ACSE (automatic canopy space expander): Automatic spacing system based on increasing plant canopy area on hydroponics for space efficiency

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Abstract. Hydroponics is a solution to increase the amount of productivity of crops to offset the growing population growth in Indonesia. In hydroponics, the NFT system which is currently widely applied in industrial scale gardens uses a gully with a planting hole that has been set and is static. This is still inefficient in the use of space because there is still space left between the two plants when the plant canopy has not reached the end of the growth phase. Besides, farmers also need more energy to move plants from one gully to another when the canopy of plants has covered each other. To overcome this problem, an automatic spacer system is necessary. The objective of this study was to design an automatic canopy space expander based on increasing plant canopy area. The system is composed of a camera, motor driver, stepper motor, and helix conveyor. When the system detects overlapping canopies, the plant's net pot will be shifted using a helix conveyor. The overlapping can be detected when the proportion of the width and height of the rectangle box that surrounding the canopy area is greater than 1:1 with tolerance value ±0.2. The results of this study indicate that overlapping plant canopies can be detected through the filtering process and the calculation of the proportion of width and height of the rectangle box that covers the canopy area. The model of the ACSE system can increase the amount of crop productivity by not leaving any free space between the canopy but still keeping it from overlapping to pay attention to the level of competition of plants in getting sunlight.

1. Introduction
The increasing number of population growth in Indonesia encourages people to increase food production so that people's food needs are fulfilled. Increasing productivity is needed technological assistance that can optimize the use of existing agricultural land. Hydroponics is one technology that can answer that problem. Hydroponics is a method of cultivating plants without the use of soil and more emphasis on meeting the nutritional needs of plants [1]. Hydroponics has advantages both in the process of cultivation, planting period, and yield. Based on a comparison of conventional and hydroponic systems [2], hydroponic systems can increase the amount of productivity by 100%.

One of the most popular hydroponic systems implemented by industrial-scale hydroponic plantations in Indonesia is the Nutrient Film Technique (NFT). The NFT system is a way to grow plants in the gully
with plant roots in thinly flowing plant nutrient solution [3]. Each plant is placed in a hole in the gully where the hole is static and the distance between holes is the same. The purpose of the spacing is to avoid competition over the sunlight by plants.

In leafy vegetables, one planting period can be divided into several phases [4]. The first is the seeding and early seedling development (phase 1), the second is early growth (phase 2), and the third is production growth (phase 3). In the NFT system implemented in Indonesia, each phase has a different gully installation where the difference between each gully installation is the distance between the planting holes. This was done to optimize the use of space but still pay attention to the level of plant competition in fighting over sunlight. Farmers move the plants from phase 1 to 2 then 3 installations manually. This is less efficient in the use of energy considering that in industrial-scale gardens there are thousands to tens of thousands of plants. To make the farmers’ work more efficient, a solution that consisted of a design model for an automatic spacing system on the NFT hydroponic system through an increase of the canopy area is necessary to be developed.

The objective of this study was to design an automatic canopy space expander based on increasing plant canopy area. The system is called Automatic Canopy Space Expander (ACSE) which employs a camera, conveyors, and a control system based on processing the Raspberry Pi microcomputer. The camera periodically takes images of the plants. Whenever there are overlapped canopy images at certain values, the control system will automatically expand the space between plants on the NFT gully.

2. Materials and Methods

2.1. Research time and location
This research was conducted from June to July 2020 at the Smart Agriculture Research Group, Agro-Informatics Sub-Laboratory, Laboratory of Energy and Agricultural Machinery, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta.

2.2. System development
The NFT installation used in this study is a square gully arranged several lines horizontally. The gully is modified so that the top forms a track like a rail that the net pot will pass through. The net pot on the rail can be moved in one direction which is shifted by helix conveyors. To rotate the helix, a Nema 17 stepper motor is connected to the helix using a belt and pulley. The stepper rotation is controlled by the L298N motor driver.

The working principle of this system is that the camera first takes a picture of the plant canopy from the top view. The images obtained are then processed to detect whether a canopy overlap or not. If overlapping occurs, the stepper will rotate with a certain number of turns so that the canopy no longer overlaps. As for processing images and instructing the stepper to spin, the processing base is used in the form of a Raspberry Pi microcomputer B+. The model and schematic of the plant spacing system are shown in Figure 1 while the method for crop removal follows the flow according to the flowchart in Figure 2.

2.3. Adjustable space operation
The net pot movement in this study is assisted using a helix conveyor. The parameter used to design the helix is pitch and lead. Pitch is known as the distance between adjacent threads axially on a helix. Meanwhile, the lead is the distance traveled by axial forward motion when the helix body rotates one full turn (360°) [5]. The lead is designed to refer to the arithmetic progression equation 2.1 as follows.

\[ Un = n^2 + 2n + 2 \]  

where Un is the lead from the start point and n is the number of the turn.
By referring to this equation, the helix will have a pattern that is not constant so that the movement of the net pot generated by the screw turns varies at a certain distance. The helix pattern is shown in Figure 3. This adjustment was made to balance plant growth. The longer, the growth of the leaves will be even greater so that the distance between the net pot movement in plants that are still small and large will be different. This adjustment is applied to avoid displacement of the net pot with the same distance between the net pots which have different canopy areas.

**Figure 1.** Schematic design of canopy space expanding system.

**Figure 2.** Flowchart for automatic canopy space expanding system.

**Figure 3.** Net pot move mechanism.
2.4. **Image processing**

The camera takes a single image in the form of two canopies that are next to each other in a row. The captured image is then stored on a microSD card on Raspberry pi and then transferred to the computer's local disk using the File Transfer Protocol (FTP). Image processing aims to detect whether overlapping canopies occur or not. To make this possible, it takes several steps that must be passed in accordance with the flow diagram in Figure 4. In this plant canopy image processing, using the canny edge detection method to determine the boundary edge of the canopy. The algorithm of this method is image refinement, calculating magnitude and orientation, non-maximum suppression, and thresholding [6].

The program of this processing is written in the Python IDE using the OpenCV library. So that the image processing results display the appropriate reading output, it is necessary to calibrate the camera by adjusting the distance of the camera with the canopy to be shot.

2.5. **Data analysis**

The image of the processed canopy shows overlapping or not based on the proportion of the rectangle box surrounding the canopy area. Canopies will be considered overlapping if the proportion between the width and height of the rectangle box is greater than 1:1. That is because the rectangle box covers the entire canopy area to the outermost limit so that if the canopy overlaps, then the two overlapping canopies are unified and when covered by a rectangle, the width and height ratio of the rectangle is greater than 1:1. If this happens, it must be calculated how much overlaps occur. To find this out, if the two plants analyzed show a rectangle ratio of more than 1:1 but below 2:1, say 1.5:1, then the overlapping area of the canopy is 0.5:1. The 0.5 value is then multiplied by the actual canopy diameter. The results of the operation show how far the two net pots must be moved.

3. **Results and Discussion**

Prototyping of this study includes the creation of a framework, gully, net pot, and rails for cameras. The framework is made using hollow stems. The framework is made to place the gully. Gully in this study was modified so that it has a track like a rail that will be the path to the net pot. Then, the camera frame is placed above the plant so the camera can take pictures from the top viewpoint. The net pot can move...
along the rail formed by the gully smoothly. The results of the prototype are shown in Figure 5. The prototype still has shortcomings in the stepper motor and helix conveyor parts.

Based on a motion study using Solidworks 2013 Computer Aided Design (CAD) software (Dassault Systèmes, Vélizy-Villacoublay, France), the net pot can be moved along the rails by the helix conveyor with a shifting distance that continues to increase with each rotation. The conveyor is connected to a stepper motor that rotates at a constant speed. The camera that works to take pictures is on a camera frame that can be shifted towards the x-axis and y-axis in the entire gully installation area. The results of a complete prototype have the following way of working. Raspberry microcomputer is connected to the camera and stepper motor. The camera will take pictures of plants, if overlapping between canopies occurs, the camera will process the image results by calculating how much overlapping between leaves. Then, the microcomputer will respond by turning the stepper so that the screw moves the net pot as far as the leaf overlapping distance.

The plants used in the detection of overlapping using a camera are red spinach (Amaranthus gangeticus). Red spinach has a single leaf and wide and contains anthocyanin pigments that cause red color [7]. With these characteristics, the canopy formed is easier to detect in this experiment. The first picture is a single photo of two spinach plants whose canopies did not overlap. The camera is placed at 30 cm measured from the highest point of the canopy. At this distance, it can be seen clearly in the frame, both canopies are detected.

After a single photo has been taken, the first thing to do is convert it to HSV (Hue, Saturation, Value). HSV color space is more suitable for use than RGB space for color segmentation because colors that are similarly perception have a closer resemblance to HSV [8]. The original image is then filtered using the mask feature. The mask is a binary image that shows a part of the whole image, which will be operated on [9]. The mask process is done using HSV images as the source and the original image as the target. By filtering the mask, the canopy that will be detected can be more easily distinguished from other objects in the image. To further clarify the outer limits of the canopy on the mask image, edge detection is done using the canny method. Canny edge detection is an algorithm that is used to get information about the outline of an object and the maximum and minimum gradients of the intensity function [10]. Canny edge detection is a popular method used not only in computer vision but also in the automated industry. The detected edges are dilated with a multiplier factor of 2 (two).

The detected canopy edge is then made of a rectangle box that covers the entire canopy area. Canopies from plants that grow normally have the same diameter on the x-axis and y-axis. Based on this, the overlapping situation does not occur when the proportion between the width and height of the rectangle box is 1: 1. In this study, the tolerance value set for the width and height ratio is ± 0.2 so that, in the canopy image detected in Figure 5, a ratio of 0.9: 1 is still considered normal and it can be stated that overlap does not occur.

The second image that is carried out by the detection process is a single image that contains two overlapping canopies. Using the same process, we get the output as shown in Figure 6. In this figure, the value of the ratio between the width and height of the rectangle box that covers the entire canopy area is 1.5: 1. The value exceeds the established tolerance limit so that it is stated that both the canopy overlaps. To separate the overlap that occurs between the two canopies, the plants must be moved so that each canopy has a 1: 1 proportion ratio back. In this case, the distance to be shifted is 0.5 multiplied by the actual diameter length of the plant canopy. The process to detect overlaps canopy is presented in Figure 7.

The model of the automatic canopy space expander system is to optimize the use of space. In industrial-scale hydroponics, the distance between planting holes is generally determined and static. The distance between the planting holes determined is based on the plant canopy diameter when it reaches the end of the phase. This has not been efficient in the use of space. When plants are transferred to a gully which is usually in the early age of the phase, the diameter of the canopy is still smaller than the distance of the planting hole that has been set so that it leaves an empty space between plants. It was from this problem that the model of the ACSE system emerged, which used the total space available to
be occupied by other plants. That way, the number of plants that can be planted increases so that it also increases the yields obtained in one planting period.

Figure 5. Automatic canopy space expander design model.

Figure 6. The process to detect no overlaps canopy.

Figure 7. The process to detect overlaps canopy.
4. Conclusions and Future Works

The model of the automatic spacer system based on canopy area expansion works by sliding the net post when the camera detects overlapping. Based on experiments that have been done, the design of the gully model has been successfully made. The net pot can move along the rail formed by the gully smoothly. However, in this experiment, the net pot cannot be moved by the helix conveyor due to the unavailability of some parts such as the helix conveyor and stepper motor.

Detection of overlapping canopy or not is done by filtering the canopy image through the stages of masking and edge detection. The results of processing can be known by looking at the ratio between the width and height of the rectangle box that covers the canopy area. If the comparison shows 1:1 with a tolerance value of ± 0.2, it is stated that the two canopies do not overlap. But if the comparison is greater than the predetermined value, then the plant is considered overlapping and must be shifted. In a future study, one of the things that can be done is comparing the energy use of a system that uses a helix conveyor with other drive systems such as actuators to find out which system has the highest level of energy efficiency.

References

[1] Nurdin S Q 2017 Mempercepat Panen Sayuran Hidroponik (Accelerating Harvesting of Hydroponic Vegetables) (Jakarta:AgroMedia Pustaka) [In Indonesian].
[2] AlShrouf A 2017 Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming. American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) 1 247-255.
[3] Baras T 2018 DIY Hydroponic Gardens (Minneapolis: Quarto Publishing Group).
[4] Resh H M 2013 Hydroponic Food Production (Boca Raton: CRC Press).
[5] Miller R, Miller M R 2004 Audel Automated Machines and Toolmaking (Canada: Willey Publishing)
[6] Mustafid A, Uyun S 2017 Segmentasi Citra Sapi Berbasis Deteksi Tepi Menggunakan Algoritma Canny Edge Detection (Image Segmentation Based Cattle Edge Detection Using Canny Edge Detection Algorithm) J.Buana Informatika 1 27-36 [In Indonesian].
[7] Setiawan S F 2017 Analisis Kadar Asam Oksalat pada Air Rebusan Bayam Merah (Amaranthus tricolor L) Awal dan yang Didiamkan pada Suhu Ruangan (Analysis of Oxalic Acid Levels in Red Spinach (Amaranthus tricolor L) Initial and Allowing at Room Temperature) Universitas Muhammadiyah Semarang [In Indonesian].
[8] Girod B, Niemann H, Seidel H P 1999 Vision Modeling and Visualization '99 Infix. (Erlangen: IOS Press).
[9] Garcia G, Suarez O D, Aranda J L E, Tercero J S, Gracia I S, Enano N V 2015 Learning Image Processin with OpenCV (Birmingham: Packt Publishing).
[10] Kabade A L, Sangam D V 2016 Canny Edge Detection Algorithm International J. Advanced Research in Electronics and Communication Engineering (IJARECE) 5 1292-1295.