Design and Implementation of Dual Axis Solar Tracker PV to Increase Cleaning Robot Operating Time

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Abstract. This paper discusses design and implementation of dual-axis tracker for PV to supply additional power to extend the operating time of cleaning robot. The system consists of PV 3.5wp, servo motor Tower Pro G90, DC motor, motor driver L298, light sensor (LDR) and microcontroller. Dual axis solar tracker PV works with the principle of comparing light intensity on four light sensors to determine the direction of the oncoming light. PV will be directed perpendicular to the direction of the sunlight in order to maximize the energy production. From the test results obtained that PV produce the highest output voltage reaches 6.10 Volts on light intensity 110800 until 116500 LUX, when PV form the angle of 0 ° to 10 ° towards the sunlight. The average time of charging the battery using the PV, with battery condition 2.5 volt to 3.7 Volt is 94 minutes 48 second. For the average operation time of mobile robot with additional PV longer 7 minutes 17 second compared to mobile robot operation time of without additional PV.

1. Introduction
In mobile robot technology of field cleaners, power source is still a major problem because battery technology has a limited capacity. Cleaners robot require energy from the surrounding environment that can charge the battery. One of them is solar energy (Vijayalakshmi, 2016). By using PV, solar energy can be converted into electrical energy, in order to battery charging the field cleaners robot. In this paper, PV that used has a maximum power output 3.5wp. Research on the use of PV for charging the battery on mobile robot has been done. As an example in a journal entitled Solar Energy Support System of Mobile Robot for Exploring Disaster Area (Muhida, Zaid and Fatah, 2008), in this study PV is able to charge the battery to extend the operation of the robot. However, absorption of solar energy is less than the maximum because the PV is installed permanently on the body of the robot. In another study, titled Design and Implementation of Automatic Power Supply System Using Solar Cell on Wheeled Robot Line Followers (Dwi, Haqqi and Rusdinar, 2015) also discuss about charging the battery in mobile robot using PV. However, PV is also installed permanently on the body of the robot.

In another study, titled Design of Solar Tracker Based Atmega8535 Microcontroller with LDR Sensor and LCD Viewer (Syafrialdi and Wildian, 2015) has been discussed about PV that is able to follow the movement of the sun. However, in the study only use one axis of motion only. When the PV is mounted on a moving object then the system is difficult to adjust to the direction of the arrival of sunlight. In another study, titled Portable PV Power plant with Solar Tracker for Disaster Affected Area
Emergency Power Supply (Riyanto, Octaviano, Suparmoko and Obara, 2016) has been discussed about PV with dual axis solar tracker technology that is utilized as an emergency energy source in the affected area. In this research has been done the design process of dual axis solar tracker PV for mobile batteries charging field-cleaning robot. PV paired on the body of the robot can move to follow the movement of the sun. Therefore, the position of PV is always perpendicular to the direction of the arrival of sunlight. PV has been designed to have two axes of motion. That is the vertical axis and horizontal axis to make the movement of PV more flexible. In addition, it is suitable if the PV is mounted on moving objects such as mobile robot field purifier.

2. System Design

The systems designed in this paper include hardware and software. Block diagram the designed system as shown in Figure 1. The hardware design of the system consists of designing a solar tracker mechanical system and solar tracker electronic system. While the software describes the design of program algorithms to be embedded into the solar tracker controller.

2.1. Block Diagram

In the block diagram of a dual system of solar axis solar tracker for mobile battery, charging robot field cleaner shows a general picture of the system. The system is designed in the form of solar tracker mounted on the field-cleaning robot, the output from PV is used to charge the battery of field cleaning robot. The field cleaning robot system works based on the principle of an open loop control system. The working principle of field cleaning robot is to receive control signal from smartphone using Bluetooth connectivity, then data is processed by control algorithm on controller to determine rotation of right and left DC motor to adjust direction of robot movement. In this study focuses on solar tracker system. The block diagram illustrating the working principle of a solar tracer mounted on the field-cleaning robot is shown in Figure 1.

2.2. Mechanical Design

The solar tracker system is designed to charge the battery of field cleaning robot, solar tracker mounted on the top of the robot. Field cleaning robot is designed with dimensions, length 30 cm, width 20 cm and height 5 cm. While diesel tracker is designed with dimensions, length 18 cm, width 17 cm, height 13 cm. The mechanical design of solar tracker position on cleaner robot shown in Figure 2.

2.3. Light Sensor Circuit

In designing dual axis solar tracker system using LDR as light sensor. LDR coupled series with a resistor. The midpoint voltage of the circuit is connected to controller analog pin, that shown in Figure 3.
2.4. Servo Motor Circuit
In the design of dual axis solar tracker system, using servo motors type Tower Pro G90 with a working voltage of 4.8 VDC - 6 VDC. Servo motor has three pins, the VCC pin, GND and Control. For VCC and GND pins are connected to +5 volt and -5 volt voltages. The servo motor control pin is connected with pins 10 and 11 of controller that shown in Figure 4.

2.5. Program Algorithm
In the design of soft propellers on dual-axis, solar diesel tracker systems PV for mobile battery cleaning robot field cleaners are written using C language, and use Arduino IDE applications as tools to create software. The program algorithm shown at the flowchart in Figure 5.

![Figure 3. Light sensor circuit.](image1)

![Figure 4. Servo motor circuit.](image2)

![Figure 5. Program algorithm (a) main program, (b) sub program PV Panel Position.](image3)
3. Result and Discussion

This chapter discusses the testing of system that has been designed. System testing includes PV module testing, battery charging testing and overall testing. Overall testing is done by comparing the robot's operating time with additional PV and without additional PV.

3.1. PV Module Testing

PV module testing aims to determine the characteristics of PV output voltage. The equipment used in the test are as follows, arc ruler to measure the angle of PV, lux meter to measure the intensity of light and volt meter to measure the output voltage of PV. The test is done at Universitas Budi Luhur basketball court at 12:15 until 12.30 WIB at light intensity 110800 lux until 116500 lux, with bright sky condition. The test is done by changing the angle of the PV at regular intervals; each change in the angle of the PV is measured voltage and light intensity measurement, then recorded data in the form of light intensity, angle and output voltage of PV. The schematic testing and setting of the PV module shown in Figure 6 and Figure 7.

![Figure 6. Schematic of PV module testing.](image1)

![Figure 7. Setting of the PV module angle position.](image2)

PV angle change is done manually and periodically. The starting angle starts from an angle of 0° and then increases by 10° every angle change. The largest angle in this test is 50°. This angular change is done within the limits of vertical PV motion that has been designed. Any change in PV angle is done measuring the output voltage of PV. Result of PV module testing shown in Table 1. Characteristics of the relationship between angle of PV position with PV output voltage shown in Figure 8.

| Time     | Light Intensity | PV Angle | Output Voltage |
|----------|-----------------|----------|----------------|
| 12.15    | 110800 lux      | 0°       | 6.10 volt      |
|          |                 | 10°      | 6.10 volt      |
|          |                 | 20°      | 6.08 volt      |
|          |                 | 30°      | 6.08 volt      |
| 12.30    | 116500 lux      | 40°      | 4.96 volt      |
|          |                 | 50°      | 4.02 volt      |
At a PV 0° angle it is seen that the PV output voltage is 6.10 Volts, after the angle changes to 20° the output voltage of PV decreases to 6.08 Volts, until it reaches the lowest voltage at an angle of 50° with an output voltage of 4.02 Volts.

3.2. Testing of Battery Charger

Battery charger circuit test aims to determine the duration of time charging using PV voltage. Equipment used in the test is as follows, Volt meter that serves to measure the voltage, PV to provide input voltage to the battery charger, clock to calculate the time of charging. The tests were conducted at Universitas Budi Luhur basketball court. The test is done at 10.00 to 14.00 with the condition of clear sky (light intensity 118200 lux until 154300 lux). The test is done by emptying the battery and then do the charging with the input voltage from PV to full battery. The battery is said to run out if the voltage of each cell is less than 2.5 volts while it is said full if the voltage of each cell reaches 3.7 volts. The time it takes to fully charge the battery is recorded in Table 2.

| No | Time  | Light Intensity | Charging time |
|----|-------|-----------------|---------------|
| 1  | 10.40 | 110800 lux      | 95 minute     |
| 2  | -     | -               | 85 minute     |
| 3  | 14.00 | 116500 lux      | 94 minute     |
| 4  | -     | -               | -             |
| 5  |       |                 | 98 minute     |

Charging time average = \( \frac{102 + 95 + 85 + 94 + 98}{5} \) = 94.8 minute = 98 minute 48 seconds

3.3. Overall Testing

The overall test aims to find out the comparison of operation time of field cleaning robot when mounted PV and without PV. The equipment used in the test is as follows, a smartphone that is functioning to control the movement of field cleaning robot and stopwatch to know the duration of operation of field cleaning robot. The test is done at Universitas Budi Luhur basketball court at 09.00 - 14.00 with the condition of clear sky with light intensity 118200 lux until 154300 lux.

Testing is done by moving the field cleaning robot with a certain pattern continuously until the battery runs out and record the robotic operation time. Operation times recorded from the beginning of the robot run until the battery runs out. In this test there are two robot conditions, the first condition of a robot with a full battery condition without a PV installed, the condition of both robots with full battery condition and fitted with PV. The movement pattern has a rectangular trajectory with a size of 5 x 3 meters. The operating time that a robot can achieve is calculated using a stopwatch and recorded in a table. To get valid data the test is done ten times.
Table 3. Robot operating time without PV.

| No | Time | Light Intensity | Robot Operating Time (sec) |
|----|------|----------------|--------------------------|
| 1  | 09.00| 118200 lux     | 1058                     |
| 2  | 14.00| 154300 lux     | 1032                     |
| 3  | -    | -              | 1151                     |
| 4  | 11.00| 118200 lux     | 1009                     |
| 5  | -    | -              | 1171                     |
| 6  | 14.00| 154300 lux     | 1158                     |
| 7  | -    | -              | 1146                     |
| 8  | -    | -              | 1121                     |
| 9  | -    | -              | 1007                     |
| 10 | -    | -              |                          |

Table 4. Robot operating time with PV.

| No | Time | Light Intensity | Robot Operating Time (sec) |
|----|------|----------------|--------------------------|
| 1  | 09.00| 118200 lux     | 1533                     |
| 2  | 14.00| 154300 lux     | 1464                     |
| 3  | -    | -              | 1455                     |
| 4  | 09.00| 118200 lux     | 1459                     |
| 5  | -    | -              | 1531                     |
| 6  | 14.00| 154300 lux     | 1549                     |
| 7  | -    | -              | 1518                     |
| 8  | -    | -              | 1576                     |
| 9  | -    | -              | 1591                     |
| 10 | -    | -              | 1647                     |

Average operating time of field cleaning robot without PV. Here is the calculation of the average operation time of the field cleaning robot:

\[
\text{Average robot operating time without PV} = \frac{1058 + 1101 + 1032 + 1151 + 1171 + 1009 + 1158 + 1146 + 1121 + 1007}{10} = 1095 \text{ seconds} = 18 \text{ minute 15 seconds}
\]

Average field operation time of field cleaning robot with additional PV. Here is the calculation of the average operation time of the field cleaning robot:

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\text{Average robot operating time with PV} = \frac{1533 + 1464 + 1455 + 1459 + 1531 + 1549 + 1518 + 1576 + 1591 + 1647}{10} = 1532 \text{ seconds} = 25 \text{ minute 32 seconds}
\]

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\Delta \text{Average robot operating time} = \text{Average operating time with PV} - \text{Average operating time without PV} = 1532 \text{ seconds} - 1095 \text{ seconds} = 7 \text{ minute 17 seconds}
\]
4. Conclusion
Based on the result of tool making and analysis on dual axis solar diesel tracker PV system for charging mobile robot battery, it can be concluded as follows. PV will produce the highest output voltage when PV angle 0° to 10° with normal line, reaching 6.10 Volt at light intensity 110800 until 116500 LUX. The average time of charging a robot battery using a PV voltage is 94 minutes 48 seconds. The average mobile operating time of the field cleaning robot with additional PV is longer 7 minutes 17 seconds compared to the mobile operating time of field cleaner robot without additional PV.

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