the cv2.imshow() function. As the image capture showed bigger than the window screen size, which unable to see the overall image, so the image should be resized to the smaller size. To resize an image, resize () method is applied by passing in a two-integer tuple argument representing the width and height of the resized image. The function does not modify the used image, it instead returns another image with the new dimensions. After resizing an image, the crop is applied because the base needs to be constant at the white net pot. This is because it will be a problem in contouring if some of the leaves grow upside down making the bottom of the rectangle box not parallel with the plant starting height. It is important to maintain the starting height of the measurement to make the measurement more reliable when compared to the real measurement later on. Therefore, the image was cropped before processing from size 616 height to 466 height. The width is maintained. When an image is cropped, a rectangular region inside the image is selected and retained while everything else outside

the region is removed. With the Python OpenCV library, an image can be cropped with the crop () method. The method takes a height that defines the size of the cropped region and returns an image object representing the cropped image. The cropped section includes the bottom row of pixels.

Step 2: Convert BGR to HSV and define range

The image captured by the smartphone Oppo A37 is in RGB (Red, Green and Blue) pixel format. When the image file is read with the OpenCV function imread (), the order of colors is BGR (blue, green, red). The red, green and blue, (RGB) color model is based on a Cartesian coordinate system as shown in Figure 4 [2].

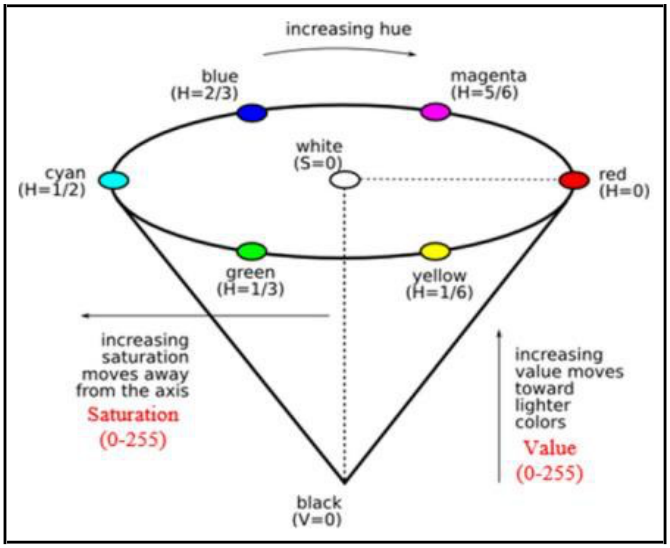

Fig. 4. HSV Color Mode

Each colour consists of primary spectral components (R, G, and B) and blue, green, red, black and white colours are defined by (255, 0, 0), (0, 255, 0), (0, 0, 255), (0, 0, 0) and (255, 255, 255), respectively. The value in each array from 0 to 255 along each axis indicates the brightness of colour whereas the diagonal from black to white represents grey levels with different brightness. Instead of using colour primaries, the Hue, Saturation and Value (HSV) are used as the colour descriptions and offer a more interesting colour map that is perceptually uniform [3]. Understanding the concepts of balancing these three elements, object recognition based on colours can be implemented. Defined the HSV ranges (low green, high green), then create the mask and showed only the object with the green colour. The Hue, Saturation and Value ranges were selected based on the identification of the plant colour of Pak Choy plants. To determine the HSV ranges, a try and error of the code are developed. Various trials have been conducted to determine the lower and upper bound values and checked at which value the clear and sharp detection of the Pak Choy plant takes place.

Step 3: Threshold, bitwise and contour

Image thresholding is a method to separate regions that are higher or lower than the set threshold value based on the upper and lower bound value of Hue, Saturation and Value. The threshold is applied for all pixels of the image by converting the HSV image to a binary image. The binary image is just a set of an array having 0 and 1 values. Bitwise marks are highly useful while

extracting any part of the image, they included bitwise AND, OR, NOT and XOR operations. The Bitwise- AND mark is used to compute the intersection of two images. Syntax of AND operator gives us the threshold green colour image, having only Pak Choy plant image and black background. Contours are a curve joining all the continuous points (along the boundary), having the same colour or intensity. The contours are a useful tool for shape analysis and object detection and recognition. For better accuracy, the binary image is used for finding the contour.

Step 4: Rectangle box and height in pixel

Rectangular contour has been drawn along the threshold green color image and contour covers the whole plant. BoundingRect() function of OpenCV is used to draw an approximate rectangle around the binary image. This function is used mainly to highlight the region of interest after obtaining contours from an image. Every function in the OpenCV is bound to return some numeric data or lists of data. Cv2 Boundingrect() returns 4 numeric values when the contour is passed as an argument. These 4 values correspond to x, y, w, h respectively. These values are more described as X is coordinate, Y is coordinate, W is Width, and His Height. The rectangle counter having 'x' and 'y' (x, y) be the bottom- left coordinate of the rectangle and 'w' and 'h' (w, h) be its width and height coordinate at the top-right of the rectangle. For each interpretation, all the X and Y coordinate going to provide each corner point of the bounding rectangle of each rectangle. Therefore, X and Y coordinate is used to draw the circle dot on an image using cv2.circle(). To display plant height in pixels, the midpoint definition is described first before calculating the midpoint. Midpoint is the value that is passed and divided by two that's means have to add one more dot at the middle of the two dots. After getting the midpoint of each of the 'contour objects, then make a midline. Connect the two midpoints using the line command cv2.line(). Add the line immediately after drawing the midpoint. The distance can be calculated from the midpoint using scipy package.

Step 5: Calibration and height in centimetre

To determine the height and width of a Pak Choy plant in an image, calibration using a reference object need to be performed. The reference object is a square box whose height and width are known. Firstly, the reference object height and width were manually measured and it was kept at a distance of 25 cm from the camera. Secondly, the number of pixels in a captured image was counted using an algorithm and calibration was done to know the number of pixels per unit of metric of image [5].

The height was computed using Euclidean Distance in pixels which are then converted to centimetres with a 1 cm to 40.4 pixels ratio. The parameter of the object is known as 20 centimetres, and the object parameter in a pixel is 808 pixels.

Pixels_per_centimetre (height); Eq. (1),

$$= \frac{Object\_pixel\ along\ y\ coordinate\ of\ frame}{Know\_heigth}$$
$$= \frac{202\ pixels}{5cm} \quad (1)$$
$$= 40.4\ pixels$$

Pixels_per_centimeter (width); Eq. (2),

$$= \frac{Object\_pixel\ along\ y\ coordinate\ of\ frame}{Know\ \ width}$$
$$= \frac{202\ pixels}{5cm} \quad (2)$$
$$= 40.4\ pixels$$

After determining the plant height and width in pixels and calibration is performed, now the last part is to display the height and width of the bounding box of contour area in centimetres. Value of height equal to dA/pixel_cm_ratio and width equal to dB/pixel cm ratio is assigned. The plant height and width in centimetres were displayed on a laptop and simultaneously, the image was saved as a binary file and plant height and width are saved in the text file.

2.4 Program Testing and Troubleshooting

The accuracy of the developed image processing algorithm was evaluated on all the 114 images that were captured earlier. After running the program, some of the contour images were not fit into a blue bounding rectangle. Leaf upside-down makes the bottom of the bounding rectangle not parallel with the plant starting height. This will distort the height measurement as the height starts from the white net pot. This problem is countered by making the lower part of the plant images constant for every image. Some modification was made to the python program in which the crop function was applied to the image before processing from size (616, 460) to (466, 460) where height is changed while the width is maintained. Besides, there is a gap between the green colour detected from the plant image. The bounding box detected three different objects in an image and the box follows the position of the leaf which is not correct. It is hard to automatically measure the plant height using image processing if the rectangle is not in x and y coordinates. Some modification was made to the Python program. The contouring of the blue bounding rectangle is added to the Python program to make sure the rectangular is in x and y coordinates.

2.6 Conclusion

To summarize, this project involved four main stages which are experimental design, algorithm development, program testing, and troubleshooting, and height measurement. In the experimental design stage, all the materials bought and Pak Choy plant seeds were sown for 2 weeks. Then continued setting up the experiment by placing the plants at two different locations for manipulating environmental factors towards the growth of the plant. A camera from a smartphone was used to capture the plant image from day to day for 3 weeks. Data of plant heights were collected manually by using a ruler as a measurement tool meanwhile the temperature and humidity value of the day was taken and recorded in MS Excel. Python and PyCharm IDE were used as a platform to perform programming of plant height measurement through image processing. The steps include reading, crop, resizing the image, converting the BGR image to HSV for easier object detection, contoured, thresholding, and converting pixels to centimetres. Next, the heights of plants were automatically displayed in the software and imported to Ms. Excel as well Orange IDE for further analysis.

3. Results and Discussion

3.1 Accuracy of Pak Choy Plant Height Measurement

The accuracy of the developed image processing algorithm was evaluated on all the images that were captured earlier, which was divided into 2 plots, manual measurement and image processing. The images in the smartphone were transferred to a laptop (HP 15-ck063TX, Hewlett-Packard, USA) through a USB interface and the program was compiled in an open-source computer vision library (OpenCV) and Python 3.9 language using PyCharm 2021.2 as an integrated development environment (IDE). The program measured the plant height, which was compared to manual measurement by using linear regressions analysis. The correlation (R2) was used as an indicator for the developed image processing algorithm with a manual. The growth of six plants has been observed throughout the experiment period. Three of them were located indoors and another three were located outdoor. Time series (day) of height measurement manual by ruler and image processing at indoor and outdoor is plotted to see the growth rate whether it is good growth or bad growth observed at two different locations.

The Pak Choy plant height was measured by using computer vision and image processing techniques. The plant height measured by the image processing method was compared with the manual measurement value shown in Figure 5. The mean height, standard deviation and mean standard error of plant measured by image processing method were 4.563 cm, 3.263 cm and 0.306 cm, respectively and the mean height, standard deviation and mean standard error of plant measured by the manual method were 4.924 cm, 2.842 cm and 0.266 cm as shown in Figure 6. For the plant height, the image processing method was strongly correlated with manual measurement having an R2 value of 0.914.

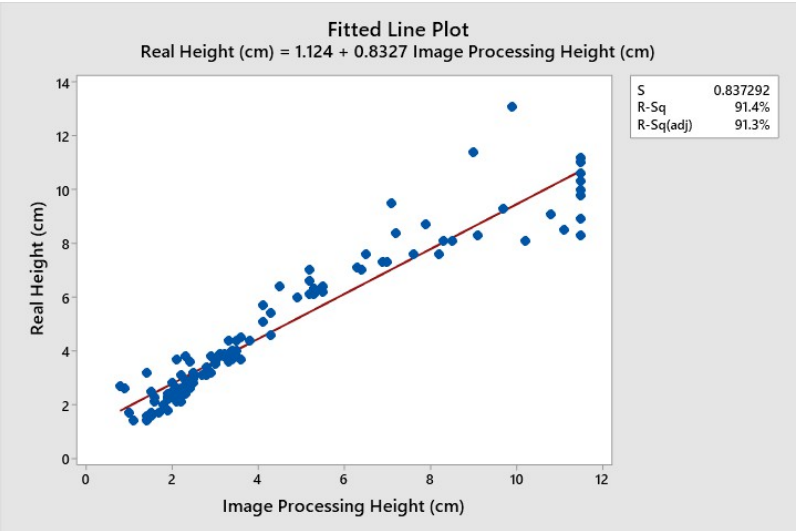

Fig. 5. Regression of real height (cm) and image processing height (cm)

MANUAL AND IMAGE

Descriptive Statistics: Manual Height (cm), Image Processing Height (cm)

Statistics

Variable	Mean	SE Mean	StDev	Minimum	Maximum
Manual Height (cm)	4.924	0.266	2.842	1.400	13.100
Image Processing Height (cm)	4.563	0.306	3.263	0.800	11.500

Fig. 6. Descriptive statistics value of manual height (cm) and image processing height (cm)

3.2 Relationship between Environmental Factors and Plant Growth

The highest indoor and outdoor environmental temperature was recorded every day from day 1 of the experiment till day 19. Indoor temperature ranges from 32.2 °C to 38.5 °C with a mean value of 35.6 °C while outdoor temperature ranges from 39.3 °C to 48.4 °C with a mean value of 44.3 °C as shown in Figure 7. Leaves number for indoor ranges from 6 to 7 leaves while for outdoor ranges from 8 to 17 leaves as shown in Figure 8. Image processing height for indoor ranges from 1.9 cm to 3cm while for outdoor ranges from 4.1 cm to 9.9 cm as shown in Figure 9. When the temperature is high, the number of leaves also increases day to day but when the temperature is low, the number of leaves maintains or decreases in number day by day. When the temperature is high, the image processing height also increases day to day but when the temperature is low, the image processing height maintains or decreases in height day by day. The Pak Choy plant growth indoor is bad while the Pak Choy plant growth outdoor is good.

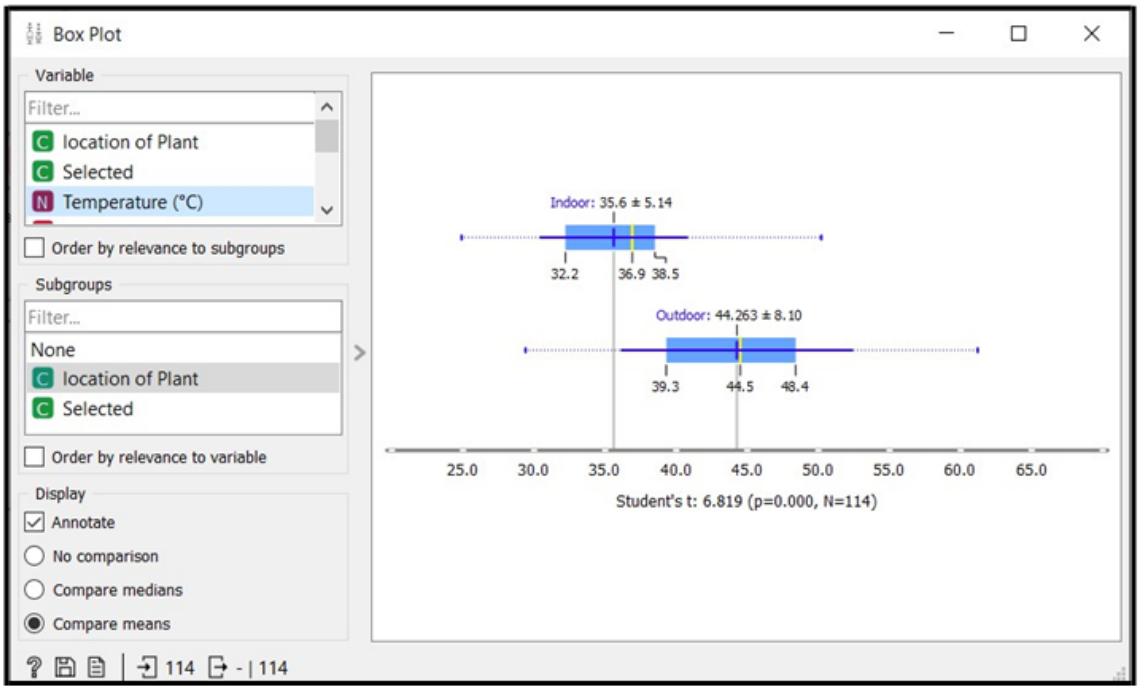

Fig. 7. Box plot of temperature

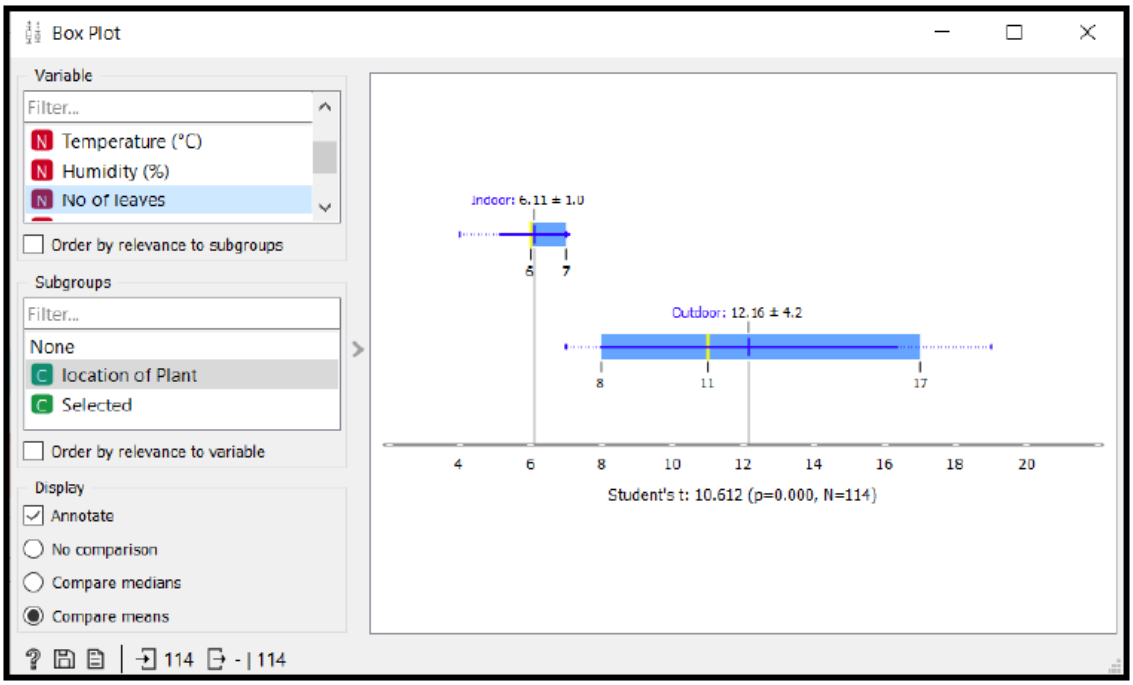

Fig. 8. Box plot of Leaves Number

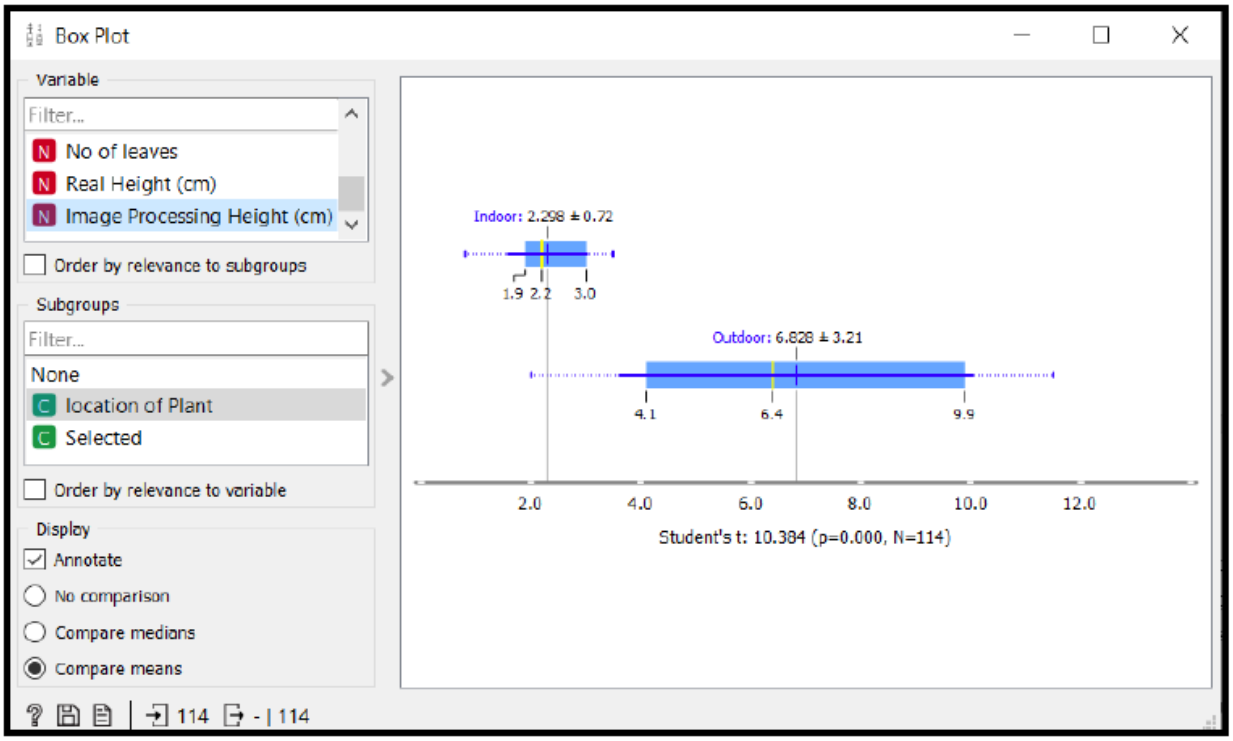

Fig. 9. Box plot of image processing height

Overall, it was evident that the plant height estimated using the image processing method was very closely validated by the manual measurement method (R2 in the range of 0.80–0.95 an SE in the range of 0.200–0.400 cm). The linear regression analysis plot was almost similar to the ideal 1:1 trend line. The present study has shown that the image processing method provides accurate height and width measurement. However, the accuracy of the image processing method can be further improved by providing minor modifications to the experiment setup. Firstly, by making a hydroponic basin completely enclosed so that the effect of wind can be reduced. Secondly, to

provide a proper shading structure to reduce the illumination of sunlight. Thirdly, to capture a plant from the root so that the bounding box will cover all the plant. Besides that, to improve the image processing approach using OpenCV and python language. Therefore, the proposed image processing method creates new methods for height measurement of plants.

The outdoor environment is more suitable for the better growth of Pak Choy hydroponic plants compared to the indoor environment because the plants receive enough temperature within 39.3 to 48.4 °C. Below that temperature, the plants will experience bad growth or stunted. The nutrient solution concentration was made constant for both hydroponic plants so that only one element is manipulated which is the temperature for indoor and outdoor and the growth is observed whether it gives good or bad growth for hydroponic plants.

4. Conclusion

In conclusion, the image processing method was found to accurately estimate the plant height of the Pak Choy plant with a root mean square error in the ranges of 0.200–0.400 cm. The proposed image processing algorithm approach using OpenCV and Python language was strongly correlated with manual measurement values with R2 in the ranges of 0.80– 0.95. This method could be particularly useful for quickly screening a large number of the geometry of plants, which creates new opportunities for field-based Pak Choy plant phenotyping. There is a strong relationship between the temperature and the number of leaves. The number of leaves depends on the temperature environment. If the temperature of the environment is between 39.3 to 48.4 °C, it experiences good growth. The number of leaves maintains or decreases in number day by day if the temperature is below 39.3 °C. The same goes for the image processing of plant height, it also has a strong relationship with the environment temperature. When the temperature is high, the image processing height also increases day to day but when the temperature is low, the image processing height maintains or decreases in height day by day. The Pak Choy plant growth indoor is bad while the Pak Choy plant growth outdoor is good. The objective of this project is achieved as the algorithm for measuring the height of hydroponic plants using image processing can measure the height from the image of the plant. Besides, the estimation value of the measurement from image processing is near to the manual measurement. This new method can replace the manual method for measuring the height of plant and plant damage can be avoided.

For the continuation of this project, some recommendation needs to be done to the system for better result of Pak Choy measurement. Firstly, make sure that the hydroponic plants are captured from the rockwool and not from the white net pot. This is because there will be inconsistency in the contouring area of the plants. The plants may have more than one contour area even it is from one plant only. So, it is hard to detect the whole plant if there is more than one contour area. Besides that, the distance of the camera from the plants must be farther so that the whole plants that grow each day can be captured. Last but not least, the temperature and humidity reading should get from the sensor for a more accurate reading.

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