Design of agrivoltaic system with internet of things control for chili fruit classification using the neural network method

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Article Info

Article history:

Received Jul 29, 2024
Revised Sep 8, 2024
Accepted Sep 28, 2024

Keywords:

Agrivoltaic
Chili fruit
Control system
Internet of things
Neural network method

ABSTRACT

Agriculture is a leading sector in the economy as well as the most dominant provider of employment for the Indonesian people. The fertile soil factor allows various types of fruit to be grown, including chilies. However, complex problems make chili farmers have limitations in implementing conventional farming systems. Therefore, the development of an agrivoltaic system with internet of things (IoT) integrated sensors on chili plants can help farmers more easily control, add vitamins, fertilizers, and provide plant nutrients that can be done automatically periodically based on a real-time clock schedule. This system also operates using photovoltaic (PV) as a pumping machine for water circulation. Other technologies such as mini smart cameras are also being developed to monitor and take pictures of chilies which will later be converted using the graphical user interface (GUI) application for segmentation. The method used in this chili fruit classification uses an artificial neural network in classifying ripe, raw, and rotten chilies. The classification results obtained an R value of 0.9, which means it is close to a value of 1 in the suitability of the chili image. Therefore, farmers will find it easier to sort the chilies that will be harvested.

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1. INTRODUCTION

The development of a smart agricultural system integrated with renewable energy should be able to be developed in Indonesia due to the geographical and climate conditions that support it [1], [2]. Fertile soil and adequate solar energy should help farmers export agricultural products and raw materials to other countries to support the achievement of farmers' welfare [3], [4]. However, the problem of inadequate technology has hampered agricultural productivity and of course has also had an impact on the decreasing number of young people pursuing this profession. Therefore, the development of systematic technology in farming should be able to stimulate the young generation and farmers to rise and compete again so that it becomes the choice of the young generation and farmers today in pursuing this agricultural work. Several modern agricultural systems have been developed today, including the agrivoltaic plant system [5]–[8]. This system operates by combining photovoltaic (PV) and agricultural technology systems on the same land [9], [10]. To support the advantages of the agrivoltaic system, this technology has also developed a model of nutrient-rich water media as a substitute for soil [11], [12]. The plants that will be implemented are chili plants which will also be developed in conditions that are resistant to disease and extreme weather [13]–[15]. Then the chili is planted using agrivoltaic which of course operates on all systems and is integrated with the sensors that have been planted. This agrivoltaic model is also equipped with the nutrient film technique (NFT) technique which is usually found in hydroponic systems [16], [17]. This technique involves flowing a thin stream of nutrient solution beneath the plant roots through an inclined channel or pipe, so that the roots are only partially submerged in the solution, allowing air to continue to flow around the roots [18]. This NFT system can be integrated with internet of things (IoT) technology to monitor and control plant conditions automatically [19], [20]. The development of IoT technology in this agrivoltaic system is capable of monitoring and controlling agricultural systems to become more sophisticated. The IoT system works based on sensors connected to the NodeMCU ESP8266 so that it can collect data in real time and send it to a central platform that can be accessed online [21]–[23]. In the nutrient and temperature monitoring system in agrivoltaic technology, sensors such as pH sensors, DHT11 humidity sensors, and nutrient sensors are installed around the plants to measure nutrient conditions, ambient temperature, and water acidity. The collected data is then sent via a website for further analysis. Then, in order for this system to work continuously, this agrivoltaic technology is developed using solar power, of course, allowing the agrivoltaic technology system to operate independently and save energy [24]. The usefulness of implementing IoT-based technology is inseparable from avoiding systems that die due to grid power outages. With this hybrid system created, it will prevent blackouts and missed monitoring when the grid power goes out, so that technology can be controlled within 24 hours. In addition, the use of solar power as an energy source in this monitoring system has several advantages, the first of which is solar power as a reliable new renewable energy source. In remote or isolated agricultural environments, access to grid power supplies may be limited. By using solar panels to generate energy, the monitoring system can operate independently without relying on external power supplies. This will certainly ensure the smooth operation of the system and continuous monitoring. This agrivoltaic system previously farmers had limitations in caring for their plants by using this technology is able to provide easy access so that it does not have to be controlled continuously. Real-time monitoring with the IoT system allows for accurate and up-to-date monitoring and control of nutritional and temperature conditions in chili plants [25]. This provides direct information to users, allowing chili farmers to immediately take necessary actions to maintain optimal growing conditions. By utilizing IoT technology and solar energy, this system is expected to be an efficient, automatic, and reliable solution in chili cultivation with the NFT system. Then to make it easier to classify ripe, raw, and rotten chilies, a neural network method was developed with the help of data collection based on data from a mini smart camera. This smart farming complex model is also very easy to implement in housing without a large area of land.

2. METHOD

Chili plant growth monitoring can be monitored remotely and chili fruit care can be controlled remotely using the IoT system. This IoT-based agrivoltaic chili plant automatic control system technology is designed to make farming easier while producing high-quality chilies. This system will also make it easier for agrivoltaic chili farmers to carry out maintenance only via mobile phones, and allow farmers to monitor and control anytime and anywhere as long as there is a stable internet connection. Chili plants that are monitored are carried out in real-time by sending image data using a mini smart camera module and several integrated sensors. Image data will be stored in the application for monitoring plant conditions during the planting period. This tool is also equipped with an ESP8266 microcontroller which functions to transfer data from sensors in the IoT concept. The special advantage of agrivoltaic technology developed from this water circulation system is its ability to accelerate the growth of chilies because the nutrients in the water tank can be maintained properly thanks to sensor readings, so that plants do not lack nutrients. In addition, this tool is also flexible and can be applied to other plants, including those planted in soil media. Then the artificial neural network method is used in the classification of chili fruits such as ripe, raw and rotten chili fruit patterns so that it is easier for farmers to sort. The integrated agrivoltaic design system of sensors and IoT is shown in Figure 1.

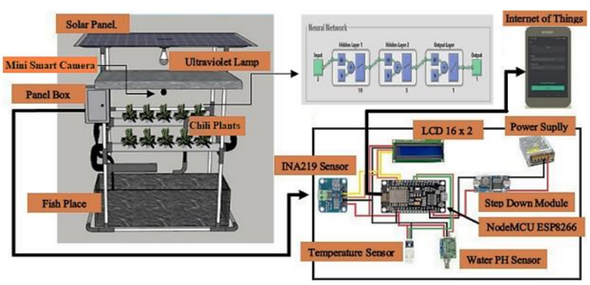


Figure 1. IoT integrated agrivoltaic system

3. RESULTS AND DISCUSSION

Network configuration and connectivity of the IoT-based agrivoltaic plant nutrient and temperature monitoring system require adequate network infrastructure. This is because reliable connectivity must be available so that data collected through sensors can be sent to the website platform smoothly. The development of networks such as cellular networks, Wi-Fi, and other wireless communication technologies has expanded the scope of connectivity and enabled efficient and real-time data delivery. With solar power in the research system, this has played an important role in supporting the operation of the IoT-based monitoring system. In the nutrient and temperature monitoring system for chili plants, solar panels are used to generate the energy needed to operate the sensors and other electronic devices. The following is the performance graph of the output produced by PVs shown in Figure 2. Based on the INA219 sensor test on agrivoltaic technology in the Figure 2(a) frequency output value of DC voltage PV measured by the INA219 sensor obtained a mean value of 13.17 with Std.DV of 113, Figure 2(b) frequency output value of DC current PV measured by the INA219 sensor obtained a mean value of 1.20 with Std.DV of 116, and Figure 2(c) frequency output value of DC power PV measured by the INA219 sensor obtained a mean value of 15.78 with Std.DV of 1.061. Then the value of the measurement results of the PV output connected to the lamp load as ultraviolet (UV) lighting in agrivoltaic technology is shown in Table 1.

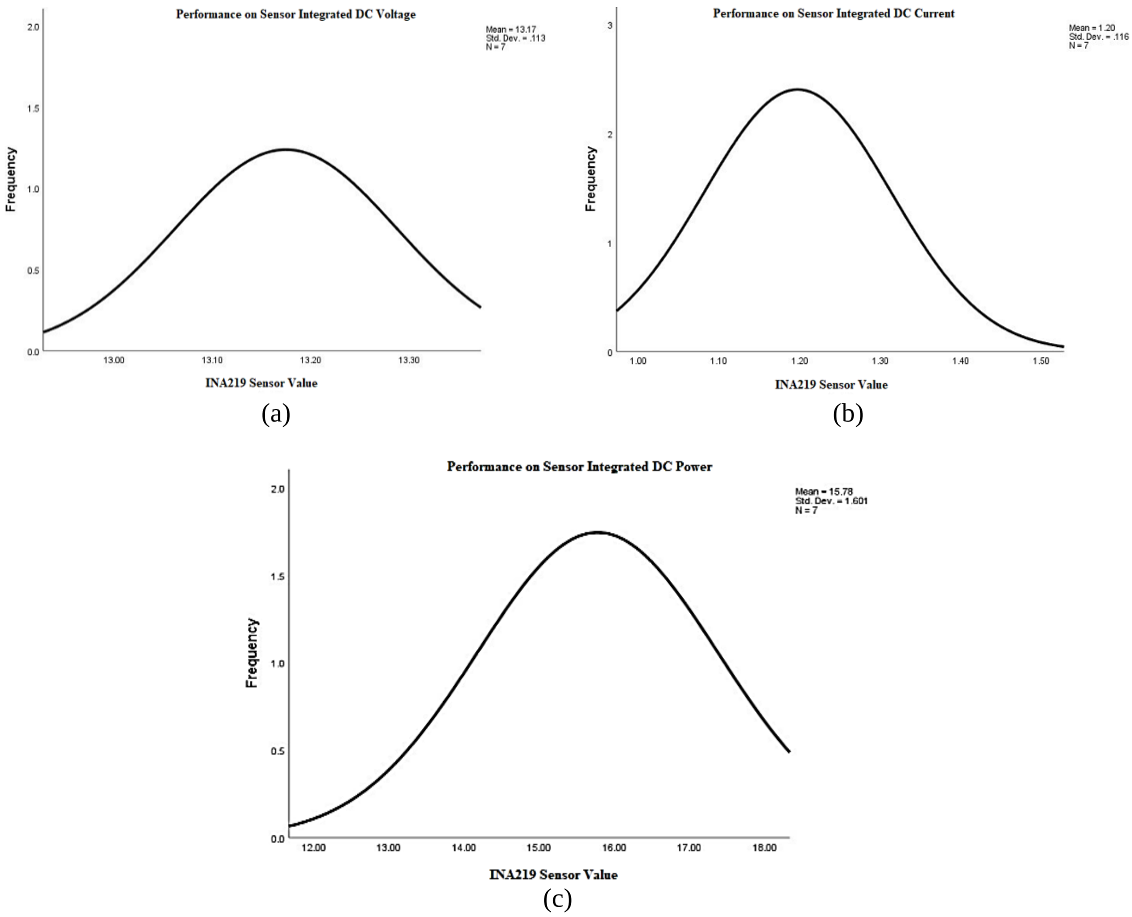


Figure 2. Frequency distribution graph system of PV output values measured by INA219 sensor frequency output value of (a) DC voltage PV, (b) DC current PV, and (c) DC power PV

Table 1. Solar panel measurement results

No	Time	Voltage (V)	Ampere (A)	Power (W)
1.	7:00 am	13.20	1.25	16.50
2.	9:00 am	13.30	1.30	17.29
3.	11:00 am	13.15	1.29	16.96
4.	1:00 pm	13.19	1.29	17.01
5.	3:00 pm	12.98	1.00	12.98

Table 1 shows the results of maximum power measurements at around 1:00 pm with a power of 17.01 W with the aim of supplying an electrical energy source to the UV lamp and also as a source for the microcontroller. Testing data transfer on NodeMCU to Blynk or vice versa using the NodeMCU ESP8266 microcontroller. This test functions as a data transmission and data receiver so that the data obtained has the stability of sending data testing sensors used on the NodeMCU ESP8266 microcontroller. This table may be used to show the efficiency or reliability of data transmission by the NodeMCU ESP8266 module. The difference between the data sent and received can indicate several factors such as data loss, signal quality, or the module's ability to transmit data as shown in Table 2.

Table 2. Testing the NodeMCU ESP8266

No	NodeMCU ESP8266	Transmitted data (kb)	Received data (bytes)
1.	Experiment 1	1.0	20
2.	Experiment 2	1.2	23
3.	Experiment 3	1.3	25
4.	Experiment 4	1.5	33
5.	Experiment 5	1.7	39
6.	Experiment 6	1.8	42

In Table 2, the transmitted data can be obtained from 1.0 kb to 1.8 kb, directly proportional to the amount of data received, there is also an increase from 20 bytes to 42 bytes. Therefore, the measurement of the NodeMCU ESP826 that has been tested obtained good efficiency values and also success in data transmission. Temperature and humidity testing changes throughout the day in the agrivoltaic technology environment. Environmental conditions greatly affect the growth of chili plants under solar panels, as well as to manage and optimize agricultural and energy production. The monitoring system at the temperature measured in degrees Celsius (°C) at each time. This temperature varies from the lowest 28.3 °C at 7:00 am to the highest temperature reaching 31.6 °C at 1:00 pm, then slightly decreased at 3:00 pm. The level of air humidity measured in percent also varies relatively from 75% in the morning (7:00 am) to 65% at noon 1:00 am, and then slightly increased in the afternoon (66%). Results of temperature and humidity testing in agrivoltaic are shown in Table 3. In Table 3, the temperature and humidity measurements are at stable and normal conditions. The sensor works well where the temperature increases and humidity decreases so that the agrivoltaic technology is stable and can operate efficiently.

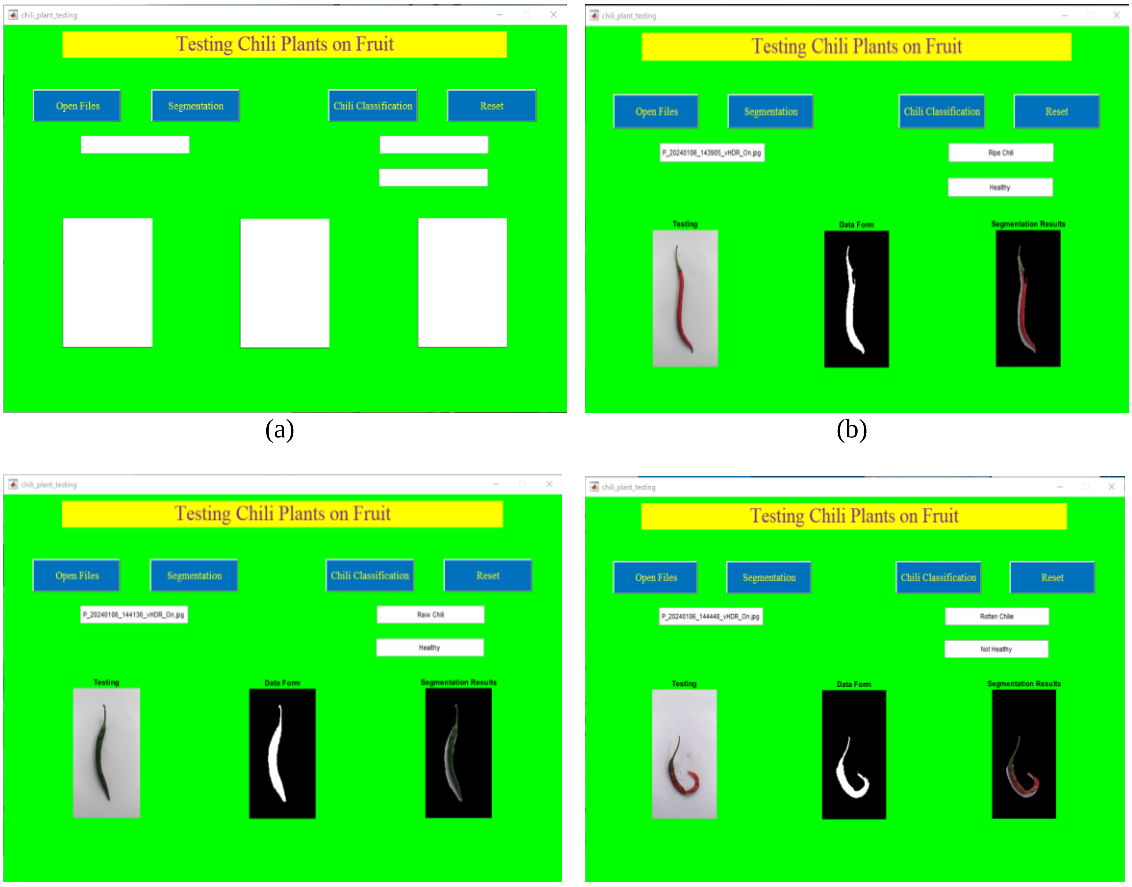
Table 3. Results of temperature and humidity testing in agrivoltaic

No	Time	Temperature (°C)	Humidity (%)	Condition
1.	7:00 am	28.3	75	Normal
2.	9:00 am	29.6	72	Normal
3.	11:00 am	30.5	68	Normal
4.	1:00 pm	31.6	65	Normal
5.	3:00 pm	31.3	66	Normal

3.1. Chili fruit classification testing based on graphical user interface

After the agrivoltaic system works well, then testing the application that has been built with MATLAB software is carried out. This development is designed based on a graphical user interface (GUI) model with the aim of analyzing the quality or type of chili fruit based on digital images. Testing is carried out by determining the accuracy of testing ripe, raw, and rotten chili fruit. The GUI system built based on the neural network method by testing ripe chili fruit, then testing raw chili fruit and finally testing rotten chili fruit. The chili fruit samples tested based on real data in the field use a mini smart camera module that has been integrated with the IoT system. The data obtained is stored in a database and then data processing is carried out using MATLAB software. The GUI system built based on the neural network method is shown in Figure 3.

The GUI application operating system which is the heart of this system consists of the first on the open file button allows users to open a chili fruit image file that will be analyzed by the system. Then on the segmentation button with this button system may be used to start the segmentation process, which is dividing the image into smaller parts or separate objects, such as chili fruit for further analysis. Chili classification, namely this system works the chili classification process which may involve recognizing the type or quality of chili based on images of ripe chili fruit, raw chili fruit, and rotten chili fruit. The reset button is used to reset or reset the application, delete data, or images that have been loaded, so that users can start a new process. Then there are three areas used to display images or analysis results, such as original images, segmentation results, and classification results. Figure 3 is the entire GUI system built based on the neural network method. Then Figure 3(a) chili fruit testing classification system based on GUI which will be compressed using neural network method, Figure 3(b) is image data that when inputting ripe chili fruit will display the classification of ripe chili fruit, in Figure 3(c) testing raw chili fruit whose data is obtained based on the image of green chili fruit with raw category and the last Figure 3(d) is the testing of rotten chili fruit so that farmers will later find it easy to sort chili fruit. The system that will be used uses a neural network method whose entire data has been input into a computer program with 2 input neurons, 2 hidden layers, and 1 output neuron with 10 and 5 neurons respectively. This structure is used to process input data and produce the desired output after going through several levels of processing.



(a) (b)

(c) (d)

Figure 3. GUI system built based on neural network method (a) chili fruit testing classification system based on GUI, (b) ripe chili fruit testing, (c) raw chili fruit testing, and (d) rotten chili fruit testing

3.1.1. Neural network training performance on chili data

The processed data is then determined to measure and monitor the performance of the neural network. There are three charts that you can monitor: training, validation, and testing. By doing this, the performance of the neural network changes during the training process and helps decide when to stop training to avoid overfitting. When the model fits too well with the training data and loses its ability to predict new data well. The following neural network training performance data is shown in Figure 4.

The results of the neural network training performance measurement shown in Figure 4, can be obtained the best validation performance graph value achieved in the 10th epoch with a mean squared error (MSE) value of around 0.00063967. In the blue graph value, there is a decrease which means that the lower the MSE in the train, the better the learning from the training data. In the green graph value is used in reading the value to evaluate the model can operate generalization well to new data where the performance in epoch 10 is the best performance on validation data before the start of overfitting.

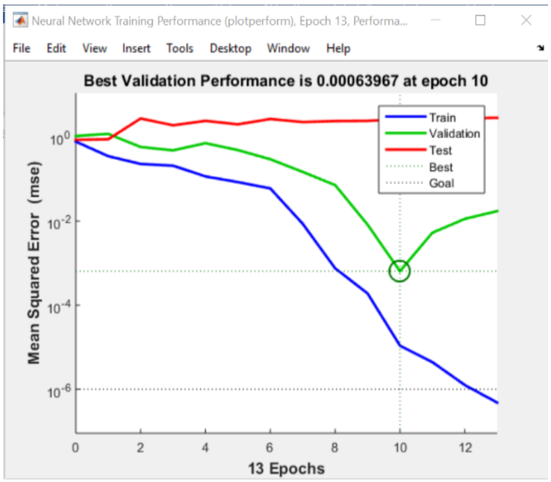


Figure 4. Neural network training performance

3.1.2. The results of the regression graph test on the neural network model on chili fruit data

The test results are in the form of a regression plot of the performance of the artificial neural network model in predicting data during the training, validation, and testing processes. This diagram can be used to evaluate how close the model's output predictions are to the actual target values (targets) shown in Figure 5. The result data in Figure 5 shows the performance of the neural network method has a very good performance model on the value of the training and validation data programmed. Then there are 4 target graphs, namely the blue graph where the fit graph value with the R value reaches 0.9 which means it is close to the value of 1, thus the model is very suitable for the training data. The green validation diagram shows the suitability of the model with valid data. Next is the red target graph, which shows the relationship between model predictions and test data targets, and finally the gray graph, which shows the overall suitability of the model to all data (training, validation, and testing).

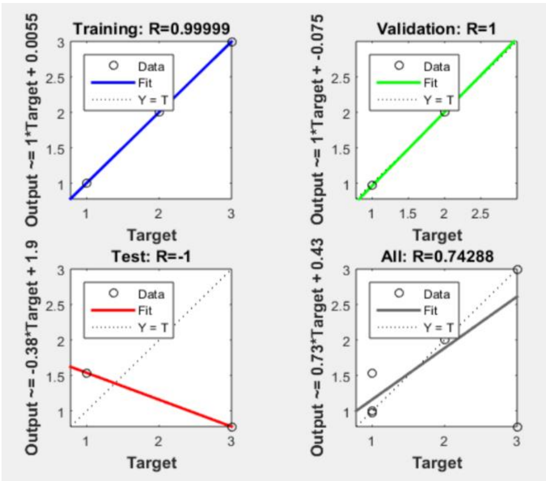


Figure 5. Results of regression graph testing on neural network models

4. CONCLUSION

The integration of agrivoltaic technology with the development of the IoT system will have an impact on farmers, especially chili farmers, in modern farming. Farmers can control and add vitamins, fertilizers, and water quality based on a control system that has been programmed with the IoT system. Plants are then given nutrients and watered automatically and regularly according to a real-time clock schedule. This system is also equipped with a PV energy source (PV-off grid), so that water circulation through the pump machine is never interrupted. The development of a small smart camera model was also developed to monitor chilies in taking pictures. This image is then converted for segmentation using a GUI that has been programmed with MATLAB software. The method used in this chili fruit classification uses an artificial neural network in classifying ripe, raw, and rotten chilies. The system to be used uses an artificial neural network method whose entire data has been input into a computer program with 2 input neurons, 2 hidden layers and 1 output neuron consisting of 10 and 5 neurons respectively. This structure is used to process input data and produce output with the desired accuracy after going through several levels of processing. The classification results obtained an R value of 0.9, which means it is close to a value of 1 in the suitability of the chili image. Thus, farmers will find it easier to sort the chilies to be harvested.

ACKNOWLEDGEMENTS

The author would like to thank Asahan University for the Internal Grant Scientific Paper Publication Assistance Programbased on Guidebook No. 103/KPTS-UNA/YEAR 2024. We would also like to thank Universitas Medan Area for supporting this research. And research collaboration with Universitas Potensi Utama.

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