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Use of Mini Solar Panels for Battery Charging in the Mini Robot Warehouse

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Abstract

Industrial businesses have employed various robot cars to execute tasks related to goods movement, such as the Warehouse Robot Car, which utilizes a line follower sensor system. However, the substantial electricity consumption poses a challenge due to excessive energy use in robot cars. In light of this issue, the research aims to assess the utilization of mini solar panels in robot cars equipped with 3.3V Li-ION 18650 batteries. The primary objective is to calculate the electricity required to operate a line-following robot car within the designated sector. The approach involves designing robotics and solar panel systems for generating input and output power, including charging measurements. According to the findings, solar panels can charge at a maximum rate of 0.206358 watts for 45 minutes, while the robot can operate at a minimum rate of 0.26 watts for 29 minutes, resulting in a charging efficiency to robot performance of 43.5 percents.

Keywords*: Robot car, Warehouse, Solar panel, Electricity*

Abstrak

Perusahaan industri telah melibatkan beberapa mobil robot untuk melaksanakan tugas dalam memindahkan barang contohnya mobil robot Warehouse yang menggunakan sistem sensor line follower. Namun konsumsi listrik yang berlebihan pada mobil robot dapat mempengaruhi nilai ketinggian dari konsumsi listrik. Sesuai dengan latar belakang tersebut tujuan dari penelitian ini untuk melakukan analisis penggunaan Mini solar panel pada mobil robot dengan menggunakan baterai Li-ION 18650 dengan kapasitas 3,3v. Tujuan penelitian tersebut menjadi estimasi dalam konsumsi daya listrik untuk menggerakkan mobil robot line follower pada industri yang dibutuhkan. Metode yang digunakan adalah melakukan perancangan sistem solar panel dan robotika. Pengukuran pengecasan dan pengukuran pada saat digunakan sehingga menghasilkan daya input dan output. Hasil penelitian ini menghasilkan pengecasan solar panel dengan daya maksimum sebesar 0,206358 watt selama 45 menit dan daya output pada saat robot digunakan daya terendah sebesar 0,26 watt dan bekerja selama 29 menit sehingga efisiensi cas terhadap keluaran kinerja robot sebesar 43.5%.

Kata kunci*: Mobil robot, Warehouse, Solar panel, Listrik*

Introduction

The industrial sector has increasingly employed various robot cars to perform tasks such as material handling, exemplified by Warehouse robots utilizing a line follower sensor system [1]. The utilization of robot cars is often associated with the use of electricity as the driving energy for these vehicles. However, excessive electricity consumption in robot cars can impact the overall electricity consumption profile [2]. Consequently, in line with this background, the objective of this research is to conduct an analysis of the use of mini solar panels on a robot car, employing a Li-ION 18650 battery with a voltage of 3.3 volts. The research goal, therefore, is to estimate the power consumption in driving the line follower robot car in the industrial setting. The use of solar panels to power robot cars has been extensively explored in previous studies. The novelty in this research lies in the use of mini solar panels with a 5-volt capacity and a generated power of 600 mWP for charging the Li-Ion battery assembled in series with a voltage of 11.1 volts. Subsequently, performance testing of the robot car is conducted, resulting in calculations and an analysis of the charging efficiency concerning the use of the robot car.

a. Solar Panel Monitoring

The assembled solar panel requires monitoring to assess the efficiency of energy absorption from the sun into the battery designated for energy storage. Monitoring is conducted from sunrise to sunset, and the connectivity arrangement is illustrated in Figure 1 [3].

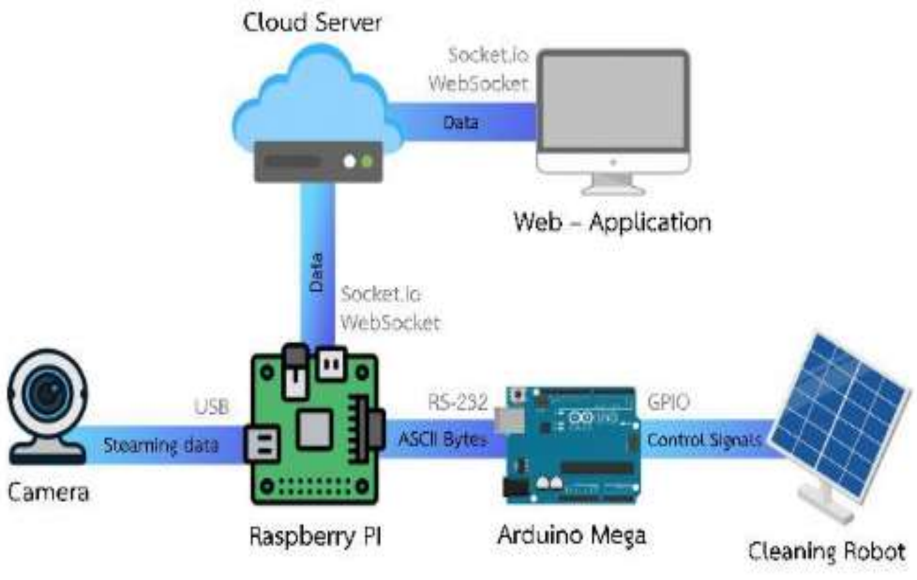

Figure 1. Solar Panel System Monitoring Process [3]

It can be explained that the generated power is processed through a processor and displayed on a monitor. The results obtained from this monitoring process include voltage and current measurements. The condition of the solar panel is monitored using CCTV connected to a Raspberry Pi. The Arduino functions to read solar panel data, such as voltage, current, and power. The Raspberry Pi receives data from the Arduino and CCTV, transmitting it to a cloud server via the Internet, allowing monitoring through a web application [4]. Several equations are required to calculate the efficiency and power values generated during a specific period [5].

b. Equations for Power

Electric power is the measure of energy generated by an electrical system against the received load, influenced by the voltage and current provided by the energy source [6]. The equation for power can be observed in (1) [7].

$$P = V \times I \qquad (1)$$

Description:

P = Power (watt)
V = Voltage (v)
I = Current (A)

Subsequently, calculate the average of the voltage and current generated using equation (2) [8].

$$\bar{X} = \frac{1}{n}(\sum x) \quad (2)$$

Description:

$\bar{X}$ = average value
n = number of data
$\sum x$ = sum of data

Then, the efficiency equation is needed to evaluate how efficient the input power is in relation to the output power, using (3)[9].

$$P\% = \frac{P_{out}}{P_{in}} \times 100\% \quad (3)$$

Description:

P% = Efficiency
Pin = Input Power
Pout = Output Power

Next, the calculation of the Fill Factor (4) is necessary to obtain the maximum charging power according to the specifications.

$$FF = \frac{Vpm \times Ipm}{Voc \times Isc} \quad (4)$$

Description:

Vpm = maximum power voltage
Ipm = maximum power current
Voc = open circuit voltage
Isc = short circuit current

A comprehension of the efficiency equation for incoming current in relation to the output current occurring in a system from solar panels is required. Previous research has developed several mobile hotspots, taking into consideration energy efficiency and utilizing isolators, as outlined in the literature review.

Literature Review

The study by Panus Nattharith and colleagues, titled "Development of Mobile Robot System for Monitoring and Cleaning of Solar Panels," employs a mobile robot with an energy-efficient solar panel drive to clean a larger solar panel system on the roof of a house [3]. The design and the robot itself can be observed in Figure 2.

Figure 2. Solar Panel Cleaning Robot [3]

The research by Bat-Erdene, titled "Shepherding algorithm of Multi-mobile robot system," explains the use of mobile robots to herd sheep by harnessing energy as the driving force for the mobile robots. The robot's design can be observed in Figure 3 [10].

Figure 3. Sheep herding robot

In the research by Sorndach and colleagues, titled "Rooftop Solar Panel Cleaning Robot Using Omni Wheels," the utilization of a solar-powered robot model is explained with the aim of cleaning solar panels on the roofs of residential homes by employing Omni Wheels. The design of the robot can be observed in Figure 4 [5].

Figure 4. Roof Solar Panel Cleaning Robot

Subsequently, the research by Thuruthel and colleagues, titled "Design of a Tendon-Drive Manipulator for Positioning a Probe of a Cooperative Robot System for Fault Diagnosis of Solar Panels at Mega Solar Power Plant," explains the use of a mobile robot system with a solar panel for detecting damaged areas on solar panels. The design and performance of the robot can be observed in Figure 5 [11].

Figure 5. Mobile robot for detecting damaged solar panels

The research by Septiarini and colleagues, titled "Fuzzy Logic Controller Application for Automatic Charging System Design of a Solar Powered Mobile Manipulator," explains the utilization of fuzzy logic control to assess the automatic energy efficiency of charging in a mobile robot during operation. The form of the robot can be observed in Figure 6 [12].

Figure 6. Solar Panel Robot with Fuzzy Logic Controller

Based on the five literature reviews, the innovation in this research lies in the utilization of mini solar panels for charging the Li-Ion battery with a voltage of 3.3 volts. The mobile robot will be employed in warehouse areas in the industry for material handling using the Line Followers mechanism [13]. Therefore, this research examines the efficiency of the charging input to the output generated in autonomously moving the robot [14]. Several components required for this study include solar panels, robot chassis, microcontroller systems, circuits, and battery power. The use of solar panels comes in various forms and functions as an alternative energy efficiency to replace the PLN [15] This research builds upon previous studies by developing the latest methods.

Methodology

In the literature review, previous research related to the study to be developed has been elucidated. This research follows the flow outlined in the diagram depicted in Figure 7.

a. Research Flowchart

The research methodology will be packaged and developed in Figure 1. By following the research flowchart, this study aims to produce the data required to assess the efficiency of the battery utilized by the solar panel.

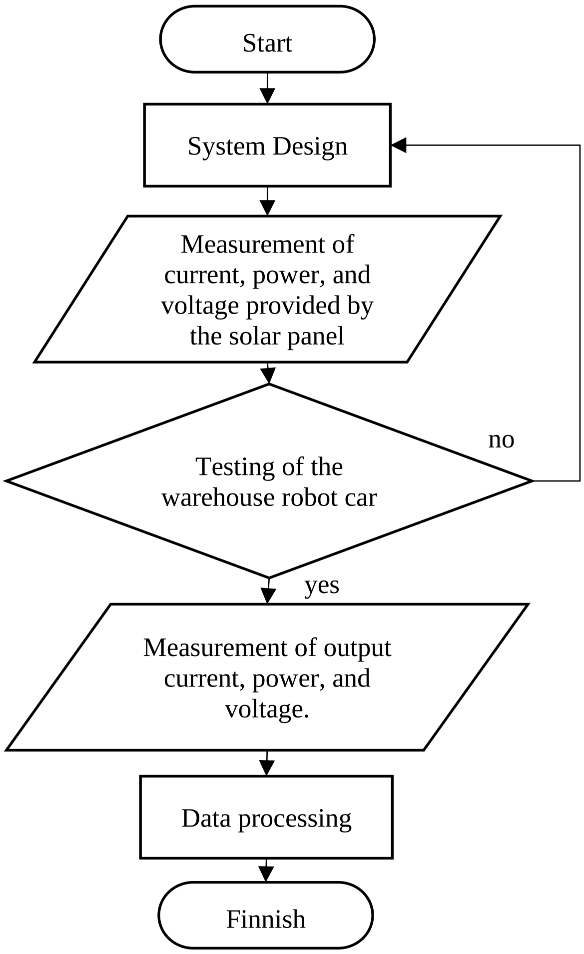

Figure 7. Research Flowchart

b. Circuit Design

The circuit system design in this study consists of two stages: the design of the solar panel circuit and the design of the microcontroller and sensor system. This design utilizes the Fritzing application to provide an illustration of the connected circuitry between various components. These components are outlined in Table 1. The interconnected circuit is intended to supply current and activate the electrical system on the controller [16].

Table 1. System Components

Component name	Function
Solar Panel	
Photovoltaic Solar Panel 68x36	Solar panel board capable of converting light into electrical energy
Battery Charging Boost Step Up Adjustable Module 2a 3.7v 9v 18650	Current Divider for Solar Panel to Battery Charging System
Current Sensor Module 30A ACS712 ACS712ELC-30A	Analog Current Sensor for Reading analog data of incoming current in the circuit

3.7V Li-Ion 18650 Battery	Chemical energy storage system for electricity generation
Microcontroller System	
Arduino UNO R3	As a controller for mechatronic system components.
L298N Motor Driver Board Module	DC Motor Controller capable of moving in both Clockwise (CW) and Counterclockwise (CCW) directions, as well as serving as a speed regulator for DC motor rotation.
9V DC Gearbox Motor	Electric current that generates a rotation.
Proximity Sensor	Detect changes in distance received by a sensor and an object.

Table 1 has detailed the components used to assemble the electrical circuit for solar panels on the warehouse robot. In Figure 8, the arrangement of the solar panel circuit can be observed.

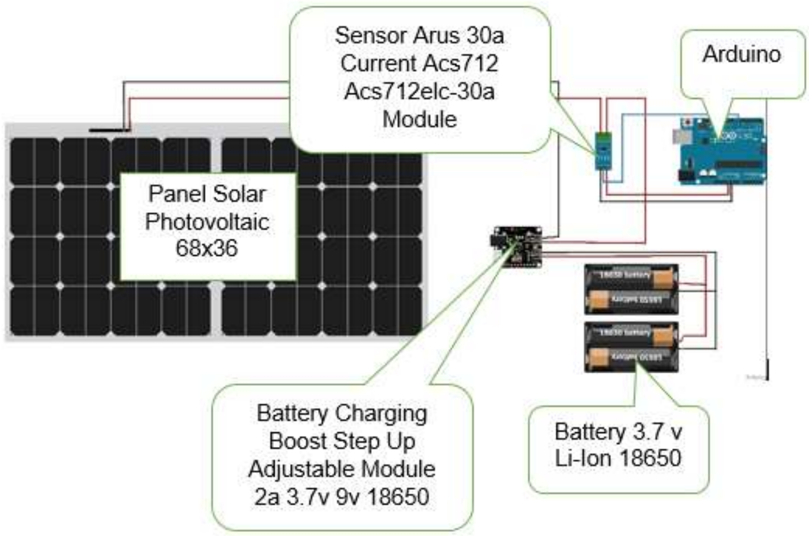

Figure 8. Solar Panel Circuit

In Figure 9, the sequence illustrates the microcontroller system configuration serving as the output medium for the automated propulsion of the robot vehicle.

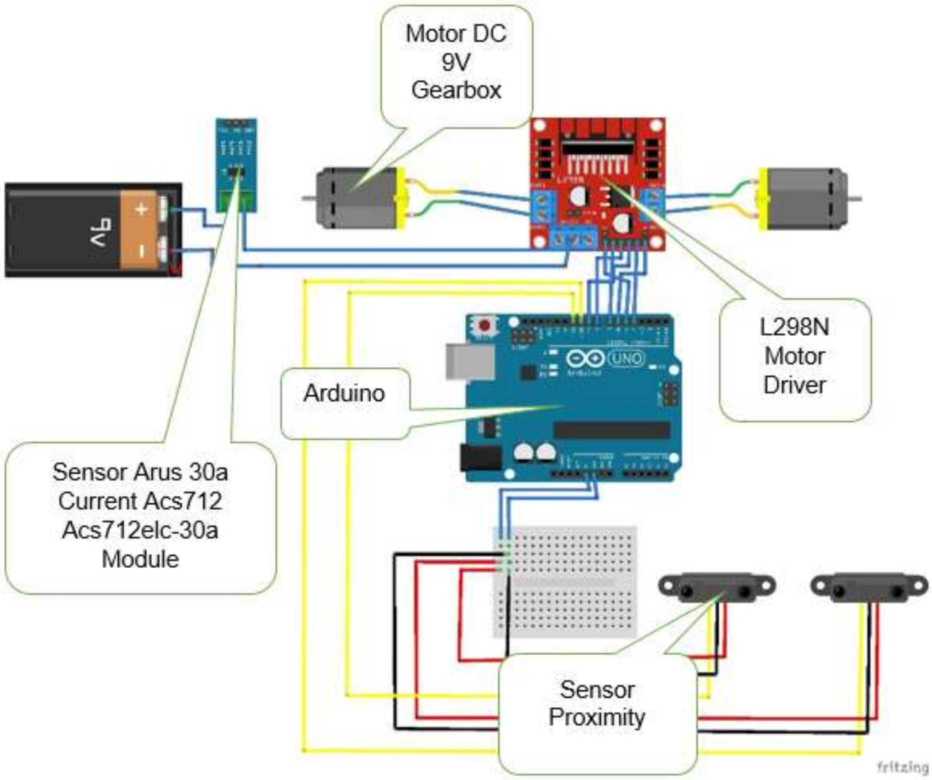

Figure 9. Circuitry of Automated Robot Vehicle

The robot vehicle utilized after assembly, incorporating various designed components, can be observed in Figure 10.

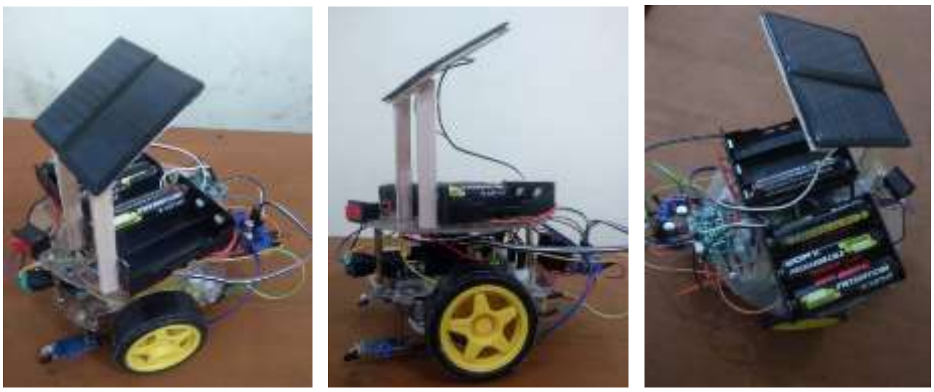

Figure 10. Warehouse Robot Vehicle

Figure 8 and 9 will be merged and integrated onto the Warehouse Robot Vehicle as depicted in Figure 10. The Warehouse Robot Vehicle, equipped with a Solar Panel, has dimensions measuring 140 mm x 146 mm x 220 mm (length x width x height).

b. Measurement of Battery Charging

All solar panel circuits are tested during the charging of Li-Ion 18650 batteries with a voltage of 3.3 V connected in parallel [17], totaling 3 units, starting from an empty battery. The battery charging process is illustrated in Figure 11.

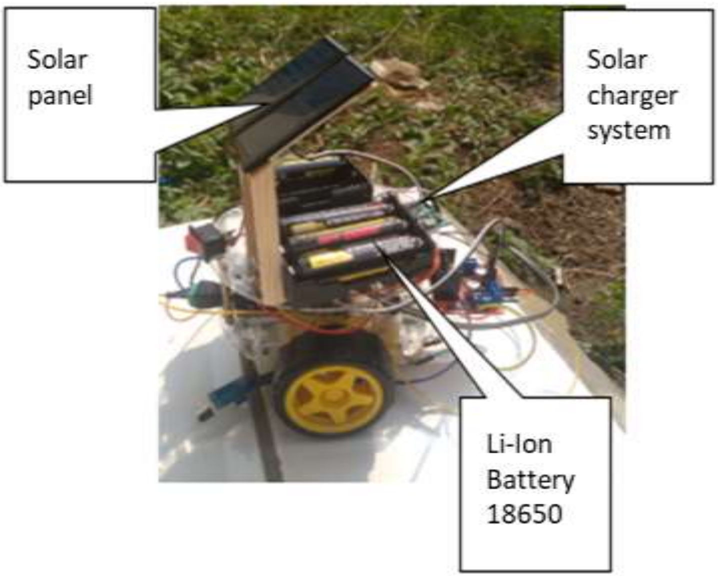

Figure 11. Battery Charging Process Using Solar Panels

After measurements are taken, the voltage, current, and power generated during the charging period are assessed to enable the estimation of the charging time. Following this, the performance of the robot vehicle is evaluated through testing.

c. Testing the Performance of the Robot Car

Testing of the line-following robot is conducted in an 80 cm x 50 cm arena, as depicted in Figure 12.

Figure 12. Robot Vehicle Testing Arena

The robot vehicle will operate by tracking the line from the beginning until the robot's battery is depleted. Consequently, the performance duration of the robot vehicle can be calculated. During the robot vehicle testing, current and voltage sensors are installed to determine the current and voltage outputs, enabling the calculation of the electrical power consumed.

d. The process of measuring the power of the robot car.

When the robot car is in motion, the Acs712 sensor measures the flowing current. Simultaneously, the data can be observed and collected, encompassing voltage, current, and power readings. Following the measurements, the energy efficiency of the incoming and outgoing power is calculated [18]. At this juncture, the batteries are connected in series, resulting in an increased voltage of 11.1 V.

Results and Discussion

The first test was conducted to observe battery charging, initiated at 09:00 and concluded at 09:45. Charging data is presented in Table 2, while the graphical representation of the charging progression can be observed in Figure 13.

Tabel 2. Measurement results

Time (hour)	Voltage (V)	Current (A)	Power (Watt)
09.00	3,32	0,0457	0,151724
09.05	3,36	0,0456	0,153216
09.10	3,42	0,0466	0,159372
09.15	3,43	0,0468	0,160524
09.20	3,46	0,0472	0,163312
09.25	3,67	0,0475	0,174325
09.30	3,75	0,0482	0,18075
09.35	3,78	0,0483	0,182574
09.40	3,95	0,0484	0,19118
09.45	4,22	0,0489	0,206358

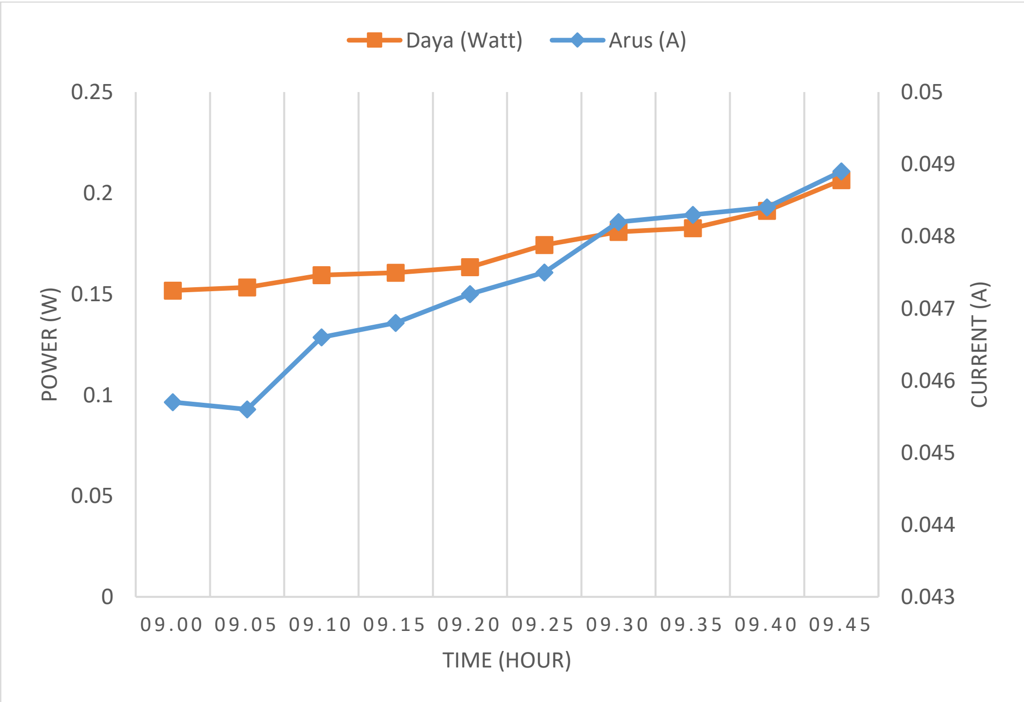

Figure 13. Power measurement graph during charging using solar panels

In Figure 13, it can be observed that the charging measurement was conducted using a mini solar panel connected to 3 Li-ION 18650 batteries arranged in parallel. The charging measurement commenced at 09:00 with an initial voltage of 3.32 V, current of

0.0457 A, resulting in a power output of 0.1517 watts. The charging process persisted until 09:45, spanning a duration of 45 minutes, reaching a voltage of 4.22 V, current of 0.048 A, and a generated power of 0.206358 watts. Consequently, the charging operation utilizing a mini solar panel with a voltage of 5 V and a current of 60mA was successfully executed and is deemed suitable for battery usage. The outcomes of this charging process can be employed to propel a warehouse robot. Figure 14 depicts the testing of the robot within the arena.

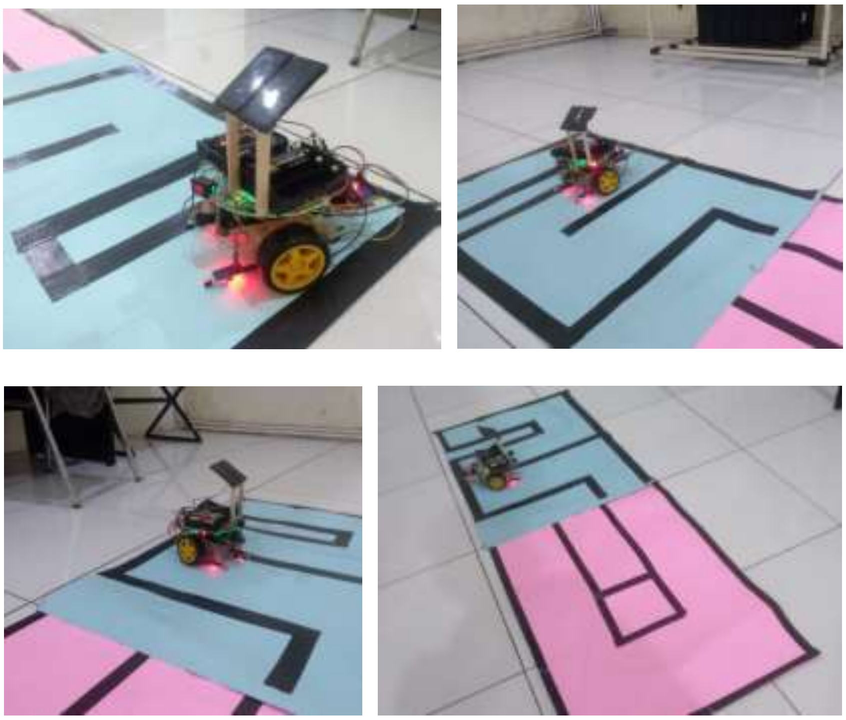

Figure 14. Robot Car Testing Process

The testing of the mobile robot commenced with the measurement of the power charged through a solar panel with a capacity of 2.06358 watts and a voltage of 4.22 V. Assembled in series to facilitate the propulsion of the mobile robot, the resultant voltage was 12.66. The testing initiative was initiated at 10:15 AM Western Indonesian Time (WIB), and the pertinent test data is elucidated in Table 3.

Table 3. Rotational Performance of the Robot Car

Time (hour)	**n^{th} rotation**	**Output voltage (V)**	**Status**
10.15	0	12,35	Normal
10.18	1	11,68	Normal
10.21	2	11,01	Normal
10.24	3	10,34	Normal
10.27	4	9,67	Normal
10.30	5	9	Slowing down
10.33	6	8,33	Slowing down
10.36	7	7,66	Slowing down
10.39	8	6,99	Stop

Table 3 illustrates that the testing of the robotic car commenced from 10:15 to 10:39. The robotic vehicle operated for a duration of 29 minutes. During the first to the fourth rounds, the performance of the robot car was flawless, aligning with the pre-programmed specifications, with a voltage range from 12.35 volts to 9.67 volts. In the fifth round to the seventh round of testing, the robotic vehicle began to decelerate, exhibiting voltages ranging from 9 volts to 7.66 volts. Finally, the robot came to a halt in the eighth round, registering a voltage of 6.99 volts.

Following the robot car testing, the subsequent step involved acquiring data on the voltage output measurements concerning the power generated by the robot during its 29-minute operation, utilizing the ACS172 current sensor. Table 4 presents the output data from the initial round to the eighth round. Figure 15 depicts the power consumption graph.

Table 4. The output power data for the robot car

Time (hour)	**Output voltage(V)**	**current (A)**	**Power (Watt)**
10.15	12,35	0,0502	0,61997
10.18	11,68	0,0482	0,562976
10.21	11,01	0,04725	0,5202225
10.24	10,34	0,0442	0,457028
10.27	9,67	0,0432	0,417744
10.30	9	0,04213	0,37917
10.33	8,33	0,0325	0,270725
10.36	7,66	0,0315	0,24129
10.39	6,99	0,0287	0,200613

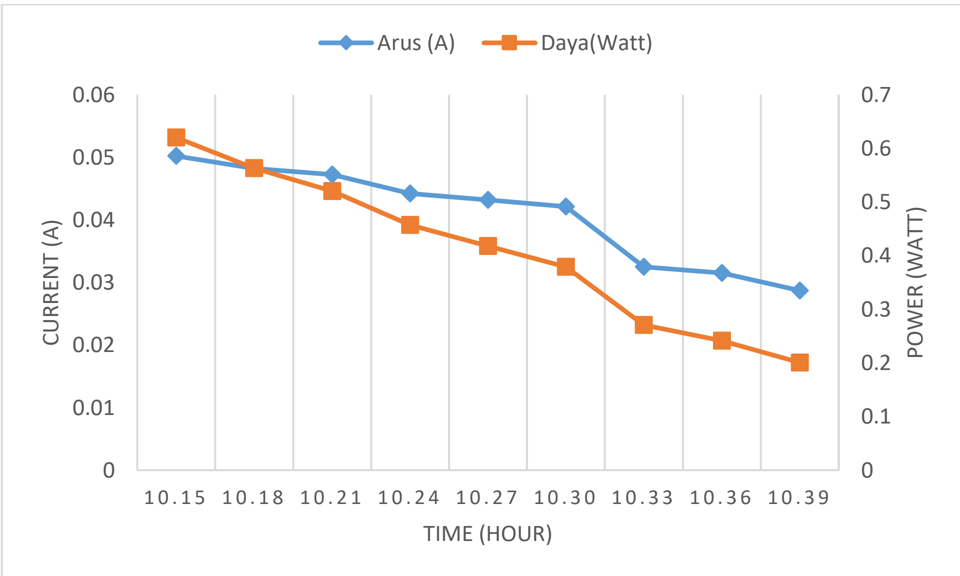

Figure 15. Power Consumption Graph of Robot Car

In Figure 15, it is observed that the current and power of the mobile robot consistently decrease throughout each test. During the 8-round, 29-minute trial, the lowest recorded current was 0.0287 A, and the corresponding power was 0.206 watts. Subsequently, an efficiency calculation for charging using solar panels was conducted. Before performing the efficiency calculation, it is essential to have the specifications of the solar panel and the battery output that powers the mobile robot. Table 5 presents the specification data and the average measurement results.

Table 5. Specification Data and Measurement Results of Solar Panel and Battery

	Specification	
Name	**Current(A)**	**Voltage(V)**
Solar Panel	0.065	4.8
Battery	0.058	11.1
	Measurement results	
Name	**Current(A)**	**Voltage(V)**
Solar Panel	0.0473	3.36
Battery	0,0408	9,67

From the data in Table 5, calculations were performed using (4). Subsequently, the Fill Factor for the solar panel was determined

$$FF = \frac{Vpm \times Ipm}{Voc \times Isc}$$
$$FFsolarpanel = \frac{3.36\text{ V} \times 0.0473\text{ A}}{4.8\text{ V} \times 0.065\text{ A}} = 0{,}55146$$

Next, the Fill Factor calculation for the Li-Ion battery during its usage was carried out using (4).

$$FF = \frac{Vpm \times Ipm}{Voc \times Isc}$$
$$FF = \frac{9{,}67\ V \times 0{,}0408\text{ A}}{11.1 \times 0.058\text{ A}} = 0{,}613959$$

Subsequently, calculating P solar Panel and P Battery, namely:

$$Psolar = 4.8 \times 0.065 \times 0{,}55146 = 0{,}17205552\ W$$
$$Pbaterai = 11.1 \times 0.058 \times 0{,}613958717 = 0{,}395266622\ W$$

By employing (3), the efficiency calculation of power concerning the solar panel and battery usage can be determined as:

$$P\% = \frac{P_{solar}}{Pbaterai} \times 100\%$$
$$P\% = \frac{0.1720\ W}{0.3952\ W} \times 100\% = 43{,}5\%$$

In accordance with the measurement results during the charging of the Li-Ion battery by the solar panel and the performance testing of the mobile robot, the obtained efficiency of Li-Ion battery charging is 43.5%. The findings of this study regarding the energy consumption of the battery in relation to the mobile robot are also consistent with the results of a study titled "Experimental analysis on solar-powered mobile robot as the prototype for environmentally friendly automated transportation." In that study, the utilization of solar panel energy to drive the mobile robot was explained, with a voltage capacity of 5.2 V, facilitated by the use of a capacitor to increase the voltage to 12.64 V. The charging process in that study spanned 5 days to mobilize the robot [2]. The novelty of this research lies in analyzing miniature solar panels used to charge Li-Ion batteries with a voltage of 3.3 V, comprising three batteries charged in parallel for 45 minutes, and at a voltage of 11.1 V when connected in series for 29 minutes.

Conclusion

This research examines the utilization of mini solar panels and the application of three Li-ION 18650 3.3V batteries in a mini mobile robot employed in a warehouse setting. The battery recharging in this study was successfully accomplished using mini solar panels connected through a solar control mechanism. The specifications of the employed solar panels include a voltage of 5V and a current of 60mA. Two solar panels were installed, resulting in a maximum power output of 0.206358 watts. The charging duration to full capacity was observed to be 45 minutes. The robot's performance was evaluated in an arena with dimensions of 80 cm x 50 cm, revealing that the robot could complete 8 rotations with a travel time of 29 minutes.

The assessment of power and output voltage was conducted based on readings from the ACS172 current sensor. It was identified that the system generated a minimum current of 0.0287 A, with a remaining battery power of 0.200613 watts. The efficiency test of the robot's performance concerning battery charging using mini solar panels yielded a 43.5% efficiency rate. Recommendations arising from this study emphasize the development of solar panels to continually enhance battery energy efficiency, thereby extending usage time and reducing charging duration. Furthermore, the integration of the solar panel energy system into the robot is envisioned to be applicable on a larger scale.

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