Experimental analysis on solar powered mobile robot as the prototype for environmentally friendly automated transportation

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Abstract. An unmanned vehicle can be deployed in a dull area such as a repetitive task of a transport vehicle in a factory setting which can be considered as automated transportation. The current problem faced by the transportation sectors are the reduction of fossil fuel availability, therefore, solar-powered automated transport vehicle is a great alternative. This paper discussed the experimental analysis of solar-powered mobile robot as the prototype for environmentally friendly automated transportation. The solar cell output is used to charge the capacitor banks functioning as the substitute for a battery system. The robot moves from one station to another imitating the stations in a factory scenario. The solar-powered robot is equipped with a voltage sensor to ensure efficient charging time. The charging time was conducted in 5 days to show the charging fluctuation affected by external factors such as weather condition. The highest average charging in a day is 4.96 V during 100.687 Lux of irradiance received by the solar cell. The highest power required during the loaded task is 0.0121 W, and during unloaded is 0.0106 W. The experiment results show that the proposed method is effective for environmentally friendly automated transportation.

1. Introduction

The unmanned vehicle has been an interesting topic investigated by many researchers with different objectives and control design. The unmanned vehicle is mostly deployed in the area of dull, dirty, and dangerous, such as an underwater vehicle, flying drone, and ground vehicle for surveillance. The dull task can be including a transport vehicle in a factory setting where it should move from one point (station) to another within the same time schedules, duration, and area. This repetitive mission can be handled by an unmanned vehicle to liberate a drive from boredom and in the long term can reduce the overall manufacture cost in a factory. This type of unmanned vehicle can be considered as automated transportation that can transport either human passengers or goods [1-3].

The automated transport system is a crucial factor in factory site where savings in this sector will significantly help to save overall production costs. Another problem currently faced by the transportation sectors are the reduction of fossil fuel availability while the demand for fuels is increasing. This condition insists that people search for renewable energy from nature. For countries located in equator, the most suitable type of renewable energies is the energy from the sun [4-6]. The price of solar panels

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is decreasing due to its reduction in panel production costs. Therefore, the solar-powered automated transport vehicle is an excellent alternative for the environment since solar power emits zero CO_2 emission.

The investigation of the possibility of solar power automated transportation can be started by using a typical two-differential driven mobile robot as the prototype of an environmentally friendly vehicle. This paper discussed the experimental analysis of solar power mobile robot as the prototype for environmentally friendly automated transportation [7, 8]. The solar panel output is used to charge the capacitor banks functioning as the substitute for a battery system. The application of capacitor bank is to ensure speedy and efficient charging time [9, 10]. The experiment is conducted with a transport setting where the vehicle has to stop in four stations.

2. Solar powered environmentally friendly automated transportation setting

The mobile robot considered in this study is a two-wheel differential driven mobile robot, which is made simple to focus on analysing the experimental analysis of the solar-powered robot. Figure 1 shows the block diagram of solar power automated transport. The main controller of this robot is Arduino Mega 2560 that receives input from two sensors to move the robot by varying the input to DC motors as the actuators in this study. The solar cell applied is 12 Volt 1.5 Watt to charge 500 Farad capacitor banks that are the main power supply of the robot. The voltage sensor is required to monitor the amount of voltage inputted to capacitor banks. The robot is moved on the track to imitate the redundant tracks of the real application of automated transport system. The electrical connection of Figure 1 is shown in Figure 2.

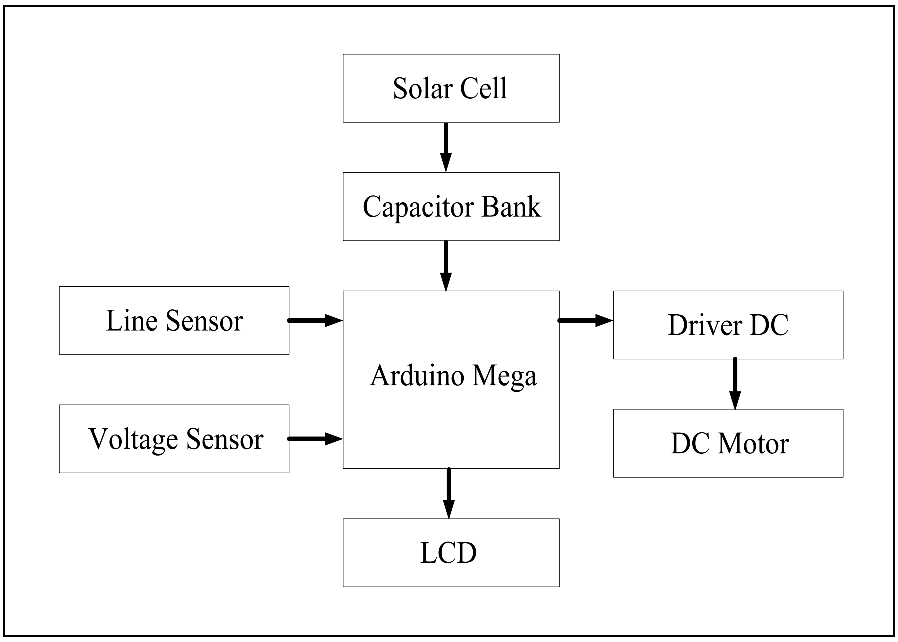


Figure 1. Block diagram of solar powered mobile robot considered in this study.

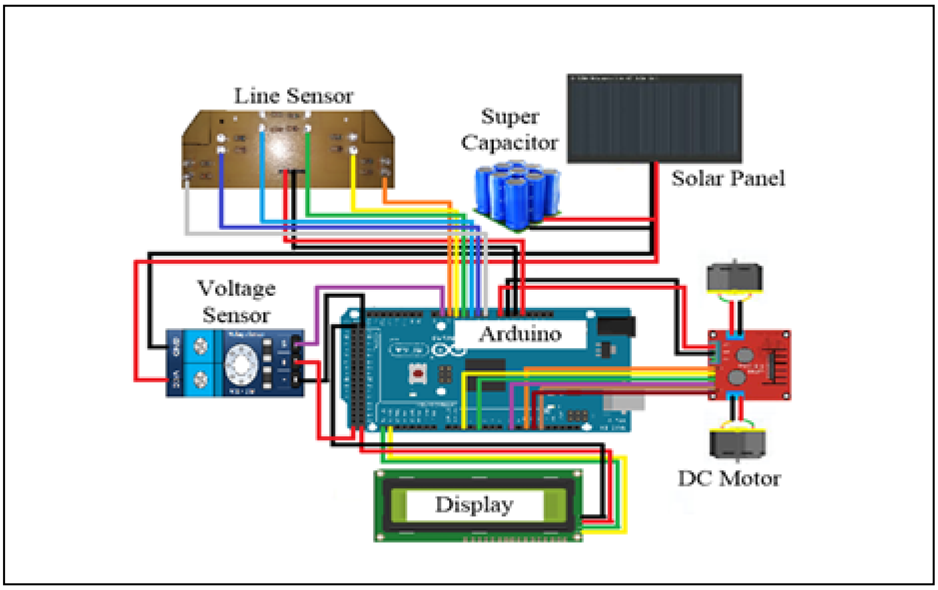
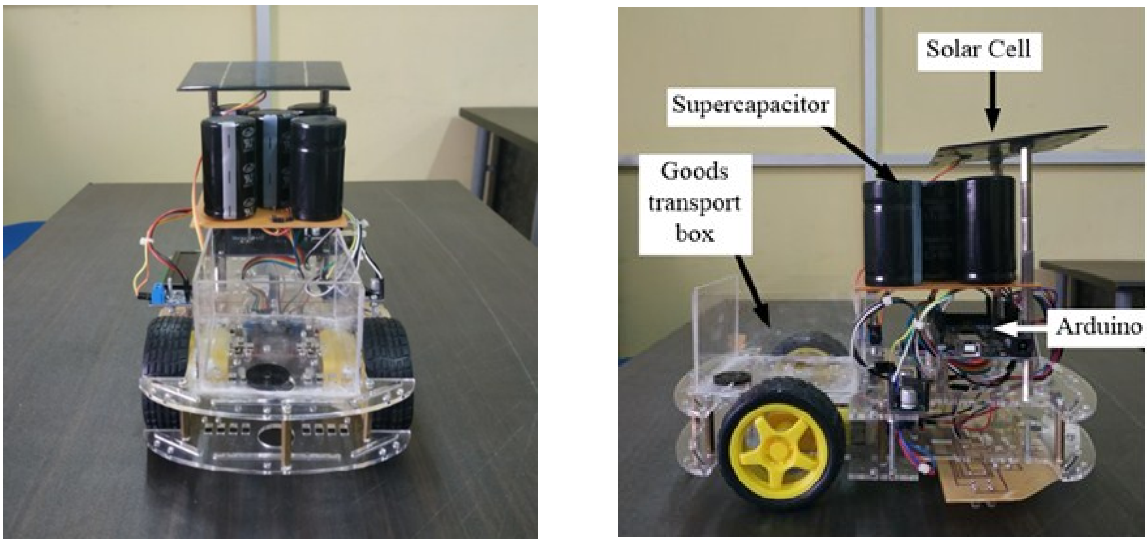


Figure 2. Electrical circuit of components used in this study.

Figure 3 Shows the prototype of a sound transport system considered in this study. The robot is equipped with a box to transport any object; in this study, the object is oranges.



(a) Robot's front view. (b) Robot side view.

Figure 3. Mobile robot as the prototype of goods transport system.

Solar cell efficiency is calculated by:

$$\eta = \frac{P}{I_{RF} \times A_C}, \tag{1}$$

where η is the efficiency, P is power (Watt), I_{RF} is the incident radiation flux (watt/m^2), and A_C is the area of collector (m^2).

3. Results and discussion

To show the effectiveness of the proposed method, an experiment is conducted to test how the robot is working by using power from the capacitor banks, which are previously charged by a solar cell. The experimental setting of the prototype of an automated transportation system is given in Figure 4. The setting is mimicking the static transport system inside a factory complex where the vehicle is moving from one point (station) to another point continuously at a particular time.

Figure 4a shows the detail of the experiment scenario; the robot moves from station 1 to station 4 and stop in each station to load and unload the goods. The considered goods in this study are two oranges. The robot started to move from Station 1 bringing loads (two oranges) to Station 2. At Station 2, the robot stopped for 5 secs, the oranges were unloaded, and the robot moved to Station 3. At Station 3, the robot stopped, and oranges were loaded. The robot moved to Station 4 bringing two oranges, and back to Station 1 without any loads. The process of loading and unloading was representing the goods transportation system in a factory. The loads and delay time of stopping in one station can be adjusted according to the needs. The experiment is shown in Figure 4a – 4f. The experiment was conducted 20 times where the robot can successfully finish the task shown in Table 1, where "✓" indicates that the robot is able to stop and continue its task in every station.

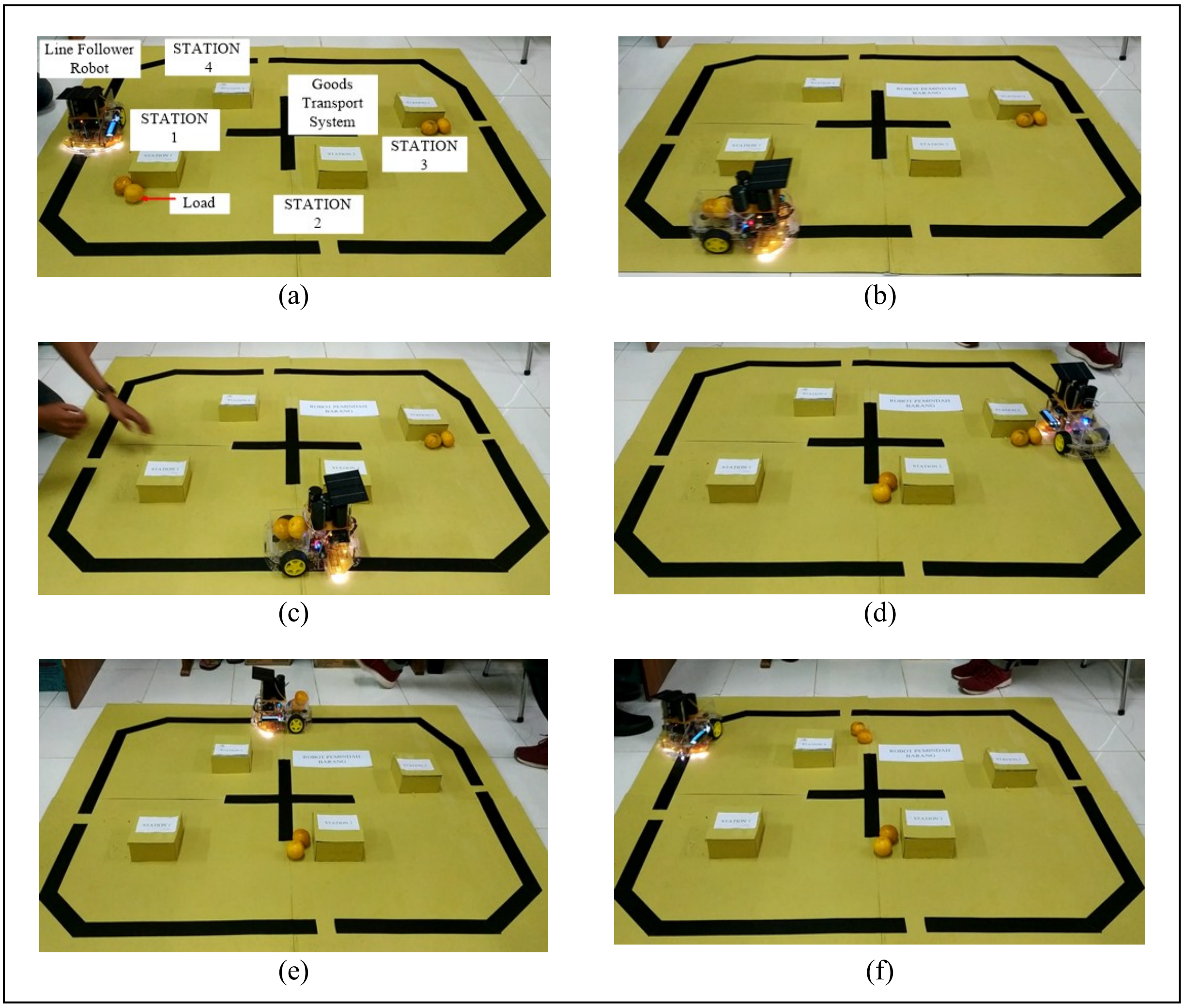


Figure 4. Screenshot of solar powered goods transport system.

Table 1. Hit-rate data to show the robot's effectiveness.

Attempts	Station 1	Station 2	Station 3	Station 4
1	√	√	√	√
2	√	√	√	√
3	√	√	√	√
4	√	√	√	√
5	√	√	√	√
6	√	√	√	√
7	√	√	√	√
8	√	√	√	√
9	√	√	√	√
10	√	√	√	√
11	√	√	√	√
12	√	√	√	√
13	√	√	√	√
14	√	√	√	√
15	√	√	√	√
16	√	√	√	√
17	√	√	√	√
18	√	√	√	√
19	√	√	√	√
20	√	√	√	√

Robot performance is strongly influenced by the availability of power at the capacitor bank, with sufficient power supply, the robot can perform well. The availability of power in the capacitor bank is influenced by the amount of energy received by the solar cell to charge the capacitor bank. The energy received by the solar cell is affected by many external factors such as the amount of lux from sunrays received, the weather condition, the ambient temperature, and the humidity of the environment [11]. Table 2 shows the external factors affecting solar cell performance in 5 days during solar cell charging and experiments from July 5th to July 9th.

A solar cell is mounted on a robot as a charger for the robot. In this study, the power results from the conversion of sunlight by solar cells as a source of electrical energy stored in 2.7 V of 500 farads capacitors. Since the robot needs 12 V to drive, the 2.7 V 500-farad capacitors are connected in series to reach the amount of needed voltage source. The series-connected results in 13.5 V. The charging time is fluctuating depending on external factors given in Table 3.

Table 3 shows the power, voltage, and current produced by the installed solar cell to charge the capacitor banks. The charging time was conducted in three terms, 09.00 to 11.00 AM, 11.00 AM to 01.00 PM, 01.00 to 03.00 PM. Solar cell efficiency is proportional to the produced voltage obtained. During the sunny times, the Power, voltage, and current produced are much higher than cloudy and rainy days. This condition is due to the nature of direct electricity generation by a solar cell or also called a photovoltaic effect. The highest generated voltage is on July 5th, 2019 during the first term (09.00 to 11.00 AM); 4.96 V with the irradiance of 100.687 Lux. The lowest generated voltage is on July 8th, 2019 at the third term (01.00 to 03.00 PM); 0.2 V with the irradiance of 6054 Lux. The low generated voltage is due to a rainy day without enough light intensity. The charging is continuously to reach enough power to move the DC motors installed on the robot.

The highest generated voltage is on July 9th, 2019 with 12.64 V, and the lowest generated voltage is on July 8th, 2019 with 5.32 V. The generated voltage is not constant in a day due to the condition of every term, such as on July 8th, 2019, the weather was cloudy, cloudy and rainy. Table 4 shows the comparison of power required to move the robot during loaded and unloaded. Averagely, the power during unloading (P wo Load) was 0.0106 W and the power during loading (P with Load) was 0.0121 W.

Table 2. The external factors during capacitor banks charging.

Date	Time	Lux	Weather	Ambient Temperature (◦c)	Humidity (%)
July 5th, 2019	09.00 to 11.00 AM	96153	Sunny	29	20.76
July 5th, 2019	11.00 AM to 01.00 PM	100687	Sunny	31	45.19
July 5th, 2019	01.00 to 03.00 PM	10921	Rainy	31	48.65
July 6th, 2019	09.00 to 11.00 AM	100420	Sunny	29	27.18
July 6th, 2019	11.00 AM to 01.00 PM	89950	Sunny	30	26.51
July 6th, 2019	01.00 to 03.00 PM	14624	Rainy	30	32.29
July 7th, 2019	09.00 to 11.00 AM	91215	Sunny	29	41.98
July 7th, 2019	11.00 AM to 01.00 PM	100021	Sunny	32	52.52
July 7th, 2019	01.00 to 03.00 PM	63875	Cloudy	30	50.12
July 8th, 2019	09.00 to 11.00 AM	87152	Cloudy	30	31.15
July 8th, 2019	11.00 AM to 01.00 PM	72148	Cloudy	30	28.76
July 8th, 2019	01.00 to 03.00 PM	6054	Rainy	29	46.22
July 9th, 2019	09.00 to 11.00 AM	96894	Sunny	31	30.18
July 9th, 2019	11.00 AM to 01.00 PM	100152	Sunny	31	32.37
July 9th, 2019	01.00 to 03.00 PM	100319	Sunny	32	24.06

Table 3. The power, voltage, and current produced to powered mobile robot.

Date	Charging Time	Power (Watt)	Voltage (Volt)	Current (Ampere)	Efficiency (%)
July 5th, 2019	09.00 to 11.00 AM	0.1239	4.13	0.03	1.267
July 5th, 2019	11.00 AM to 01.00 PM	0.1488	4.96	0.03	1.522
July 5th, 2019	01.00 to 03.00 PM	0.0489	1.63	0.03	0.005
July 6th, 2019	09.00 to 11.00 AM	0.147	4.90	0.03	1.503
July 6th, 2019	11.00 AM to 01.00 PM	0.0765	2.55	0.03	0.007
July 6th, 2019	01.00 to 03.00 PM	0.0129	0.43	0.03	0.001
July 7th, 2019	09.00 to 11.00 AM	0.1065	3.55	0.03	0.01
July 7th, 2019	11.00 AM to 01.00 PM	0.1242	4.14	0.03	0.012
July 7th, 2019	01.00 to 03.00 PM	0.0477	1.59	0.03	0.004
July 8th, 2019	09.00 to 11.00 AM	0.0915	3.05	0.03	0.009
July 8th, 2019	11.00 AM to 01.00 PM	0.0621	2.07	0.03	0.006
July 8th, 2019	01.00 to 03.00 PM	0.006	0.2	0.03	0.0006
July 9th, 2019	09.00 to 11.00 AM	0.1176	3.92	0.03	0.012
July 9th, 2019	11.00 AM to 01.00 PM	0.1215	4.05	0.03	0.012
July 9th, 2019	01.00 to 03.00 PM	0.1401	4.67	0.03	0.014

Table 4. Power taken from capacitor bank during with and without load.

Experiment	P_{wo_Load} (Watt)	P_{with_Load} (Watt)
1	0.0108	0.0117
2	0.0096	0.0129
3	0,0108	0.0129
4	0.0114	0.0114
5	0.0099	0.0117
6	0.0111	0.0123
7	0.0108	0.012

The automated transportation system is possible to be realised by using power converted from solar irradiance converted by the solar cell. The performance is good indicated by the experiment results.

4. Conclusions

This paper discusses the experimental analysis of on solar-powered mobile robot as the prototype for environmentally friendly automated transportation. The prototype in this study is a two-wheel differential driven mobile robot equipped with a line sensor to differentiate its black track against a white background. The robot is moved from one station to other three stations to imitate the stations in a factory scenario. The solar-powered robot is also equipped with a voltage sensor to ensure efficient charging time. The charging time was conducted in 5 days to show the charging fluctuation affected by external factors such as weather condition. The highest average charging in a day is 4.96 V during 100.687 lux of irradiance received by the solar cell. The robot moves as expected carrying load and unloaded during its task. The highest power required during the loaded task is 0.0121 W, and during unloaded is 0.0106 W. The experiment results show that the proposed method is effective for environmentally friendly automated transportation.

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