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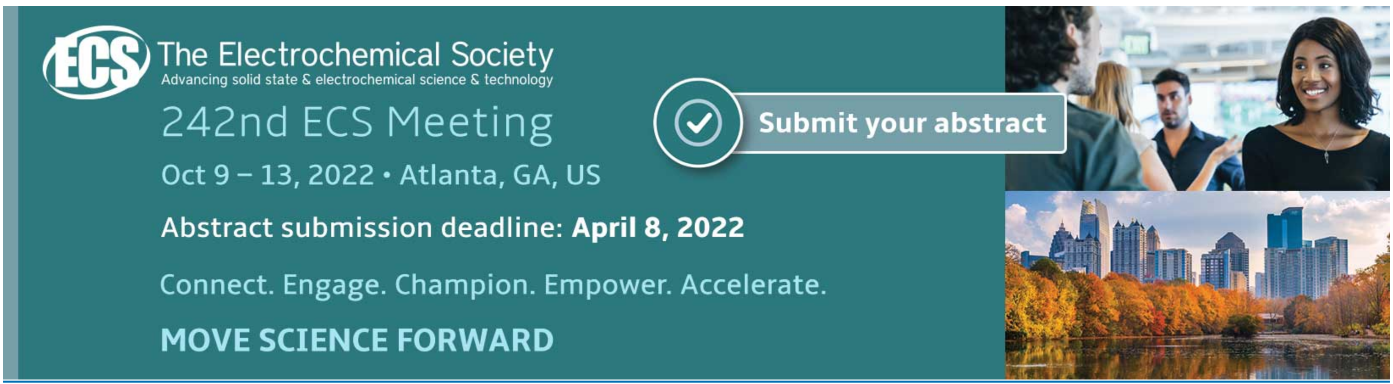


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# Development of plant monitoring systems based on multi-camera image processing techniques on hydroponic system

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# Development of plant monitoring systems based on multi-camera image processing techniques on hydroponic system

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**Abstract.** The research objective is to develop a monitoring system for the growth of red spinach plants based on image processing techniques from images captured using multiple cameras. The plant used is red spinach (*Amaranthusgangeticus L.*). Three cameras are installed in the top, side and front position of the plants in the photo box with lighting every 2 days up to 39 days. Model development uses a sample of 236 plants divided into 178 plants used model and 58 plants for model testing every two days. This model tested by the determination coefecient ($R^2$) to measure how much the independent variables ability to explain the dependent variable. The network architecture were three input , first hidden layer (5 neurons), second hidden layer (5 neurons), and output layers with 1 neuron. ANN function with value of the learning level is 0.001. The activation function to predict fresh weight and leaf area of plants is tansig-logsig-tansig and tansig-tansig-logsig. ANN model can predict fresh plant weight with MSE value of 0.02385 and RMSE of 0.154, while for leaf area MSE value of 0.26428 and RMSE of 0.514.

## 1. Introduction

Plant growth is a process in plant life that results in changes in plant size getting larger and determining the yield of plants. The process of growth is a very important object of study if the mechanism of crop formation is to be well understood. Explanation of the growth process for the tested treatment requires observation on plant growth [1]. Research with the orientation of cultivation business income will use the leaf area parameter because it can be known the yield or yield of a crop which has implications for economic benefits [2].

Direct measurement of leaf area is usually destructive because the leaf must be cut and separated from the plant [3]. This treatment causes some or all plants to not be able to grow back [4]. Whereas some growth analyzes require plants to be measured to find growth trends over a certain time interval [5]. Weaknesses in direct measurements such as damage to objects can solved by indirect measurements. This is the reason for the use of image processing techniques in observing research objects, especially in agriculture [6]. Image processing technique is a method for converting an image into digital form and carrying out certain operations in order to obtain information on the image [7]. In image processing techniques, data is only obtained from object images so that this method is non- destructive and does not damage plants [8].

The accuracy in prediction based on the extracted image features will reduce by the complexity of this object [9]. The application of multiple cameras in image processing has increased the accuracy of the results. This can be seen in increasing the accuracy of the predicted value of leaf length and paprika plant height [10]. Mathematical models have been widely applied in image processing techniques because they increase the value of accuracy in prediction based on the extraction of image features [11]. Multiple linear regression

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model is a mathematical model that describes the relationship between several independent variables with the dependent variable [12].Based on the previous description, leaf area and fresh weight value were monitored non-destructively [13].

## 2. Literature Review

In low-level image processing, image acquisition is a transfer of the form of image capture in the form of electrical signals from image capture devices such as cameras or scanners into numerical forms of digital images. After image acquisition, image pre-processing is the first process of processing digital images captured by the device. Image pre-processing is done to correct image geometry errors, eliminate image disturbances, correct image gray level or correct image cleanliness in order to improve the quality of digital images [14].

## 3. Research Metodology

The research object used was a red spinach plant (*Amaranthus Gangeticus L.)* which was cultivated hydroponically with the NFT (nutrient film technique) method in the greenhouse. The nutrients used had a total N content of 2.5%, Ca 18.2%, K 32.3%, Mg 6.4%, S 8.3%, P 5.8%, Fe 1.3 ppm, Mn 0.68 ppm, Cu 0.68 ppm, Bo 0.35 ppm, Zn 0.28 ppm, Mo 0.03 ppm. Each 0.5 liter of nutrients was dissolved with 999.5 mL of water so that in 1 liter of water has a nutritional content of 1000 ppm. Cultivation started from seedlings to the harvesting phase while monitoring began after the plants were transferred from the nursery to hydroponic media. Hydroponic installation was made from a 4" pipe as a place of cultivation, perforated iron as a buffer and other components.
The image was captured in the image capture box as shown in Figure 1. The size of the drawing box was 2 m × 2 m × 1,5 and Styrofoam with a thickness of 2 cm. Three fluorescent lamps (20 W) with an intensity of 133 lux were installed perpendicular to the object. One camera was installed at the top of the box, and two cameras were installed in the front and side walls of the box. All cameras were set to capture objects with a maximum size of 25 $cm^2$ × 25 $cm^2$.

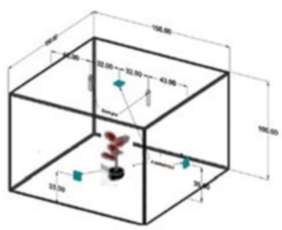


**Figure 1.** Red Spinach Image Capture Box

Plant image was processed using a plant monitoring program. The program was created using Delphi 7 software and DSPack version 2.3.4 component. Making the program was done in several phases. These phases are making Graphical User Interface (GUI), coding the camera display program on the GUI, coding capturing and storing images, coding image caller, coding image segmentation, coding plant area calculation, coding gathering and storing image area data, coding area image input plants, coding prediction of plant growth parameters and coding gathering and storing plant growth parameter data.The development of the model used sample of 236 plants which were divided into 178 plants for the development of the mo el and 58 plants for the testing of the model. The model was tested with the coefficient of determination ($R^2$) to measure how much the independent variable's ability to explain the dependent variable.

### *3.1 Research Location*
This research activity was conducted from May to November 2019. The research was conducted in Jember Regency, East Java.

### *3.2 Tool and Material*
The tools used in this research were Matlab 2018a Software, Borland Delphi 7, cameras, laptops, water pumps, saws, drill tools, meters, buckets, scales, lights, knives and blades. The ingredients used in this research were red spinach seeds, AB mix nutrition and glue.

### *3.3 Research Method*
The initial research activities carried out by designing software systems in monitoring plant growth. Then proceed with the manufacture of hydroponic installations along with devices for capturing digital images. Red spinach seedlings were placed in a hydroponic installation and then analyzed the data.

## 4. Experiment and Result

### *4.1 Graphical User Interface (GUI)*
The first step in conducting this research was creating the program by using Borland Delphi 7 software to ease the user in picture and prediction segmentation. All of the parts in the program were showed in Graphic User Interface (GUI). GUI facilitated the user to process the area of plant picture to predict the fresh weight and the area of leaf that can be seen in Figure 2. The initial step of the use of the program showed the visual shape of the camera in the program. Firstly, camera selection that would be used was conducted and the result of the camera capture can be directly saved to be used as the input for the next data collection. The next step was processing the picture to get the value of the plant picture area. The step was capturing the picture and the picture segmentation that would be processed and by changing the score of hugeness, intensity, and saturation; up or down. The picture segmentation was carried out manually by changing the color score of each scroll bar until the plant picture was segmented from the background of the picture. During the picture segmentation, the picture area score appeared automatically in the column "Value". The data of plant picture area obtained from the picture extraction was used as the input to predict the parameter of the plant growth. The accuracy of the prediction value came from the development of JST model. The development used three picture areas, so it needed input of picture area that is appropriate with the position of camera. Proccess button used for data prediction of fresh weight and leaf area. Then, the data were collected and stored in the data storage based on the needs.

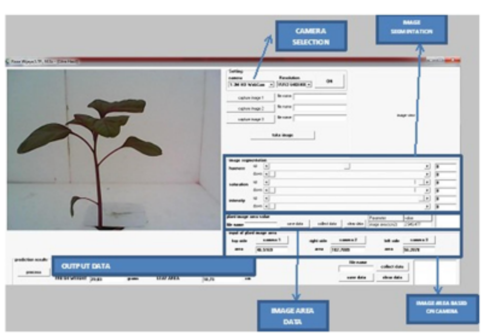



**Figure 2.** Graphical User Interface Program

### *4.2 The creation of Artificial Neural Network (ANN) Model*

The development of ANN model was based on the variable used in this research. The independent variable consisted of the value of image area captured by the upper, front and side parts of the camera, while the dependent variable consisted of the fresh weight of plant (Y1) and leaf area (Y2). The modeling used artificial neural network model in the form of Backpropagation Neural Network (BNN) and the tissue structure can be seen in Figure 3.

Function activation used was chosen based on the value of the best $R^2$ to get the architecture of the tissue [15]. The activation function consisted of three types of combination and each was looked for the $R^2$ value. The functions are logsig-logsig-logsig, logsig-tansig-logsig, logsig-logsig-tansig, tansig- tansig-tansig, tansig-logsig-tansig dan tansig-tansig-logsig. ANN architecture in this research can be seen in Figure 3 with 3 inputs that were the image from top, front and side camera [16].

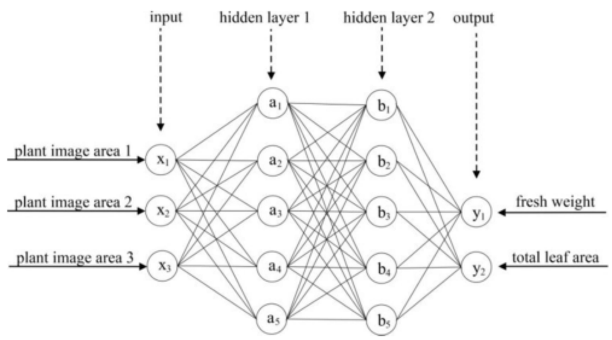
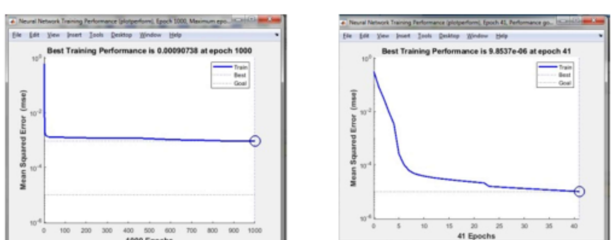



**Figure 3**. BNN Network Structure

### *4.3 Algorithm Backpropagation Training Data*

After conducting weighting and data input, training data was also conducted. In the training process, the total number of Epoch and the error limit obtained were seen. This phase used training of architecture 5-5-1 to get the pattern. To get the target in this training, it needed 4 minutes 3 second with epoch tissue architecture consisted of four layers with three neuron inputs, the first hidden layer with five neurons, the second hidden layer with five neurons, and layer output with one neuron. The level of learning was 0.001, the type of training was tra1m, the maximum literacy was 1000, and the MSE threshold was 0,00001. In the form of graphic, it can be seen on the following Figure 4.

From Figure 4 in the training of backpropagation algorithm of set data used, there were 3 data inputs that were the data of image front, side, and upper camera in predicting the fresh weight of plant and leaf area. The architecture chosen was 5-5-1 with the error target of 0.01, the results of training obtained when network learning reached convergence on epoch of 1000th for the fresh weight of plant and epoch 41th for leaf area, with the value of error mean square resulted as the performance indicator of neuron tissue reached 0.009 for the fresh wight of plant and 0,0000098 for leaf area [17].




(a) (b)

**Figure 4.** The graphic of Backpropagation Training (a) fresh weight of plant and (b) leaf area

### *4.4 Fresh Weight of Plant*

The prediction of fresh weight of plan used BNN method was firstly done by selecting the appropriate activation combination. The determination of the use of function by plotting the data of observation training and prediction result training displayed in Figure 5.

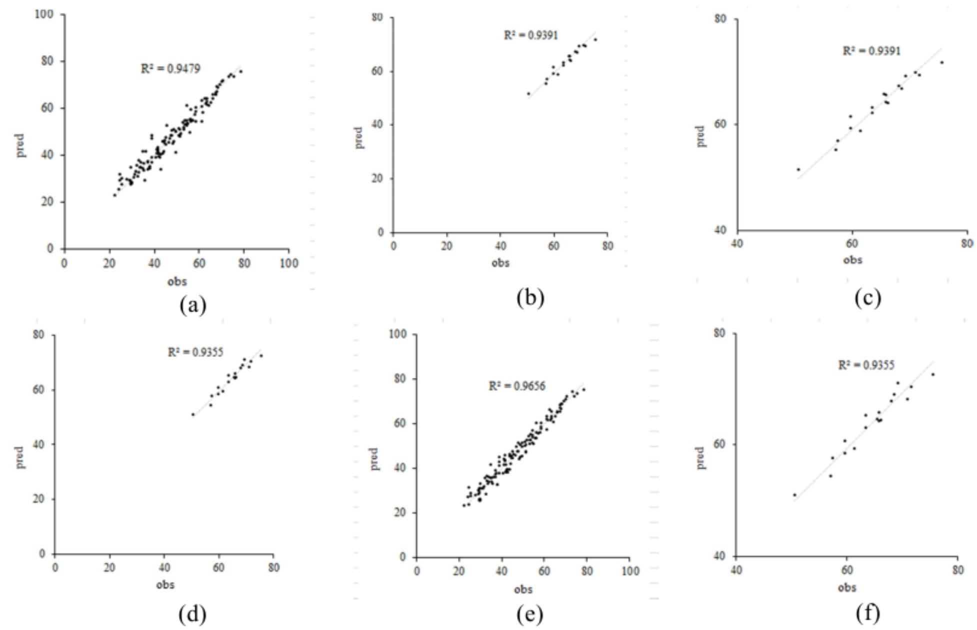



**Figure 5.** the combination of activation function in the variable of fresh weight, (a) (a) logsig-logsig-logsig (b) logsig-tansig-logsig (c) logsig-logsig-tansig (d) tansig-tansig-tansig (e) tansig-logsig-tansig (f) tansig-tansig-logsig

From Figure 5 we can see that the combination of good activation function for the variable of fresh weight was tansig-logsig-tansig with the value of $R^2$ of 0,9656. Then, ANN was built with the help of bias weight from 3 inputs, 5 hidden layers 1 (H1), 5 hidden layer 2 (H2), and 1 output. The value of bias weight of each can be seen on Table 1.

**Table 1.**The bias value of the plant fresh weight variable

| I – H1 | H1 – H2 | H2 – O |
|---|---|---|
| -1.9093450e+02 | 7.4083841e+00 | |
| 1.0897135e+01 | -9.1328877e+00 | |
| 3.6235514e+00 | -4.1106882e+00 | 1.9244257e+00 |
| -4.4745759e+00 | -1.0592469e+00 | |
| 3.7686500e+00 | -9.1393889e+00 | |

From Table 1, it can be seen that if the bias value obtained vary according to the training given to ANN. Tissues were formed and predicted the value of the fresh weight of plant by placing them on an area of the image. From the test results obtained (Figure 6), if the network architecture made was very well in predicting the fresh weight of plants with a value of $R^2$ 0,9959. MSE value obtained was 0,02385, this showed that the error level generated from this network was very small. After conducting training and testing to the pattern, the results showed that the test of these patterns was true (accurate). The mean of the network error in the testing process was RMSE 0.154 [18].

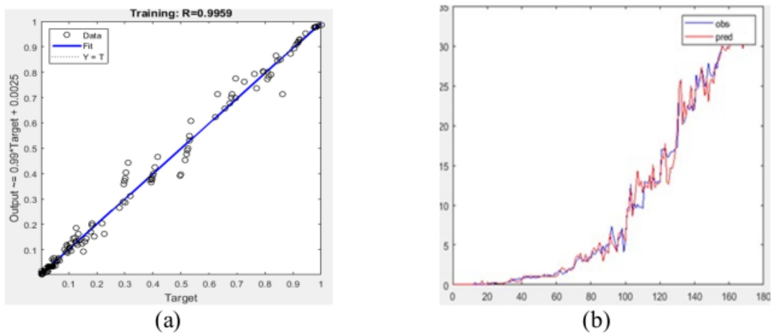



**Figure 6.**(a) Graph of the observed and predicted fresh weight test data,
(b) The value of $R^2$ Observation vs predicted fresh weight

### *4.5 Leaf Area*

Leaf area measurement in this study used ImageJ with image segmentation first as in Figure 7.

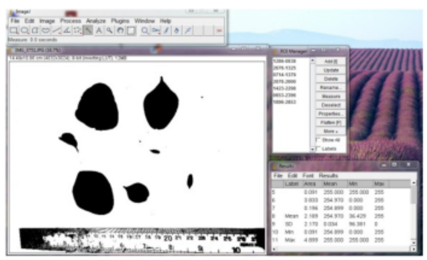


**Figure 7**. Leaf Area Measurement Using Image J

The leaves were digitally imaged through photograph using a webcam placed on the box as a tool for making images in JPEG format. Leaves that had been released from the stems (petiole) were placed on white A4 paper in a row of 6 strands together with the bar. Then the top was covered with clear paper aimed that the leaf surface became flat. Then the leaves were photographed and the images stored in the computer [19].

The results of digitizing images of red spinach leaves were processed and measured from the cross- sectional area, length, width, perimeter, and ratio using ImageJ. Measurements were made beginning with processing color images into gray scale images on the menu (Image> Type> 8bit) then (Threshold) to change to binary images. Under (Set Measurements), "area", "Shape descriptors", Perimeter "and" Feret's diameter "were checked. The wand tool on the tool bar was used to click on the object to be measured. The measurement results were produced through Measure on the Analyze menu.The scale of the leaf area was predicted by first determining the activation combination that was used appropriately. This can be seen on the following figure 8.

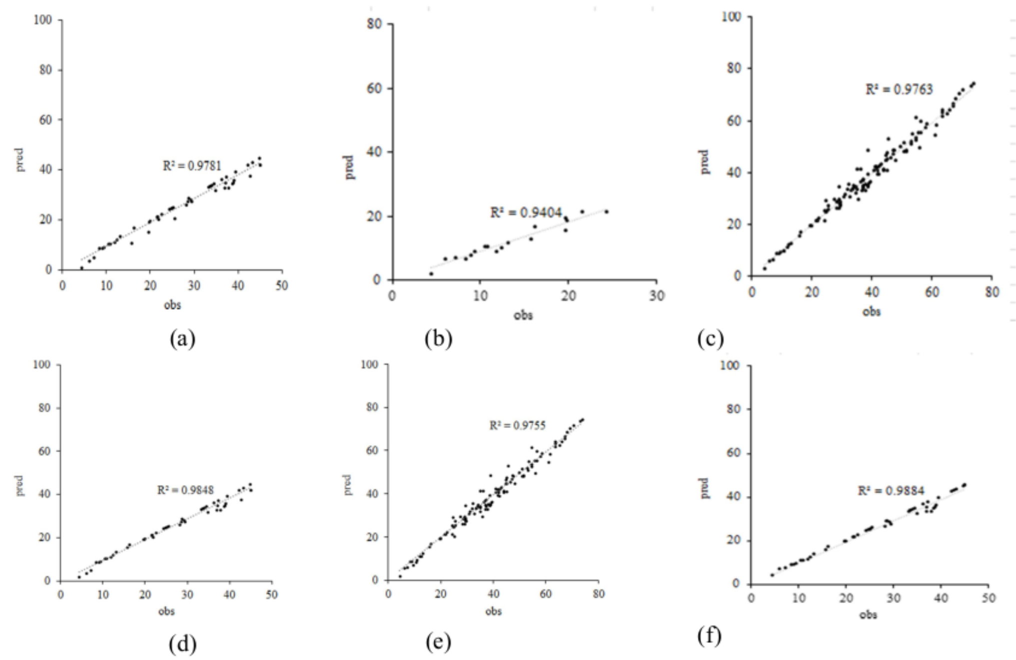


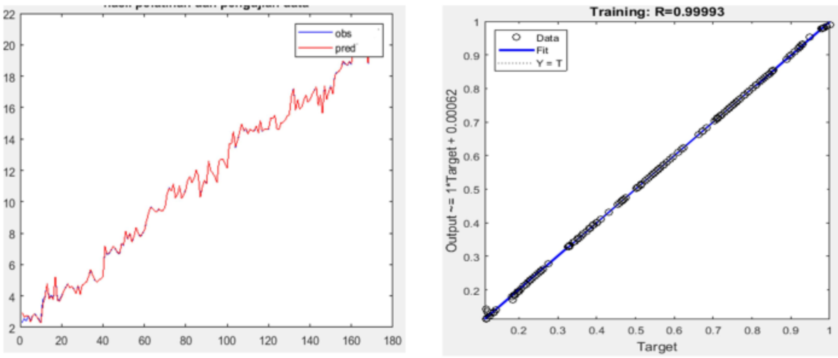

**Figure 8**. Combination of activation function in leaf area variables, (a) logsig-logsig-logsig (b) logsig-tansig-logsig (c) logsig-logsig-logsig-tansig (d) tansig-tansig-tansig (e) tansig-logsig- tansig (f) tansig-tansig-logsig

From Figure 8 it can be seen that if the best combination of activation function was tansig-tansig- logsig with $R^2$ value of 0,9884. After the activation function was obtained, the bias weight value of each layer of the network structure was determined. The value of bias in the leaf area variable can be seen on table 2.

**Table 2.**The bias value of the leaf area variable

| I – H1 | H1 – H2 | H2 – O |
|---|---|---|
| -1.4645302e+01 | 5.8400288e+00 | |
| 3.3639700e+00 | -2.5050842e+00 | |
| -7.0661833e-01 | -3.0558485e+00 | 7.0708407e-01 |
| -1.0547793e+01 | 4.4666991e-01 | |
| 4.7422374e+00 | 1.7600608e+00 | |

From Table 2, it can be seen that a variety of bias weight value used as an algorithm in determining the leaf area. Tissue formed and predicted the value of leaf area based on the area of the image. Test data was used as the input to determine the reliability of the network structure that had been made. From the test results obtained (Figure 9), if the network architecture was made very well to predict the fresh weight of plant with a value of $R^2$ 0.99. MSE value obtained was 0.26428, this showed that the error level generated from this network was very small. After training and testing the pattern, the results obtained that the test of the patterns was correct (accurate). The mean of network error in the testing process was RMSE 0.514 [20].




(a) (b)

**Figure 9**. (a) observation and prediction leaf area test chart data, (b) $R^2$ value of Observation vs prediction fresh weight

## 5. Conclusion

Architecture of ANN model network consists of 4 layers with 5 input neurons, the first hidden layer (5 neurons), the second hidden layer (5 neurons), and the output layer with 1 neuron. The function of ANN with value of the learning level is 0.001. The activation function to predict fresh weight and leaf area of plants is tansig-logsig-tansig and tansig-tansig-logsig. ANN model can predict fresh plant weight with MSE value of 0.02385 and RMSE of 0.154, while for leaf area MSE value of 0.26428 and RMSE of 0.514.

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