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Design of Single and Dual-axis Solar Tracker System using Neural Network

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ABSTRACT

Nowadays, solar energy is becoming more popular as it promotes awareness of an eco-friendly lifestyle. However, solar power generation is insufficient as the primary power generation in Malaysia. To overcome this issue, many private companies are devoting themselves to research to increase the amount of electricity produced by solar panels. Research has shown that a surface perpendicular to direct sunlight increases power generation significantly. Therefore, positioning the solar panel perpendicular to the direct sunlight is crucial as there are many factors to be considered. We will study the difference in dimensional movement and the method of tracking sunlight to make solar panels more efficient in power generation. Light can come from omnidirectional, the movement of the robot must have a higher dimension. Finding the highest intensity of sunlight becomes a challenges because sunlight does not constantly stagnate in a particular location. Therefore, a static solar panel is not as useful as a dynamic solar panel. Besides, the positioning of the sun will change accordingly based on the season. Hence, we need a dynamic solar tracker that can changes its solar panel position as the sun rises or falls. A neural network is chosen as the method of positioning the solar panel by moving with single-axis and moving with dual-axis.

Key words: Single-axis, dual-axis, solar tracker, neural network

1. INTRODUCTION

Light energy is usually generated by a light source, the most popular of which is the sun. Humanity has meddled with the use of energy, especially light energy, to produce something. This has been achieved multiple times over many years, the most recent of which is presented in the form of solar energy. Solar energy is created by solar radiation, which causes certain chemical reactions and generates a sufficient amount of electricity. If used appropriately, solar energy can potentially meet a majority of future energy needs. So far, it has been proven sufficient and beneficial for the public whether they are at work or at home.

While many researchers attempt to create robots by using artificial intelligence (AI) methods [1][2][3], it is often hard to deal with attached wires to set the robots in motion. Remote controlled robots may be reliable, but sometimes they are impractical, especially when the robot has to move around. Tripping cables will definitely result in a fall or worse, accidental damage to the sensor units. Furthermore, there has not been an efficient or reliable method of generating energy with a robot as the subject has not been fully explored nowadays. Although several attempts have been made while trying the method. Besides, it is unclear how much energy can be generated or how accurate the input sensors are when it comes to navigating a light source.

The main goal of this study is to increase the efficiency of producing clean energy so that companies can choose a better option of tracking the position of the sun and moving the solar panel accordingly. It can be placed in many places. This movement is achieved by connecting a stepper motor to the solar panel that changes its direction depending on the position of the sun. It can be achieved using a time reference that controls the movement time for 12 hours through a program written so that the solar panel faces the sun for each time to generate maximum power which is stored in the batteries.

The rest of this paper is organized as follows: Section 2 analysis of solar tracker and comparison with other system. Section 3 elaborates the structure of the solar tracker, while in Section 4 elaborates the mechanism of the solar tracker system. Lastly, Section 5 depicts the results and discussion whereas Section 6 draws the conclusion.

2. ANALYSIS

The predictive model proposed in this paper consists of two main components: (1) the analysis of the current system, (2) the analysis of the proposed system.

2.1 Analysis of Current System

Solar energy is obtained from the solar radiation. The sun is a powerful source of energy and this energy source can be used by installing a solar panel. Some methods of managing the solar tracker system are shown in Table 1.

Table 1: Analysis of methods

Method	Description	Pros and Cons Solar Energy
Solar panel with sun position tracking by voltage regulator and a circuit board	The light dependent resistor (LDR) is installed on the sides of the solar panel	▪ Low cost, larger user base, wide availability, extensive collection of application notes, serial programming, availability of low cost or free development tools, and re-programmable flash-memory capability
Solar tracking system based on photovoltaic system (PV)	Specific device intended to move the PV modules so that they are continuously facing the sun in order to maximize the irradiation received by the PV array [4][5][6].	▪ Solar energy from nature and PV panels provide clean-green energy ▪ The maintenance and operating costs for PV panels are considered to be low and almost negligible compared to other renewable energy system ▪ Fragile and relatively easy to damage, and its efficiency is relatively low
Solar energy with an artificial neural network (ANN) and particle swarm optimization (PSO)	Optimize power generation for the PV system under different operating conditions such as different solar radiation and cell temperatures [7].	▪ Can be easy to implement and has few parameters to adjust, can also do parallel computation and does not overlap or mutate ▪ It can be difficult to define initial design parameters and it can converge prematurely and be trapped into a local minimum especially with complex problem
Fuzzy logic based controller for controlling the solar tracking system.	Fuzzy logic controller will be used to control the two motors that move the PV panel, so that it is always perpendicular to the direct sunlight [8].	▪ Can achieve the highest possible efficiency by allowing direct sunlight to fall perpendicularly on the PV panel ▪ Allow the interaction of multiple inputs and multiple outputs.

2.2. Analysis of the Proposed System

The proposed solar tracker system will solve the problem of the current use of solar tracker. The robot is designed and programmed to determine the direction of the sun. The robot tracks using the light sensor. Then, this robot will keep track the position of the sun. Besides, this robot will make a movement and read the data. This robot can help to increase the efficiency of the photovoltaic panel and increase the energy output of solar panels and solar receivers.

3. STRUCTURE OF THE SOLAR TRACKER

The whole framework of the solar tracker system is successfully built up. The solar tracker uses the EV3 Lego Mindstorm component to complete the architecture and design as shown in Figure 1. The main component of the robot is the four light sensors that detect light sources from four different position: top, bottom, right and left. The input of the light sensor is calculated in the intelligent model (2-layer model of the neural network). The output of the neuron is activated and the movement is then triggered.

Figure 1: Structure of the Solar Tracker

Figure 2 shows the flowchart of the solar tracking robot. Table 2 shows the movement of the solar tracking robot.

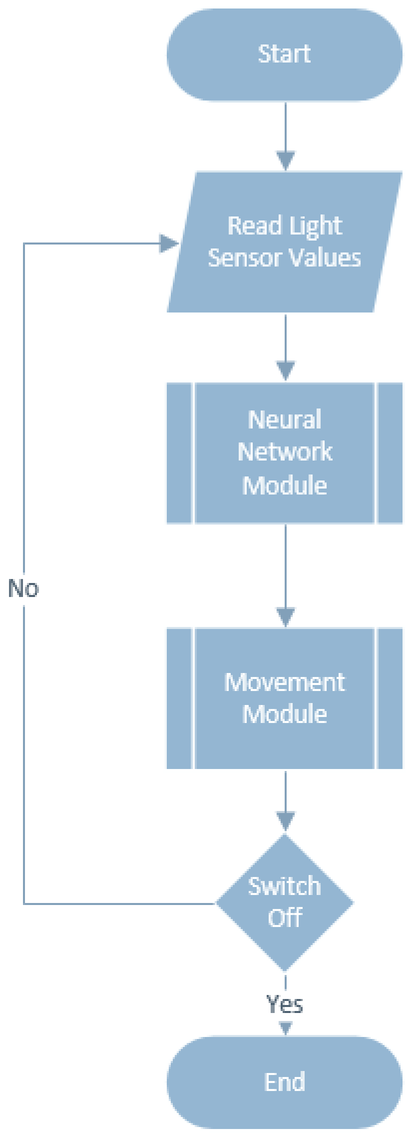

Figure 2: Flow Chart of the Solar Tracking Robot

Table 2: Movement of the Solar Tracking Robot

Movement	Up	Down	Left	Right
Single-Axis	No	No	Yes	Yes
Dual-Axis	Yes	Yes	Yes	Yes

4. MECHANISM OF THE SOLAR TRACKER SYSTEM

The predictive model proposed in this paper has three main components: (1) the data acquisition and pre-processing module, (2) the neural network, and (3) the movement module.

4.1. The Data Acquisition and Pre-processing Module

The training dataset is trained in the neural network using backpropagation. The number of train data is 300. The dataset is generated randomly under the following conditions, as shown in Table 3 and Table 4.

Table 3: Training Data for Neural Networks

Input Sensor	Input Value	Predicted (Output)
Top	0~1.0	-1.0~1.0
Bottom	0~1.0	-1.0~1.0
Left	0~1.0	-1.0~1.0
Right	0~1.0	-1.0~1.0

Table 4: Condition for the Output (Training Data)

Predicted (Output)	Condition
1	• Difference between input (top) and input (bottom) more than 0.3, vice versa • Difference between input (left) and input (right) more than 0.3, vice versa
0	• Input (top) more than input (bottom), vice versa • Input (left) more than input (right), vice versa
-1.0	• Input (top) less than input (bottom), vice versa • Input (left) less than input (right), vice versa

4.2. Structure of the Neural Network

The input layer is the four-light sensor. The light sensor receives the light intensity in ambient mode. The range of the value obtained is between 0 and 100. The value then normalizes to 0~1.0. Figure 3 shows the FP-Tree with First log (A, B, C).

Rule-of-thumb method for determining an acceptable neuron to use in the hidden layer [9]:

- The number of hidden neurons should be between the size of the input layer and the size of the output layer.
- The number of hidden neurons should be 2/3 the size of the input layer plus the size of the output layer.
- The number of hidden neurons should be less than twice the size of the input layer.

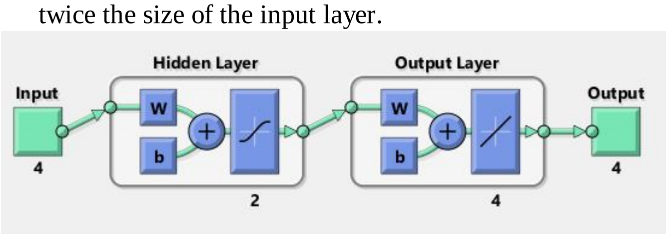

Figure 3: FP-Tree with First log (A, B, C)

4.2.1 Backpropagation in Neural Network

Backpropagation algorithm has been widely applied in the area such as computer science, agricultural, healthcare and engineering [10][11][12]. It consists of two steps: forward propagation and backward propagation. Figure 4 shows the preparation for backpropagation. Figure 5 shows the backpropagation and the best validation performance of neural network is shown in Figure 6. The structure of neural network is depicted in Figure 7 and the results is shown in Figure 8.

I. Forward Propagation

a. Calculate weighted sums in the first hidden layer:

$$y_n = i1 * w1 + \cdots + i_n * w_n + b$$

b. Apply the activation function:

$$h_n = \frac{1}{1 + e^{-y_n}}$$

c. Calculate the weighted sum of node 5: v5 = w35y3 + w45y4 = 2 · 1 − 1 · 1 = 1

d. The same process is done to calculate the predicted output value.

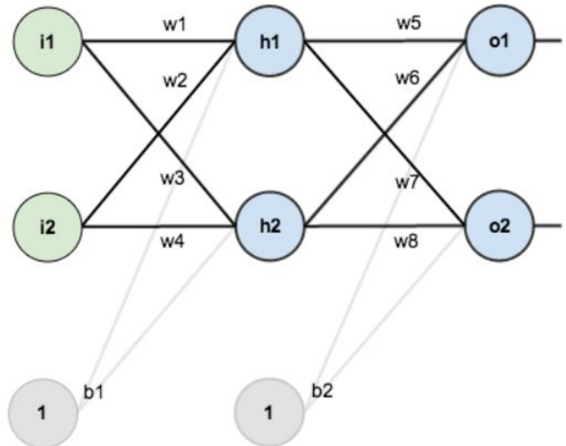

Figure 4: Preparation for Backpropagation

II. Backward Propagation

a. Calculate the differences between actual output and predicted output:

$$E_{on} = \frac{1}{2} * (actual - predicted)^2$$

$$E_{total} = \sum \frac{1}{2} * (actual - predicted)^2$$

b. Calculate the influence of a particular weight towards the neuron:

$$\frac{\partial E_{total}}{\partial w_m} = \frac{\partial E_{total}}{\partial out_{o1}} * \frac{\partial out_{on}}{\partial net_{on}} * \frac{\partial E_{total}}{\partial w_m}$$

c. Update the latest weightage

$$W_n^{+} = W_n - \eta * \frac{\partial E_{total}}{\partial w_m}$$

d. The same process is done to calculate the input-hidden layer weightage.

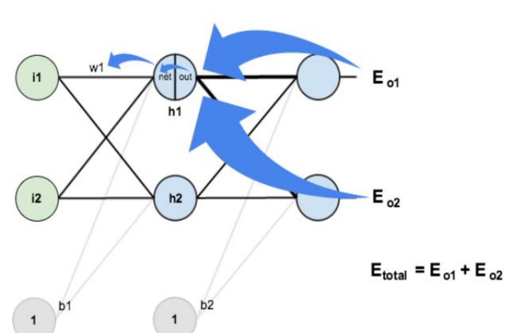

Figure 5: Backpropagation

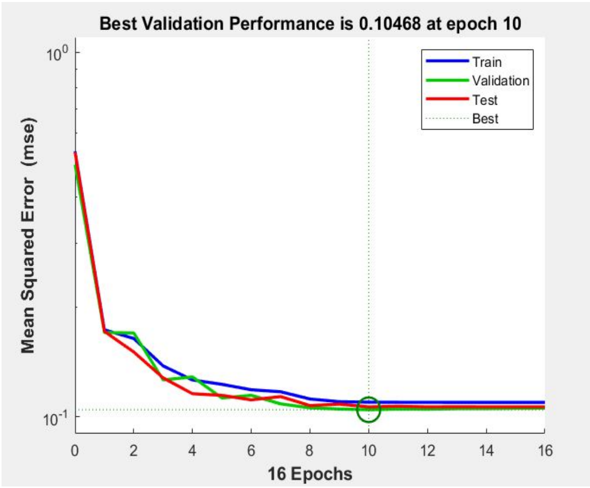

Figure 6: Best Validation Performance of Neural Network

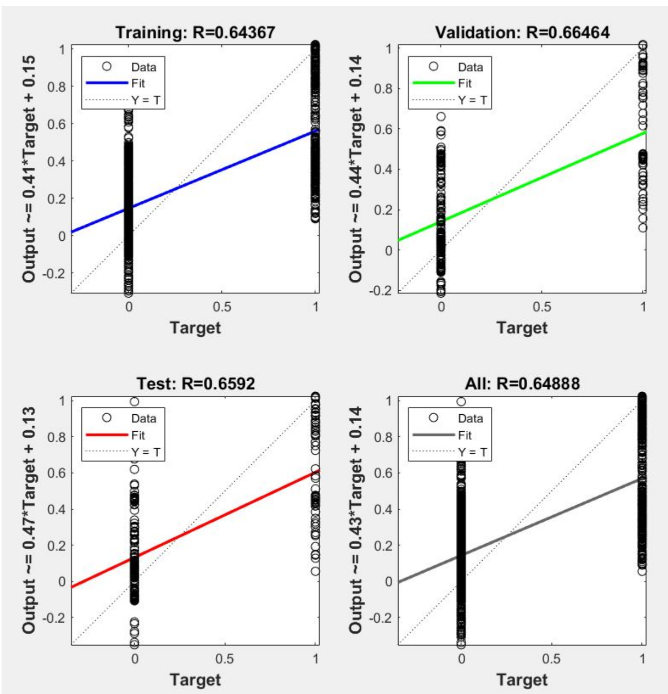

Figure 7: Structures of Neural Network

	Samples	MSE	R
Training:	350	1.09817e-1	6.43665e-1
Validation:	75	1.04682e-1	6.64639e-1
Testing:	75	1.06594e-1	6.59203e-1

Figure 8: Results of Neural Network

4.3 Movement Module

Table 5: Movement Module for Single-Axis and Dual-Axis

Movement	Up	Down	Left	Right
Single-Axis	No	No	Yes	Yes
Dual-Axis	Yes	Yes	Yes	Yes

A single-axis motion is a 2-D motion that can be a left-right or an up-down motion, while a dual-axis motion is a 3-D motion that can be a left-right and an up-down motion simultaneously. The accuracy of the solar tracking robot is determined by its ability to locate the maximum light intensity and the positioning of the robot perpendicularly to the sunlight. Such comparisons are made against single-axis and dual-axis motions.

The solar tracking robot tracks the light source and is tested in a simulation. The simulation was to done for the robot to tackle the positioning of the direct sunlight with both single-axis and dual-axis motions using neural network. The robot tracks the direct sunlight over a period of 60 second. The measured value is taken in real time every 0.02 seconds. The comparison is tested on both single-axis and dual-axis motions for the efficiency of power generation using a neural network.

5. RESULTS AND DISCUSSION

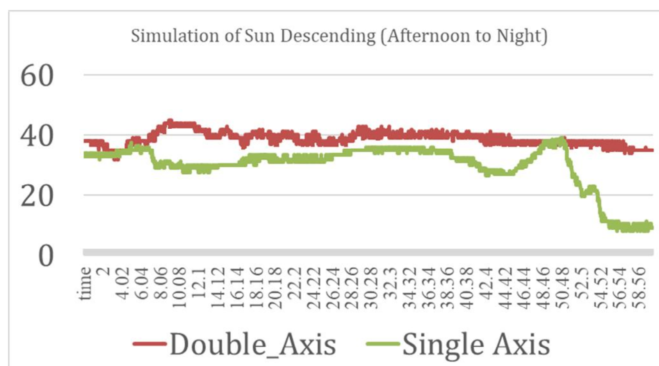

Figure 9: Simulation of Sun Descending

Figure 9 shows the simulation of sun descending. In Figure 9, we can observe that the significant decrease in power generation at sunset towards the end of the simulation. This is because the solar panel for single-axis is unable to move upward and downward. Not only is the value generated by the single-axis solar panel slightly lower compared to the dual-axis motion. This is because the solar panel is stagnating at 45 degrees and is unable to move up and down. Therefore, the solar tracking robot was not able to locate perpendicular to the direct sunlight also affects the efficiency of power generation.

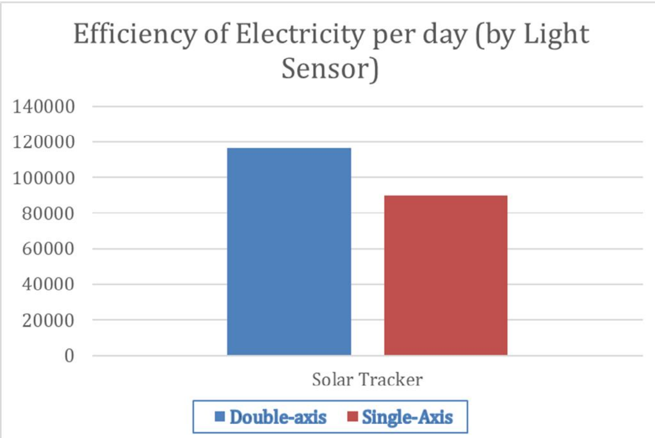

Figure 10: Efficiency of Generating Electricity

Figure 10 shows the efficiency of electricity per day. By comparing the generated values for the simulation in a single day, we can observe that dual-axis motion using neural network increases power generation. Dual-axis motion is 30% (116392) higher than single-axis motion in terms of efficiency of generating electricity per day.

6. CONCLUSION

Solar Tracking Robot was designed to increase the efficiency of power generation by positioning the solar panel perpendicular to the sun. Biomass has long been the main source of power generation. However, there are many environmental and sustainability issue that many experts concern about. Therefore, there is a need for clean and sustainable energy. As a result, solar energy came along as an alternative solution. However, solar energy is inefficient because the position of the sun and seasonal weather conditions affect the efficiency of power generation. When the solar panel is integrated with the solar tracking robot, power generation can be maximized.

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