

## Fuzzy Logic Controller Application for Automatic Charging System Design of a Solar Powered Mobile Manipulator

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### ABSTRACT

Agriculture is a vital industry that affects the livelihoods of many people. Given the reduction in agricultural employees and the increasing strain on farmers, this sector requires convenience, which the automation system may provide. One of the automations is mobile manipulator implementation to substitute farmers. This study investigates the automatic battery charging system supported by the Fuzzy Logic Controller (FLC) to power a mobile manipulator. The application of solar charging is an ideal power source for the robot applied in the open field with high irradiance all year long. This charging system is equipped with IoT monitoring online to monitor the available power produced by solar panel and the battery capacity condition. The effectiveness of the proposed method is proven by experiments conducted for ten times charging in ten days, where the highest power produced by the panel is 1.080 W with 0.563 W charged to the battery. The highest irradiance comes with the highest surface panel temperature of 58.9°C at the irradiance rate of 1021 W/m<sup>2</sup>. The experimental results show the possibility of the solar-powered robot, which is ideal for agriculture implementation.

**Keywords:** Fuzzy Logic Controller, Internet of Things, Mobile Manipulator, Renewable Energy, Solar-powered Robot, Solar Panel.

### 1. INTRODUCTION

Agriculture is a vital industry that affects the livelihoods of many people. However, it is regrettable that the agricultural day is gradually being abandoned by the younger generation, who believe that this sector is unprofitable, and that the farmer profession is less proud and less preferable. Agriculture is gradually losing its status in Indonesia, as seen by the increasing number of agricultural lands that have been converted into shops or factories.

Given the reduction in agricultural employees and the increasing strain on farmers, this sector requires convenience, which the automation system may provide. Digital agricultural applications are made possible by technological developments and the ease of obtaining components of technology that are also becoming increasingly inexpensive [1]. This digital farm is supposed to facilitate farmers' work and, to a lesser extent, make this activity more popular among the younger generation, who are generally interested in the latest technology.

A robot application in agriculture is one example of digital farming [1]-[3]. Farmers will benefit from using robots, and the cost of building robots is now considerably lower because components such as sensors, motors, and microcontrollers are becoming more affordable and widely available. Various types of robots can be used in agriculture, such as seed sowing [4], pest control on plants [5][6], harvesting [8]-[10], and even post-harvest processing.

The agricultural robot does not need to be overly advanced to perform well. The material to build a robot can be modified to the local availability; for example, a robot body can be built of wood or light acrylic. The main components of the robot are sensors that are tailored to robot application requirements, a camera when the robot is required to have an eye, and motors as the actuators. Mobile robots are the most suitable robot applied in agriculture due to their mobility [8]-[10]. However, an agriculture robot is also required to have a hand as the substitute for a farmer's hand [11]-[14]. Thus, a mobile manipulator is the most appropriate type of robot applied in agriculture [4][7][16]-[19].

One of the challenges that farmers will face when integrating robotics in agriculture is the power supply for the robots. Farmers will be burdened by the use of batteries that must be replenished on a regular basis. Therefore, alternative energy is required to make farming easier and less expensive. This alternative energy comes from the sky in the form of sunlight, which shines all year [20][21]. Agricultural robots are almost probably utilized in fields that receive the most sunlight that can be utilized to power the agricultural robots. An IoT-based online monitoring system can help farmers check the battery capacity installed on the robot and when to charge the robot [22].

This paper covers a preliminary study of a solar-powered mobile manipulator used in agriculture. This study investigates the automatic battery charging system because it is critical in maintaining the robot's power supply. The charging automation is supported by the Fuzzy Logic Controller (FLC) application to ensure the battery is never too low capacity or too full. Fuzzy Logic Controller (FLC) makes the robot decide based on the conditions found during its application [23]-[27]. Solar energy is promising because the robot is deployed in a field where the sunlight directly hits the PV panel and charges batteries [28]. This advantage of solar power is a promising supply for an agricultural robot. The analysis in this paper is supported by an experimental testbed of a mobile manipulator.

## **2. MATERIAL AND METHODS**

This study describes the design of a battery charging mechanism for agricultural robots. The charging system utilizes a solar panel that receives direct sunshine. A mobile manipulator, which has a base like a mobile robot and hands like an arm robot manipulator, was used in this investigation. The mobile manipulator's power source is a battery charged by a solar panel; hence this robot is referred to as a solar mobile manipulator.

### **2.1 MOBILE MANIPULATOR DESIGN**

Mobile robots are the most applied robot in industry and domestic applications, ranging from a service robot to entertainment. In order to enhance its ability, it is a

common practice to add a manipulator to a mobile platform creating a system with at least nine degrees of freedom (DOF). A mobile manipulation system combines the mobility of a mobile platform with the dexterity of the manipulator. The additional degrees of freedom provided by the mobile platform also present users with more options. A mobile manipulator has the advantages of being lightweight compared to a static arm robot manipulator, compact combining mobile robot and arm robot, power-efficient due to battery-powered, and portable as the main features.

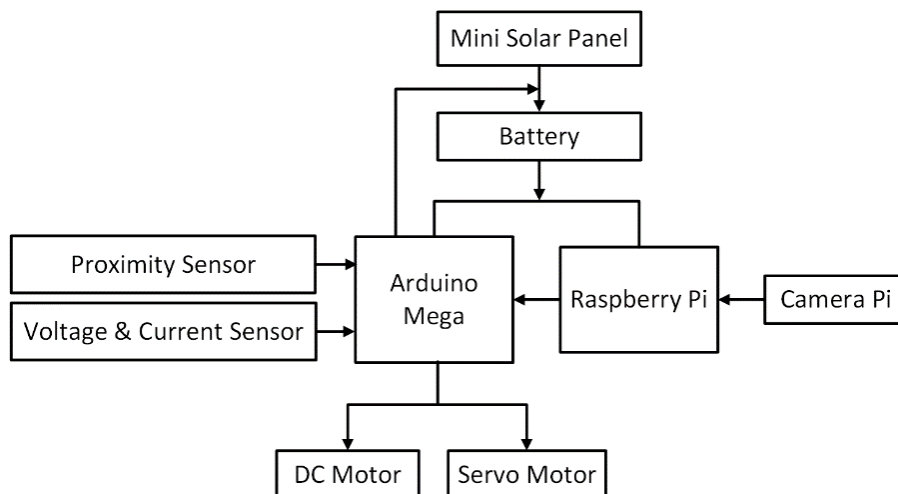


FIGURE 1. Block diagram of the proposed solar-powered mobile manipulator.

A block diagram is an essential component in a robot's design to show how the entire robot works and is activated, from the input to the output. Figure 1 shows the design of the solar-powered mobile manipulator considered in this study. The primary source of power for the robot comes from the sun, converted into electricity by a mini solar panel.

The inputs include cameras, sensors, and battery charging from the solar panel, while the outputs are DC motors and servos to operate the robot. The controllers are the Raspberry Pi, which handles image processing, and the Arduino processes all inputs and sends the proper sequence to activate the motor. The sensors implemented in the mobile manipulator are proximity sensors and voltage and current sensors. Proximity sensors are attached to the base and end-effector of the arm robot to ensure the robot can avoid any obstacle found. The camera is for any application that requires the robot to see the targeted object. Voltage and current sensors are utilized to detect how much voltage and/or current are charged to the battery to prevent overcharging. Figure 2 shows the mobile manipulator applied in this study.

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FIGURE 2. Block diagram of the proposed solar-powered mobile manipulator.

The installed components on mobile manipulator in Figure 2 are

1. Two mini solar panel with 2 Volt 1.5 Watt for each panel
2. Three lithium-ion batteries with 18650 type, 3.7 Volt, 30 A, and 2600 mAh
3. Pi Camera for object detection.
4. Four ultrasonics HR-SR04 as proximity sensor
5. Arduino Mega 2560
6. Five servo motors as the arm robot manipulator actuators
7. Four DC motors to move the mobile base.

## 2.2 IOT MONITORING DESIGN

This research uses a cellular network or WiFi linked to a cellphone and a variety of charging devices on the robot. By using an Internet of Things (IoT) monitoring system, a mobile manipulator user can monitor the charging system in the form of how much voltage and current are being charged to the battery. This system is helpful during the application of a mobile manipulator since farmers can monitor the robot's performance remotely. Therefore, online monitoring is more beneficial than manually increasing the efficiency of time and human resources. The Blynk application is applied in this study's IoT monitoring system.

This study's mobile manipulator includes a current and voltage sensor that measures how much current, and voltage enters the battery to prevent overcharging. The voltage and current values from the sensors are sent into the Arduino. Arduino sends this data to the cloud, allowing farmers to monitor how much voltage and current is charged into the battery and the current value of the battery voltage and current. All of this data will be monitored and kept up to date online using IoT technologies.

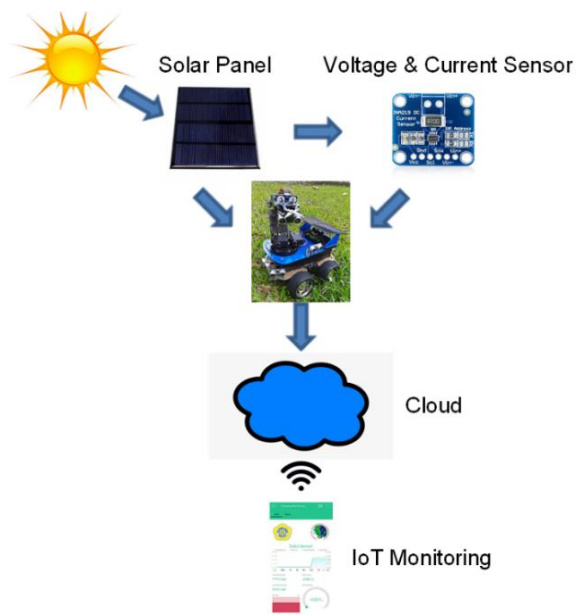


FIGURE 3. Diagram schematic of IoT monitoring system applied in this study.

### 2.3 SOLAR PANEL MODELING

The Photovoltaic cell is modelled as an ideal diode shown in Figure 4a to analyse the current and voltage produce as the irradiance from the sun hits the semiconductor inside the cell. The electrons in silicon, as the most used semiconductor material, are excited and move to the positive side (conduction band), and holes move to the negative side. As the electrons and holes move, respectively, the second region or the depletion region will have the same number of electrons and holes, creating a barrier with the same principle as a diode [29]. The generated current ( $I$ ) during this excitation is given by:

$$I = I_{ph} - I_0 \left( e^{q \left( \frac{V + IR_s}{AkT} \right)} - 1 \right) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where  $I_{ph}$  is the photocurrent,  $R_s$  is series resistance,  $R_{sh}$  is shunt resistance,  $I_D$  is voltage-dependent current due to recombination, and  $V$  is voltage.

The result of this modeling, the IV curve in Figure 4b is given as the illustration of the maximum power ( $P_{MP}$ ) produced by a solar cell.  $P_{MP}$  is the function of short-circuit current ( $I_{sc}$ ) and open-circuit voltage ( $V_{oc}$ ). Hence, the efficiency of a solar cell is

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%, = \frac{I_{mp} \cdot V_{mp}}{P_{in}} \times 100\%, \quad (2)$$

where  $I_{mp}$  and  $V_{mp}$  are the maximum current and voltage produced by the PV cell.

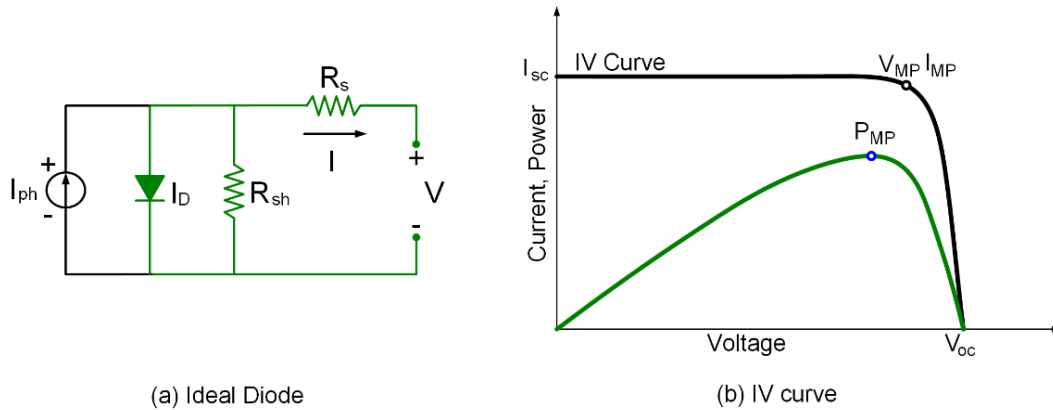


FIGURE 4. PV cell modeling as an ideal diode [29].

## 2.4 FUZZY LOGIC CONTROLLER CHARGING DESIGN

The robot's automated charging controller employs a Fuzzy Logic Controller (FLC) to aid decision-making based on previously established rules, also known as the rule base. FLC will be the input to decide the switching charging and no charging settings on the battery automatically based on the input from the battery's current capacity. The battery's current capacity data is given by the amount of voltage collected from the solar cell. The feasibility of FLC design in this study is simulated using Scilab [23]-[27].

TABLE 1  
 Rule-based smart charging system considered in this study.

No.	Input		Output Relay
	Battery Voltage Capacity	Voltage Input	
1	Small	Small	Charging
2	Small	Medium	Charging
3	Small	High	Charging
4	Medium	Small	Discharging
5	Medium	Medium	Charging
6	Medium	High	Charging
7	High	Small	Full
8	High	Medium	Full
9	High	High	Full

The rules considered in this research are; IF Voltage sensor, small voltage, and small solar voltage, THEN Relay Battery Charging. The complete smart charging rules is presented in Table 1.

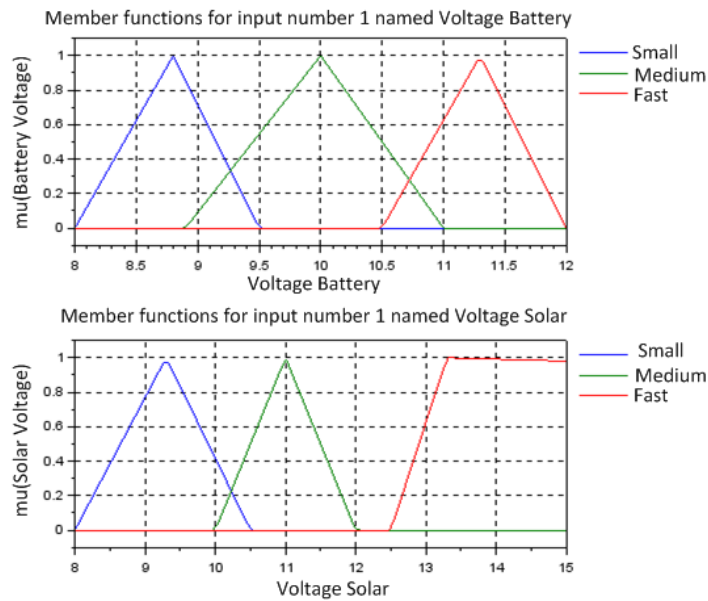


FIGURE 5. Membership function of inputs considered in this study.

The number of membership function inputs shown in Figure 5 is from battery capacity and the amount of voltage produced by the solar panel. The battery capacity Fuzzy set consists of Small (8 8.5), Medium (8 8.11), and High (10.5 12). The produced voltage from the solar panel also consists of three fuzzy sets; Small (8 10.5), Medium (10 12), and High (12 12.5). The membership function of output is relay output for charging or no charging on the battery, while the membership function output given in Figure 6 is relay status for charging "OFF," not charging "ON," and Full "ON."

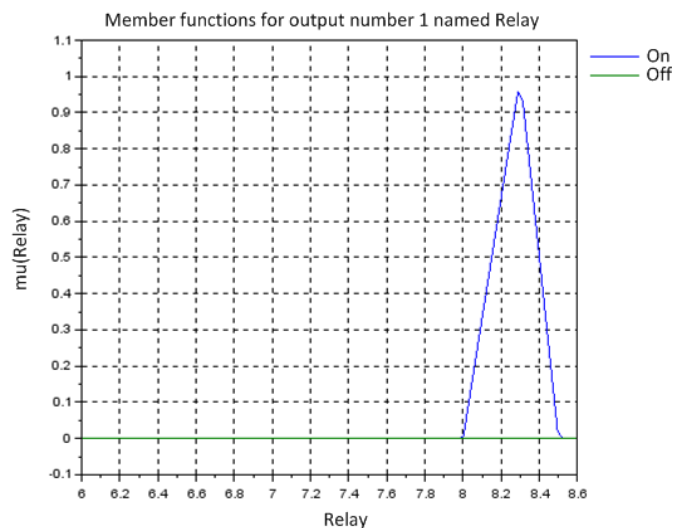


FIGURE 6. Output membership function of smart charging this study.

### 3. RESULT AND DISCUSSION

This paper analyzes the application of solar energy as the main supply for a mobile manipulator employed in agriculture. Solar energy is the ideal source for agriculture robots due to its application during the day and in the orchard or field where no shading and maximum irradiance is applied.

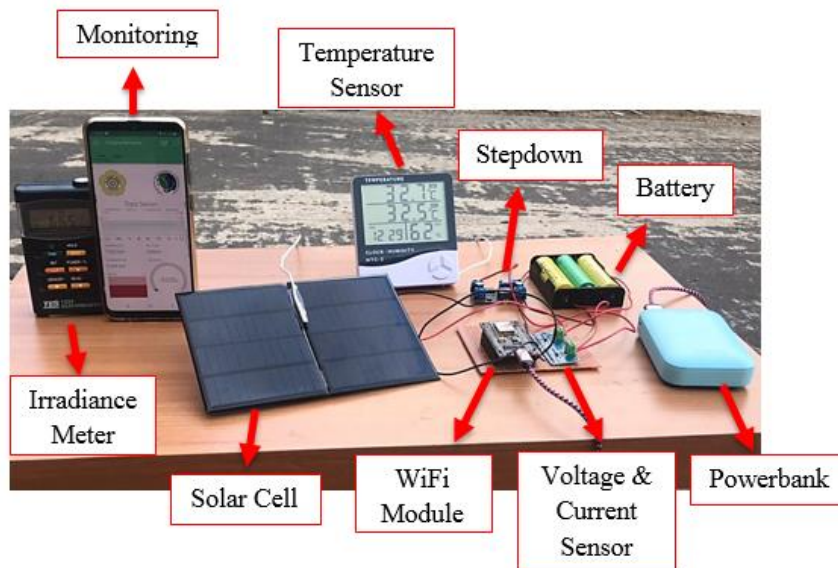


FIGURE 7. Output membership function of smart charging this study.

The battery charging experiment was conducted ten times. The battery to move the robot is charged by a solar panel until full or enough to move the mobile manipulator. The voltage and current produced by the solar panel are measured every 15 minutes. The experiment was conducted under varied weather, including sunny, cloudy, overcast, and rainy. These conditions are necessary to give the actual implementation of agriculture robots in tropical weather of Indonesia. Figure 7 shows the charging system of the mobile manipulator considered in this study.

The IoT monitoring system for a solar-powered battery charging system in this study includes sensor INA219 sensor and WiFi module node MCU 8266. WiFi module node MCU 8266 is the development of an Internet of Things tool to access the internet network to send or retrieve data via a WiFi connection. The stepdown transformer is to reduce the voltage generated by the solar panel to avoid excessive voltage input. Three batteries are used to move the robot.



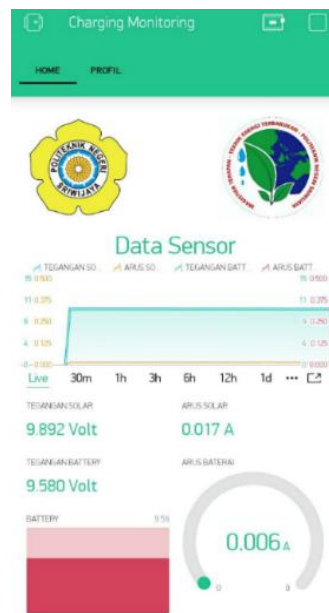


FIGURE 8. IoT monitoring system for automatic charging in this study.

Figure 8 shows IoT monitoring for automatic charging in this study. The monitoring is including the battery capacity condition and how much voltage and current are produced at the moment. During sunny weather, the voltage and current produced by PV panels are sufficient to charge the battery. IoT-based measurements are performed using the nodeMCU 8266 module, which is similar to Arduino but has the added benefit of having WiFi; hence, the data received by the voltage sensor and current are converted into digital data and become input to the Arduino Mega 2560 controller after being sent via the WiFi module. Table 2 shows the produced voltage and current during 10 days of experiments.

TABLE 2  
The result of automatic solar charging system.

Date	V Load (V)	I Load (A)	Voc (V)	Isc (A)
01/05/2021	10.163	0.053	12.986	0.071
02/05/2021	10.223	0.038	12.741	0.075
03/05/2021	10.235	0.056	12.958	0.085
04/05/2021	10.109	0.039	12.616	0.065
05/05/2021	10.221	0.057	12.301	0.071
06/05/2021	10.231	0.048	12.644	0.063
07/05/2021	10.163	0.043	12.992	0.065
08/05/2021	10.216	0.043	12.722	0.065
09/05/2021	10.213	0.046	12.922	0.064
10/05/2021	10.211	0.056	12.941	0.066

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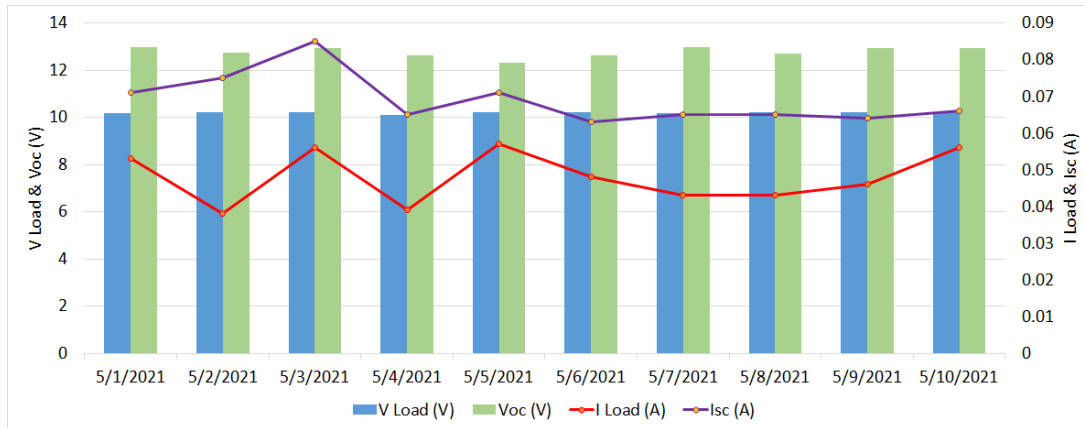


FIGURE 9. Measurement results of V Solar (Voc), V Baterai (Vload) dan I Solar (Isc), I Baterai (Iload) IoT.

Figure 9 shows the voltage produced by the solar panel (Voc), the voltage charged to the battery (Vload), the current produced by the solar panel (Isc), and the current charged to the battery (Iload). The voltage (Voc) and current (Isc) produced by the solar panel are higher than the one charged to the battery. This condition indicates that the power produced by the solar panel is sufficient to charge the batteries applied in this study: the higher voltage and current produced by the solar panel results in a faster charging time. Table 2 and Figure show that on May 3, 2021, the solar panel produced 0.085 A Isc and 12.958 V Voc, while the battery is charged with 0.085 A Iload and 10.235 V Vload.

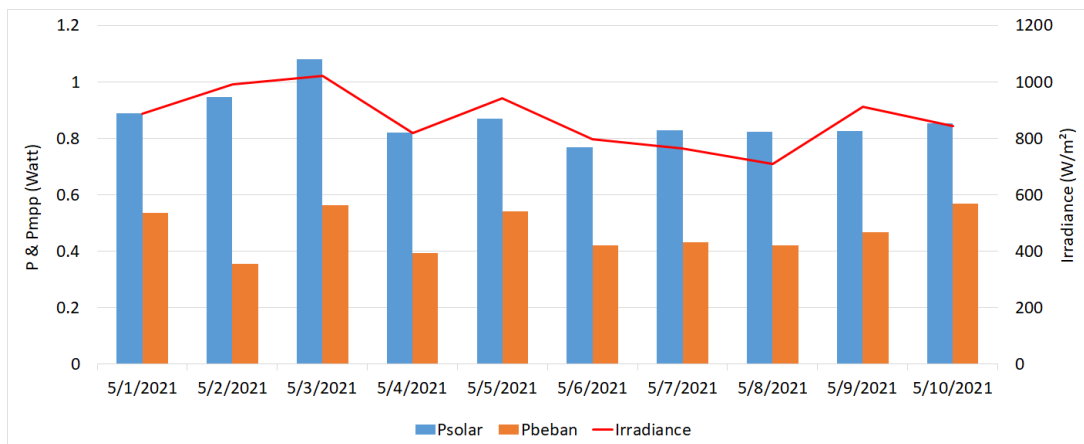


FIGURE 10. The relationship between power produced by solar panel and power charged to the battery.

Figure 10 shows the relationship between the power produced by the solar panel and the irradiance received by the solar panel. The higher irradiance received by the solar panel, the higher power is produced. For example, on May 2, 2021, irradiance hits the panel was 992.1 W/m<sup>2</sup> and the power produced by the panel is 0.945 W, and the power charged to the battery is 0.356 W. On the other hand, the irradiance received by the solar panel on May 3, 2021, was 1021 W/m<sup>2</sup> and produced the power of 1.080 W and charged battery in 0.563 W.

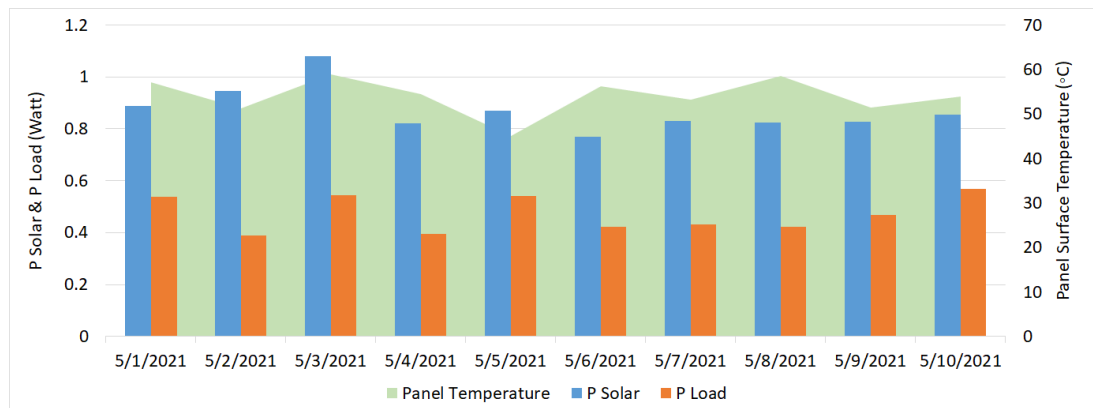


FIGURE 11. The relationship between the produced power and panel surface temperature.

The relationship between the produced power and panel surface temperature is shown in Figure. Even though the temperature has little influence on power production, the power produced more during the higher temperature. However, the overheated panel surface can damage the solar cell. This overheated condition can be resulted from partial shading by dirt and alike [30][31]. Figure 11 shows that the temperature on May 2, 2021, was 51.3°C, and on May 3, 2021, it was 58.9 °C. Irradiance received by the panel can increase the temperature; however, in the mountainous area, even though the irradiance is high, the temperature is maintained low, creating an ideal condition for a solar-powered agriculture robot [32]. Coincidentally, plantations, such as vegetable plantations, thrive in mountainous areas.

#### 4. CONCLUSION

This paper presents the automatic charging system for a solar-powered mobile manipulator applied in agriculture. The application of solar charging is an ideal power source for the robot applied in the open field with high irradiance all year long. The charging system is equipped with IoT monitoring online to monitor the available power from the panel and the battery capacity condition. The experiment was conducted for ten times charging in ten days, where the highest power produced by the panel is 1.080 W with 0.563 W charged to the battery. The highest irradiance comes with the highest surface panel temperature of 58.9 °C at the irradiance rate of 1021 1021 W/m<sup>2</sup>. The experimental results show the possibility of powering a mobile manipulator with the source from the sun. This solar-powered robot is ideal for agriculture implementation.

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