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Development of a Solar-Powered Grass Cutter with Dual Mode Operation and Solar Tracking for Residential Use

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Abstract

This paper presents the design and development of an automated grass cutter powered by a solar system for residential applications. The system, named MOWI ECO-BLADE which integrates dual operation modes, manual and autonomous along with a single-axis solar tracking mechanism to maximize energy efficiency. The primary objective is to offer an environmentally friendly and alternative solution to conventional gasoline-powered lawnmowers, which contribute to noise and air pollution. The proposed MOWI ECO-BLADE system incorporates a 20W photovoltaic panel, a 12V battery, and an ESP8266 (Wi-Fi enabled microcontroller) based IoT control system utilizing Blynk technology. In automatic mode, ultrasonic sensors enable obstacle detection and zigzag path navigation, while the solar tracker uses LDR (Light Dependent Resistor) sensors and a servo motor to follow the sun's position. Key performance metrics include runtime duration, energy consumption, solar charging efficiency, and navigation effectiveness. Testing conducted in outdoor residential conditions demonstrates that the system can operate autonomously for one hour with an additional hour of energy reserve. This project highlights the potential of combining green energy and IoT for sustainable and user-friendly lawn maintenance solutions.

1. Introduction

In today's world, the shift toward sustainable and smart technologies in residential applications is becoming increasingly important due to the environmental and practical issues caused by fossil-fuel-powered tools [1], [2]. Traditional grass cutters, which often run on gasoline, contribute to air and noise pollution and require significant manual effort, especially in hot weather conditions [3]. These challenges highlight the need for cleaner and more automated solutions aligned with global sustainability goals. Previous studies have explored IoT-enabled solar grass cutters such as the one using NodeMCU for smartphone-based control yet lacking automation and obstacle avoidance capabilities. Another project incorporated ultrasonic sensors and IoT via ThingSpeak but did not include a solar tracking system and relied on a small-sized panel, limiting performance [4]. A more recent design integrated automation and safety features using ultrasonic sensors but excluded manual mode, solar tracking, and real-time performance analysis [5]. Building on these gaps, this project introduces the MOWI ECO-BLADE, a solar-powered grass cutter designed for residential lawn care. The system uses a 20W solar panel, 12V battery, and IoT-based control through the Blynk platform, allowing for both manual control with smartphone and automatic navigation using ultrasonic sensors. In automatic mode, the system follows a zigzag path and makes U-turns to ensure full grass coverage. A single-axis solar tracking system, controlled by LDR sensors and a servo motor, helps the panel follow the sun to improve charging efficiency [6]. This study aims to design and implement a solar-powered grass-cutting system optimized for residential use, featuring dual-mode control via IoT and solar tracking to enhance energy efficiency. Specifically, the project analyses power consumption under tracking vs. fixed solar inputs, implements real-time control via Blynk and autonomous navigation, and evaluates energy usage per square meter of grass cut.

2. Methodology

The development of the MOWI ECO-BLADE follows a structured approach consisting of six key stages: energy requirement analysis, component selection, system integration, control implementation, performance testing, and system integration and wiring.

2.1 System Overview

The development of the MOWI ECO-BLADE followed a structured process in Fig. 1 covering energy analysis, component selection, control integration, and real-world testing.

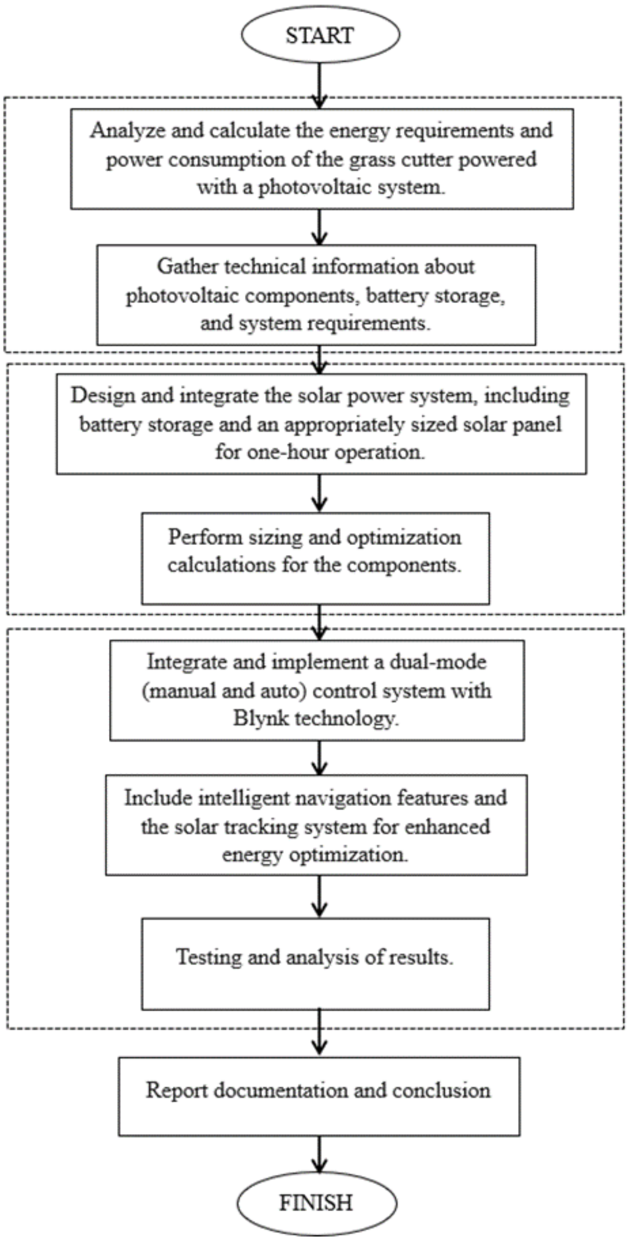

Fig. 1 *Overall project methodology*

The system is powered by a 20W solar panel, stores energy in a 12V battery, and is controlled by ESP8266 and Arduino Uno microcontrollers. Dual-mode operation (manual and auto) is enabled through IoT and sensor integration, supported by a solar tracking system to enhance energy efficiency.

2.2 Energy Requirement and Power Design

The energy requirement of the grass cutter system was estimated based on the total power consumed by major components, including DC motors, microcontrollers, sensors, and support circuitry. The total energy consumption E is given by.

$$E = P \times t \tag{1}$$

where, P is the total power consumption (W) and t is the runtime in hours. A battery was sized accordingly using the formula [7]:

$$E_{Battery} = \frac{E_{Total}}{DoD} \tag{2}$$

where, E battery is the total battery capacity (Wh), and DoD (Depth of Discharge), chosen to ensure extended battery life. The corresponding ampere-hour (Ah) rating of the battery [7] as follows:

$$Capacity_{Ah} = \frac{E_{Battery}}{V_{Battery}} \tag{3}$$

A 12V sealed lead-acid battery was selected to meet this requirement. The solar panel sizing was determined using Malaysia's average Peak Sun Hour (PSH) [7] as:

$$P_{Solar} = \frac{E_{Total}}{PSH} \tag{4}$$

2.3 Solar Tracking Mechanism

A single-axis solar tracking system was used to improve solar panel efficiency. Two LDR sensors were used to detect light intensity differences. An Arduino Uno microcontroller controls a servo motor (MG995) to tilt the panel between −60° and +60°. This tracking system improves power output compared to fixed panels, especially in varying sunlight angles throughout the day [8].

2.4 Dual-Mode Control System

The ESP8266 NodeMCU handles dual-mode control logic. Referring to Fig. 2 in manual mode, the system is operated using the Blynk smartphone application, allowing remote control of the cutting motor and movement. In auto mode, ultrasonic sensors detect obstacles, enabling autonomous zigzag mowing. The L298N motor driver controls the four-wheel DC motors, while the cutting motor is activated with a relay module [3], [7], [8].

2.5 Data Collection and Testing Performance

Since only one prototype was available, the testing used a rotational method to collect performance data from both the fixed and tracking solar panels within short intervals. Each 10-minute testing period was split between the two conditions, with the first 5 minutes measuring the fixed panel, followed by 5 minutes measuring the tracking panel, with a brief interval in between. Referring to Fig. 3, this cycle repeated continuously throughout the testing phase, which took place on 31 May 2025 from 11:00 AM to 12:00 PM, ensuring both panels experienced similar environmental conditions and minimizing the effects of changing weather.

2.6 System Integration and Wiring

System integration included combining all hardware into a mobile chassis in Fig. 4. The ESP8266 handles the movement system while Arduino Uno is dedicated to the solar tracking function, reducing processing load. Proper wiring should be arranged between the power supply, drivers, sensors, and microcontrollers to prevent voltage drops or interference [1], [3], [8], [9].

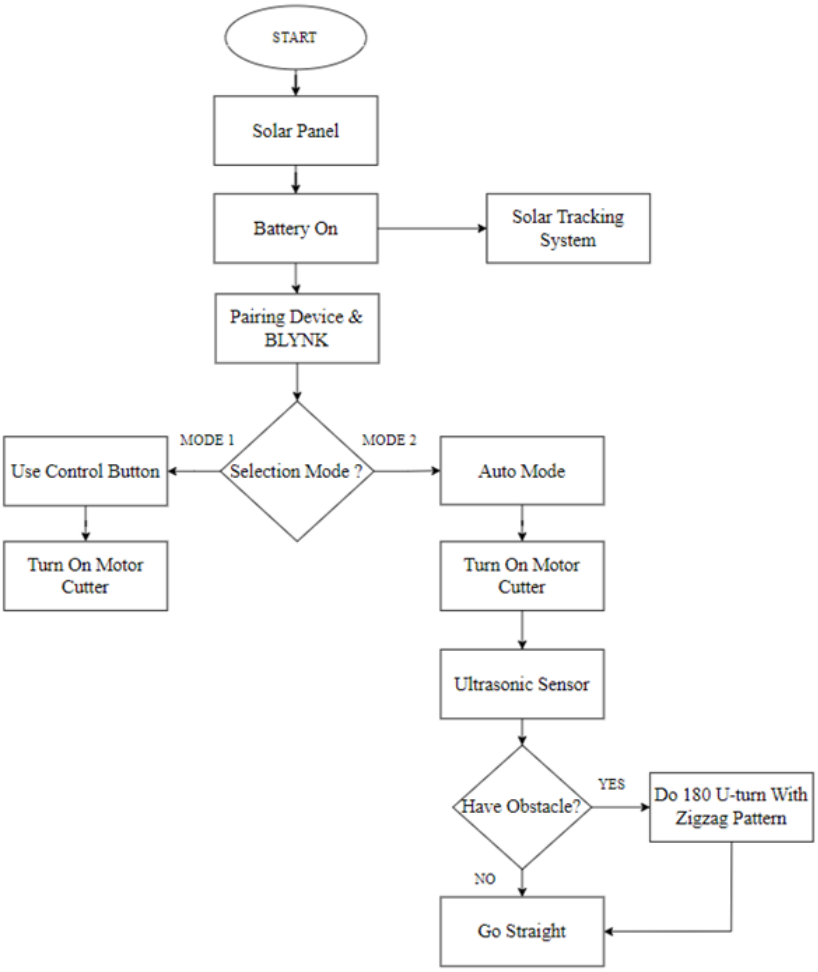

Fig. 2 *Proposed system operation for MOWI ECO-BLADE*

Fig. 3 *Performances testing and evaluation (a) Current measurement; (b) Irradiance, temperature, and tilt angle measurement*

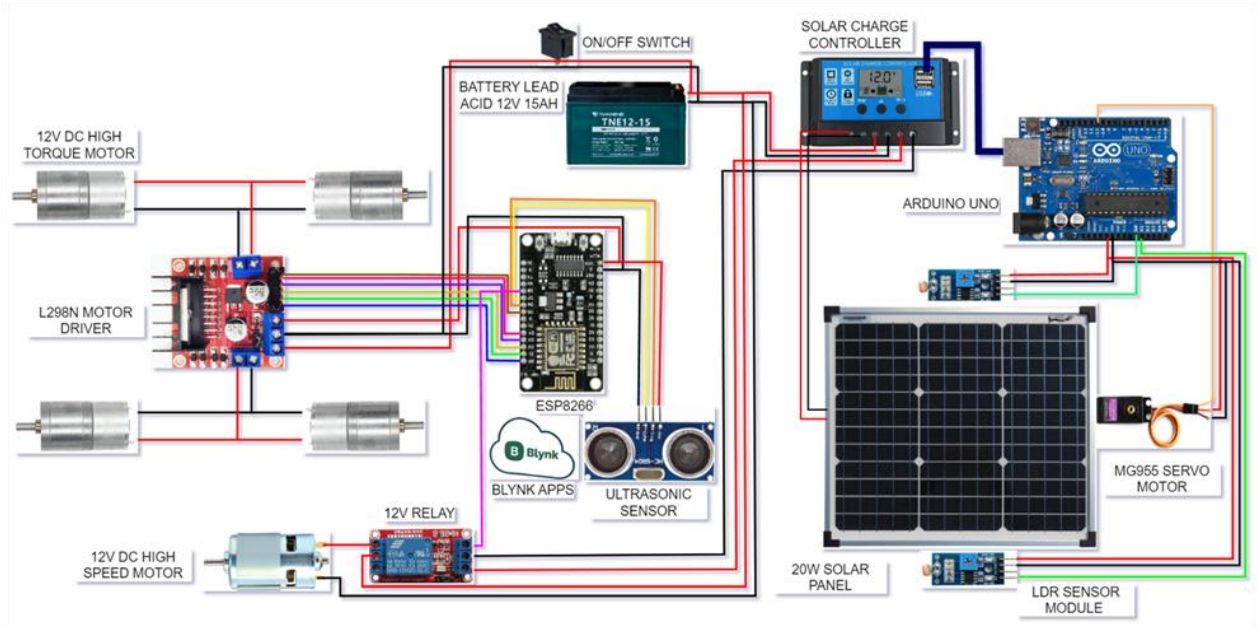

Fig. 4 *Proposed system configuration and wiring diagram*

3. Results and Discussion

3.1 Energy and Power Consumption

Table 1 summarizes the power ratings and energy requirements for each major component of the system during 1-hour operation. The calculated energy values were used to estimate system demands and size the energy storage accordingly and the calculated result is 88.64 Wh.

Table 1 *Total energy and power consumption*

Components	Voltage (V)	Current (A)	Power (W)	Operation Time (h)	Energy (Wh)
ESP8266 Board	3.3	0.07	0.23	1	0.23
L298N Motor Driver	5	2	10	1	10
4 x 12V DC Motors (Wheels)	12	1.2	57.6	1	57.6
1 x 12V DC Motors (Cutter)	12	0.5	6	1	6
12VRelay Module	12	1	12	1	12
Ultrasonic Sensor	5	0.009	0.045	1	0.045
Arduino Board	5	0.05	0.25	1	0.25
MG955 Servo	5	0.5	2.5	1	2.5
LDR Sensor	5	0.003	0.015	1	0.015
				Total "Wh"	**88.64**

Battery sizing was based on the system's energy requirement and the allowable Depth of Discharge (DoD). The battery capacity and backup duration are presented in Table 2. The system's runtime was calculated by comparing the battery's energy with how much power the system uses. A 12V, 15Ah battery can run the system for about 2.03 hours, which is more than the 1-hour target. The battery's depth of discharge is about 49%, which is safe and helps extend its lifespan.

Table 2 *Battery sizing and operation*

Calculated Battery Size	
Total Energy (Wh)	88.64
Depth of Discharge (%)	50
Battery Energy (Wh)	177.28
Battery Voltage (V)	12
Battery Capacity (Ah)	14.77
Selected Battery Size	
Voltage (V)	12
Capacity (Ah)	15
Energy (Wh)	180
Run Time Operation	
Battery Energy (Wh)	180
Total Power (W)	88.64
Run Time (h)	2.03
Depth of Discharge (%) system	
Total Energy (Wh)	88.64
Battery Energy (Wh)	180
Depth of Discharge (%)	49

3.2 Solar Charging and System Design

Solar panel wattage was selected based on Malaysia's peak sun hour values. Table 3 provides the estimated daily energy output and charging time. With an average of 4.65 peak sunlight hours per day [10], the 20W solar panel can generate about 93Wh of energy daily, which is more than enough for the system. Since the battery has a capacity of 180Wh, it can be fully charged in about 2 days under good sunlight. This means the battery can recharge efficiently, even after long use. The 20W panel not only meets the system's energy needs but also provides extra power to handle changes in sunlight. This makes the grass cutter more reliable, independent, and sustainable in different weather conditions. Choosing a larger panel improves energy management and overall system performance [11].

Table 3 *Solar design and charging time*

Calculated Solar Panel Rating	
Total Energy (Wh)	88.64
Depth of Discharge (%)	50
Solar Energy (Wh)	44.32
Peak Hour Sunlight (h)	4.65
Power Rated (W)	9.53
Selected Solar Panel Rating	
Power Rated (W)	20
Peak Hour Sunlight (h)	4.65
Daily Output Energy (Wh/day)	93
Charging Time	
Battery Energy (Wh)	180
Daily Output Energy (Wh/day)	93
Charging Time (day)	2

The completed final product, MOWI ECO-BLADE, is shown on Fig. 5, incorporating the solar panel, chassis, wheels, and cutting system. The final product is called MOWI ECO-BLADE, a smart and compact solar-powered grass cutter for home use. The name stands for Mobile, Operation, Wireless, Intelligent, Ecological, Bot, Light-powered, Autonomous, Dual-mode, and Efficiency. It reflects the system’s main goals, being eco-friendly, energy-efficient, and easy to use in different conditions.

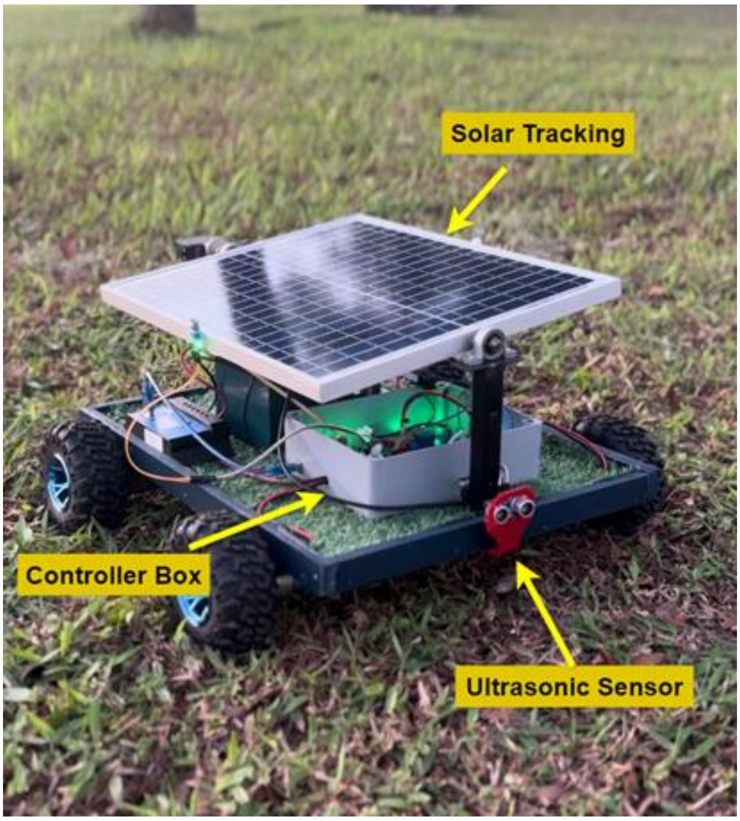

Fig. 5 *MOWI ECO-BLADE*

3.3 Environmental Testing and Data Collection

The test location was open and realistic, simulating residential lawn conditions. Table 4 shows the environmental data, including irradiance and ambient temperature during testing. On 31 May 2025, from 11:00 AM to 12:00 PM, solar panel performance testing was done along with collecting extra environmental data. This included panel temperature, tilt angle, and solar irradiance. Data was taken for both fixed and tracking panel setups using tools like an irradiance meter [12], [13]. The goal was to see how environmental factors affect the panel's power output.

Table 4 *Environmental data result*

Time (h)	Fixed Solar Panel			Tracking Solar Panel		
	PV_{Temp} (°C)	Tilt Angle (°)	Irradiance (W/m^2)	PV_{Temp} (°C)	Tilt Angle (°)	Irradiance (W/m^2)
11:00-11:10	36	0	688	37	34	729
11:10-11:20	37	0	626	39	22	685
11:20-11:30	41	0	721	43	19	791
11:30-11:40	43	0	602	44	-12	773
11:40-11:50	43	0	497	45	-17	611
11:50-12:00	45	0	451	46	-29	512

Table 5 presents electrical output data comparing the fixed and tracking panels, recorded during alternating 5-minute intervals. During testing, data was collected by switching between the fixed and tracking solar panels every 10 minutes. The first 5 minutes were for the fixed panel, and the next 5 minutes for the tracking panel. This method ensured both panels were tested under similar sunlight conditions for a fair comparison. Based on Table 5, the tracking panel consistently produced higher power, current, and voltage than the fixed panel.

Table 5 *Comparison of the solar power output between fixed and tracking panel*

Time (h)	Fixed Solar Panel			Tracking Solar Panel			
	Current (A)	Voltage (V)	Power (W)	Current (A)	Voltage (V)	Power (W)	Power Improvement (%)
11:00-11:10	0.72	13.82	9.89	0.94	15.71	14.77	49.34
11:10-11:20	0.75	14.57	10.92	0.98	16.34	16.01	46.61
11:20-11:30	0.79	13.95	11.09	1.02	16.91	17.25	55.54
11:30-11:40	0.78	13.93	10.87	1.04	15.98	16.62	52.84
11:40-11:50	0.82	14.81	12.14	1.00	16.76	16.76	38.06
11:50-12:00	0.91	15.22	13.85	1.09	17.29	18.85	36.11

3.4 Solar Tracking Effectiveness

Fig. 6 illustrates the actual voltage and current output differences between the fixed panel and the tracking panel. The graph shows that the tracking solar panel always produces more power than the fixed panel during the test. The fixed panel's power ranges from 9.89W to 13.85W, while the tracking panel ranges from 14.77W to 18.85W. The tracking panel performs better because it follows the sun and gets more direct sunlight, while the fixed panel stays in one position. Overall, the tracking panel gives higher current, voltage, and power always, proving its advantage in generating more energy.

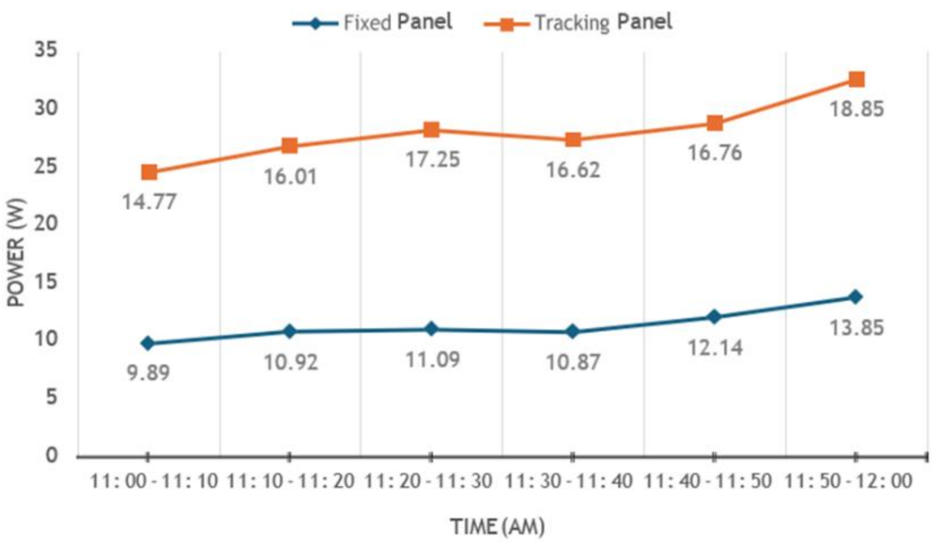

Fig. 6 *Power output comparison*

Fig. 7 presents the calculated percentage improvement in power output, verifying the benefit of the single axis tracking system. The results show not only the power improvement percentage but also the sunlight levels (irradiance) for each 10-minute period. There's a clear link between higher sunlight and better performance from the tracking panel. For example, at 11:20–11:30 AM, when irradiance was 791 W/m^2, the tracking panel had its highest power improvement of 55.54%. This shows that the tracking system works best under strong sunlight. By following the sun, the tracking panel gets more direct light, leading to higher energy output. These results prove that solar tracking, especially in good sunlight, is a great way to boost performance for systems like the solar-powered grass cutter.

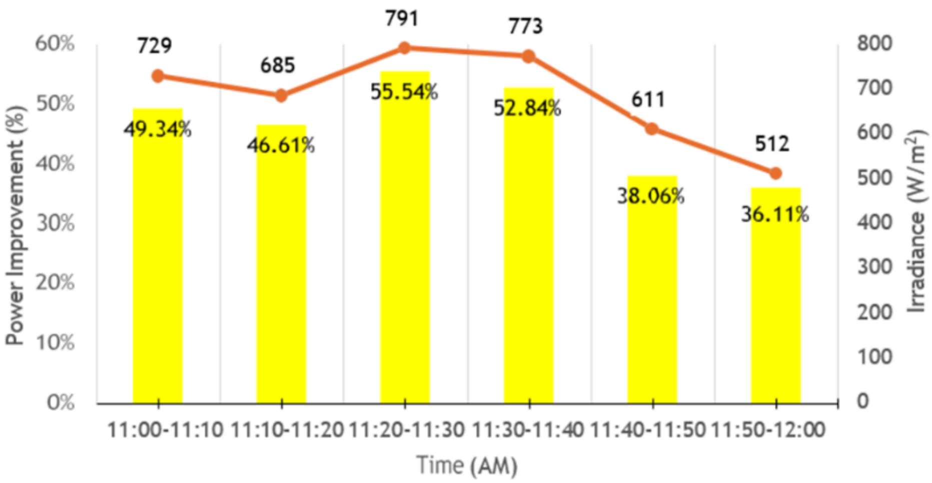

Fig. 7 *Percentage of power improvement*

4. Conclusion

This paper presented the design and development of a solar-powered grass cutter with dual-mode operation and an integrated solar tracking system, intended for residential lawn care applications. The system, named MOWI ECO-BLADE, was designed to be energy-efficient, environmentally friendly, and user-friendly using photovoltaic technology and IoT control with the Blynk platform. The system achieved reliable performance during testing, with stable operation under both manual and automatic modes. The use of ultrasonic sensors enabled effective obstacle detection, and the zigzag mowing pattern improved coverage efficiency. The energy requirement of the system was met using a 12V, 15Ah battery charged by a 20W solar panel. Comparative analysis between fixed and tracking panels confirmed a noticeable improvement in energy capture using a single-axis LDR-based tracking mechanism. This project demonstrates the potential of combining renewable energy, embedded systems, and wireless control in developing sustainable and practical home automation tools. The modular design also allows for ease of maintenance and scalability for larger lawn applications.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception, design, data analysis and manuscript preparation:*** *Fikhri Endrizal;* ***manuscript verification:*** *Mohd Noor Abdullah. All authors reviewed the results and approved the final version of the manuscript.*

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