

# Development and Performance Evaluation of Locally Fabricated Robotic Solar Lawnmower

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## ABSTRACT

Research in robotic instrumentation and application is advancing technology towards reduction of human labour. Hence, the aim of this research work is to develop an automated robotic lawn mower powered by solar system. The novel approaches are logging of voltage, current, date, time, temperature and humidity automatically, thereby enhancing evaluation of performance of the instrument. The design is built on a mobile robot carrying a 20 Watts polycrystalline solar panel. The material requirement of the design includes esp32 microcontroller programmed in integrated development environment (IDE). Other modules interfaced with the microcontroller are DHT11 humidity sensor for humidity measurement, HC-SR04 ultrasonic sensor for obstacle detection, ACS712 30A current sensor model for current drained sensing of the cutter motor, a dc cutter motor of 2800 rpm, five 12V relays (one for the cutter motor, two per rear wheel motor of the two wheels of the mower), two wiper motors of 50RPM for driving the rear wheels, UNL2003 IC for outputting to the relays, real time clock for timing, 16 X 2 LCD (in I2C format) for alphanumeric display, pulse width modulation charging system and configured android phone. A graphic user interface is created in the IDE for the robot using google chrome browser via wi-fi android phone application. The result on covered area and grass type by the mower shows that *Sida acuta* (stubborn grass) with an average voltage of 10.93V and an average current of 6.45A consumed 70.5Watts in terms of power requirement. *Sida rhombifolia* (arrowleaf sida) with an average voltage of 11.80V and average expended current of 5.62A consumed 66.3Watts. While *Axonopus compressus* with an average trimming voltage of 11.11V, expended an average current of 4.75A. Hence, 53Watts in terms of power consumption from the machine. Similarly, *Setaria palmifolia* (palmgrass) consumed 52Watts. The battery is steadily charged as temperature increases and humidity decreases. The lower the power consumption requirement per grass, the easier it is to cut the grass. Palmgrass and carpet grass on the one hand consumes less power compared to stubborn grass and arrow leaf sida on the other hand.

**Keywords:** Microcontroller, Integrated Development Environment (IDE), Alphanumeric, Polycrystalline, Robotic

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## I. INTRODUCTION

Technological advancement today has made it expediently necessary to develop user friendly utility tools. There is need for the development of automated device that will mow lawn grass autonomously.

A transition from traditional hand guided or ride on mowers to automatic mowers is beginning to take place, with the growth in global robotic lawn mower market size of 2020 being USD 1.29 billion, and is projected to grow from USD 1.48 billion in 2021 to USD 4.04 billion in 2028 (Fortune Business Insight, 2021). The view is that at current rates of growth, automated lawn mowers are set to soon reach the point of outselling traditional mowers in some regions of the world, mostly the advanced countries. A robotic lawn mower is designed to operate either entirely on its own, or less commonly by an operator by remote control.

This research work entails designing an autonomous solar powered lawn mowing mobile robot that can navigate a defined area with the use of Wi-Fi control (wi-fi direct). However, with the use of photovoltaic panel (solar panel) to generate the energy needed to power the mower, it will address a number of issues that the

standard internal combustion engine and electric motors lawn mowers do not. Therefore, the development of driverless wi-fi controlled lawnmower is of utmost importance.

There have been many academic research works on robot lawn mowers. The available technologies are using global positioning system (GPS) and perimeter wire (special cable) to find the boundary of the lawn (Newstadt et al., 2015). That is the GPS on the one hand, in conjunction with PIR, humidity and ultrasonic sensors, while on the other hand GPS in conjunction with cameras coupled with sensors all as means of defining boundaries and avoiding obstacles. The drawback in using GPS is that if weather is cloudy or if it is humid the signal from the satellites can be distorted and interfered with and this will give inaccurate readings. The same problem can be found if the receiving unit (the GPS receiver) is surrounded by tall and large objects such as buildings, trees or mountains. The signals may then bounce off such objects which can distort the message and will take the signal longer time to arrive.

Innovations of existing technology may decrease environmental pollution. This research is focused to overcome the difficulties associated with the manually handled lawn mower on the one hand and the stress in laying boundary cable and perimeter wire as in most automatic lawn mower.

### **Aim**

The aim of the research is to build a prototype of a self - obstacle evading, Wi-Fi direct-controlled solar powered robotic lawn mower, functioning without the need of a bounding cable or perimeter wire installed at edges using ESP32 microcontroller in Integrated Development Environment (IDE). Hence, the ultimate aim of this research work is to make a solar powered automated robotic lawn mower system which will mow the lawn with lesser human effort.

### **Objective**

The specific objectives of the research are as follows:

- (a) To design and construct gears and hardware for rugged automatic lawn mower.
- (b) Use obstacle avoidance sensor to be able to detect obstacles and take actions to avoid them.

Summarily, the research serves as an additional knowledge in the utilization of solar energy as a green alternative. A novel approach is the design of a special motor driver circuitry for the rear wheels due to the weight of the machine.

### **Justification of Research**

- a. The research work (Solar Powered Robotic Lawn mower with Obstacle Avoidance), neither utilizes GPS nor perimeter wire used in commercial robot lawn mower in defining its boundaries. It makes use of wi-fi direct via android phone to define its area of activity.
- b. A new algorithm for obstacle detection that does not need a cable installed around an obstacle has been developed in C++ to utilize the obstacle sensor input.
- c. The mower addresses a number of issues that the standard internal combustion engine and electric lawn mower do not; such as carbon emission due to the use of petrochemical fuels by using a self-charging mobile PV supply.

## **EXISTING EMERGING LAWN MOWING TECHNOLOGY PLATFORMS**

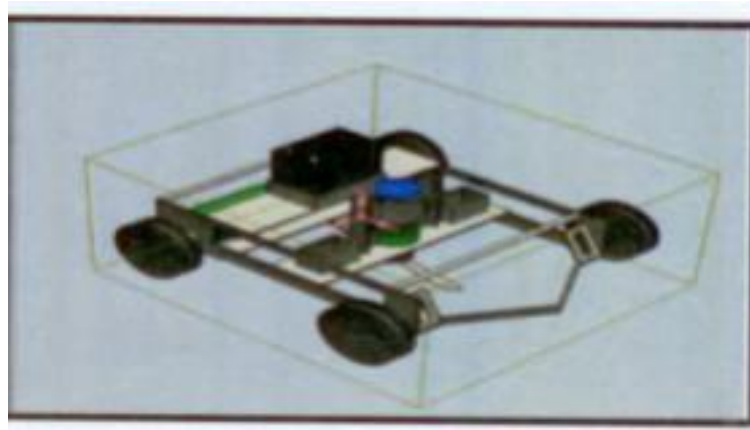
In most of the researches, many types of guidance systems and obstacle detection systems were developed and applied to the vehicle; such as global positioning system (GPS), vision capture by camera, infrared or sonar wave sensor, and all these devices collect the data and input information and send for analysis and calculation by computer which then convert it into command for controlling the actuator and motor. When the actuator and motor are activated, it will control the wheel steer at a certain angle or direction and the sensor attached to the wheels and actuator will give feedback information to the main computer to analyze and give a command to respond for the next step. This cycle will repeat until the job is finished.

Patil et al. (2016) worked on cordless remote controlled lawn mower with a view to developing lawn mowing machine whereby the user could specify the area to be mowed, coupled with height specifics of the grass using key pads. The design consists of Atmega 16 microcontroller, liquid crystal display (LCD), multiple sensors and key board.

The Atmega 16 microcontroller was used for analogue to digital conversions from the sensors. It also controls the speed of the wheels. The battery can be charged using power supply and solar panel. ADXL335 sensor (an accelerometer) was used to detect orientation based on pre- calibrated axis orientation. A high performance ultrasonic sensor was used to detect an object in its vision from 20 feet away. The key board was

used in inserting input. Three direct current (DC) motors were used: One DC motor was connected to the linear blade and the others were connected to the rear wheels.

Singh and Mehta (2015) took advantage of mechanical finite element analysis software while conducting a research on wireless remote controlled lawn mower. They used it to simulate a computer model of structures (electronics and machine components for analyzing motor strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes). The ultimate goal was to come up with a machine that is compact (smaller), lighter weight and environment friendly. An adjustable cutting height motor was introduced for better mowing of grass at intricate locations as shown below:



**Figure 1:** CAD Model of a Wireless Remote Control Mower (Singh and Mehta, 2015)

Dipin and Chandrasekhar (2014) developed a robotic solar lawn mower consisting of an array of sensors taking major consideration with the help of installed camera and MATLAB programming. It is able to follow predefined pattern in the algorithm coupled with the ability to detect land boundaries. PIC16F877A microcontroller and zigbee module were utilized. The attendant complexities in its operations makes it not user friendly to all; hence the end user must have the requisite understanding to be able to navigate the control user interface. Besides, the solar panel is not attached.

Spur gear displacement mechanism based lawn mower was designed and fabricated by Satwik et al. (2015). It is a lever operated solar lawn mower using contact stress analysis. They tried to develop a height adjustable mechanism for the cutting blade. The mechanism involves a pair of spur gears of different face width and a lever which adjust the rotor height such that the smaller spur gear slides on the face width of the larger spur gear. See figure 2 below:



**Figure 2:** Gear mount of different face width at the cutting deck (Satwik, et al., 2015)

An arduino board was used to control the speed of the rotor blade and obstacle detection, Solar panel receives the sunlight and powers the battery which in turn runs the motor. Battery and motor selection were done after the design analysis of blade. Active stress on the spur gear is calculated by using America Gear Manufacturers Association (AGMA) Hertz equation, and Finite Element Analysis.

The AGMA contact stress equation (Pitting resistance) and Hertz equation are as follows:

**AGMA contact stress equation**

$$\sigma_H = Z_E \sqrt{F_t K_o K_v K_s} \frac{K_H}{2r_1 W Z_1} \tag{1.0}$$

**Hertz Equation for contact stress**

$$\sigma_C = -C_p \sqrt{\frac{k_0 W_t}{F_c \cos \phi}} \chi \sqrt{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \text{ SI Unit in } \text{N/mm}^2 \text{ or MPa} \tag{1.1}$$

Source: Satwik et al. (2015)

Where:

$F_t$  is transmitted tangential load

$Z_E$  is elastic coefficient

$K_o$  is overload factor

$K_H$  is Load distributon factor

$K_v$  is Dynamic factor

$K_s$  is Size factor

$W$  is Face width

$Z_1$  is Geometry factor for pitting resistance

$r_1$  is Pitch radius of the pinion.  $C_p$  is Elastic coefficient for Hertz equation, and

$R_1$  and  $R_2$  being radii of curvature of pair of gear teeth.

**II. METHODOLOGY**

**Project Design Concept**

The block diagram of the system is shown below in figure 1.0. The central integrated circuit of the system is ESP32 microcontroller.

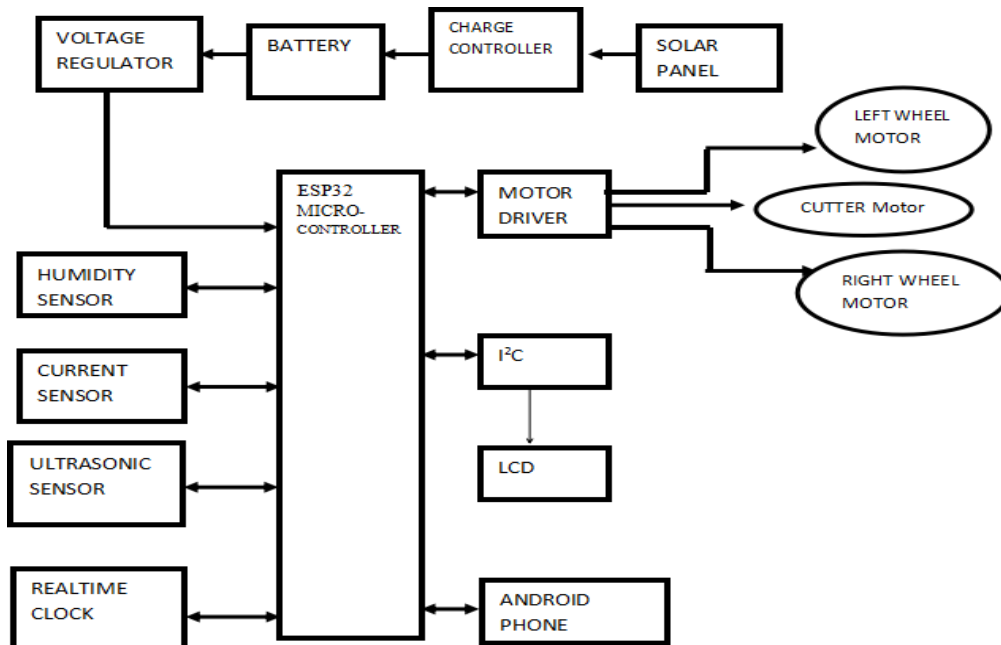


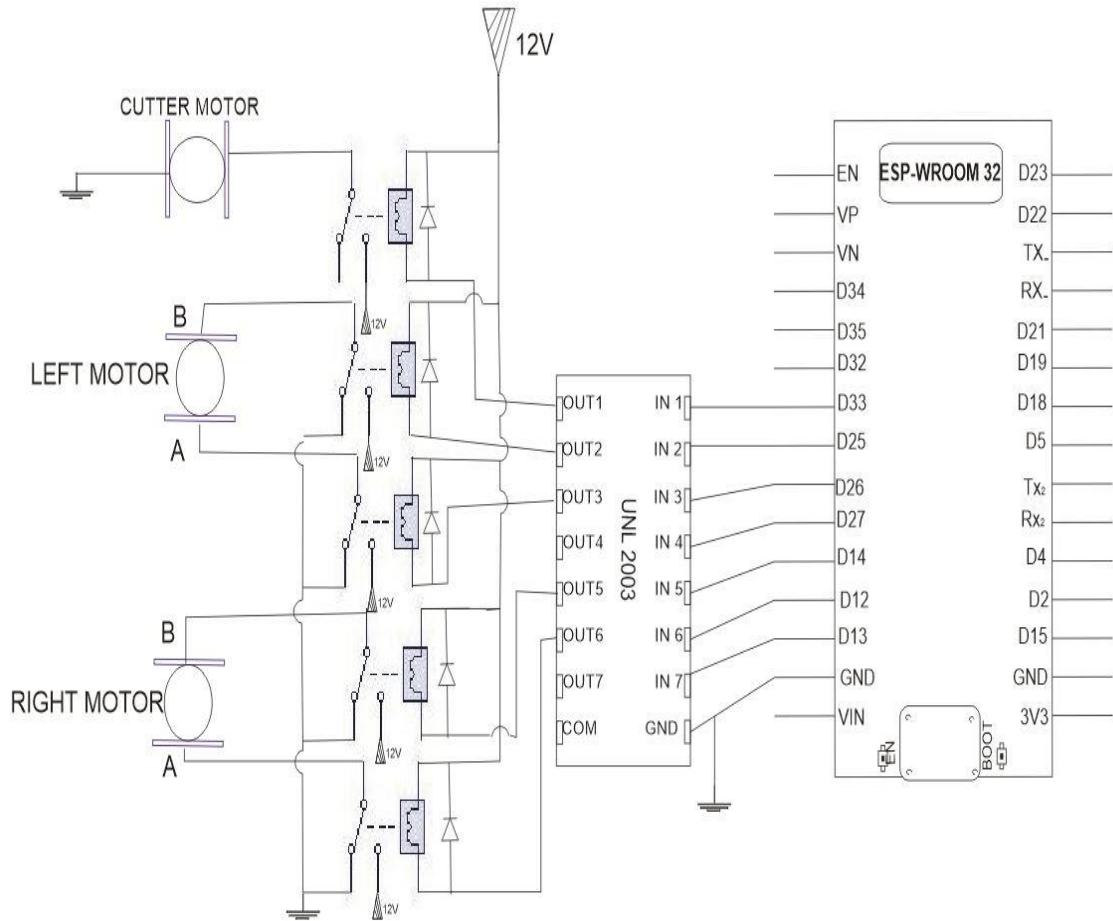
Figure 1: Block diagram of the system

The design contains ESP32 microcontroller, humidity sensor, current sensor, ultrasonic sensor, wiper motors, cutter motor (a DC motor), charging system and a relay-UNL2003 based motor control driver. Adding these elements together and controlled by Wi-Fi direct android application, we get our robotic lawn

mower. The sensors are the eyes of the robot. In addition to sensing humidity/temperature, object detection is a factor; humans inclusive. An ultrasonic sensor is used to detect if the robot was heading into an object. The arduino Integrated Development Environment (IDE) is used to write and upload programs to arduino boards/esp32 microcontroller board which is the physical programmable circuit board.

**Interface of Esp32 with DC Motors**

The wiring schematic is as shown in figure 2.



**Figure 2:** Wiring Schematics of ESP32 Interface with DC Motors via UNL2003-Relay Driver (Motor Driver)

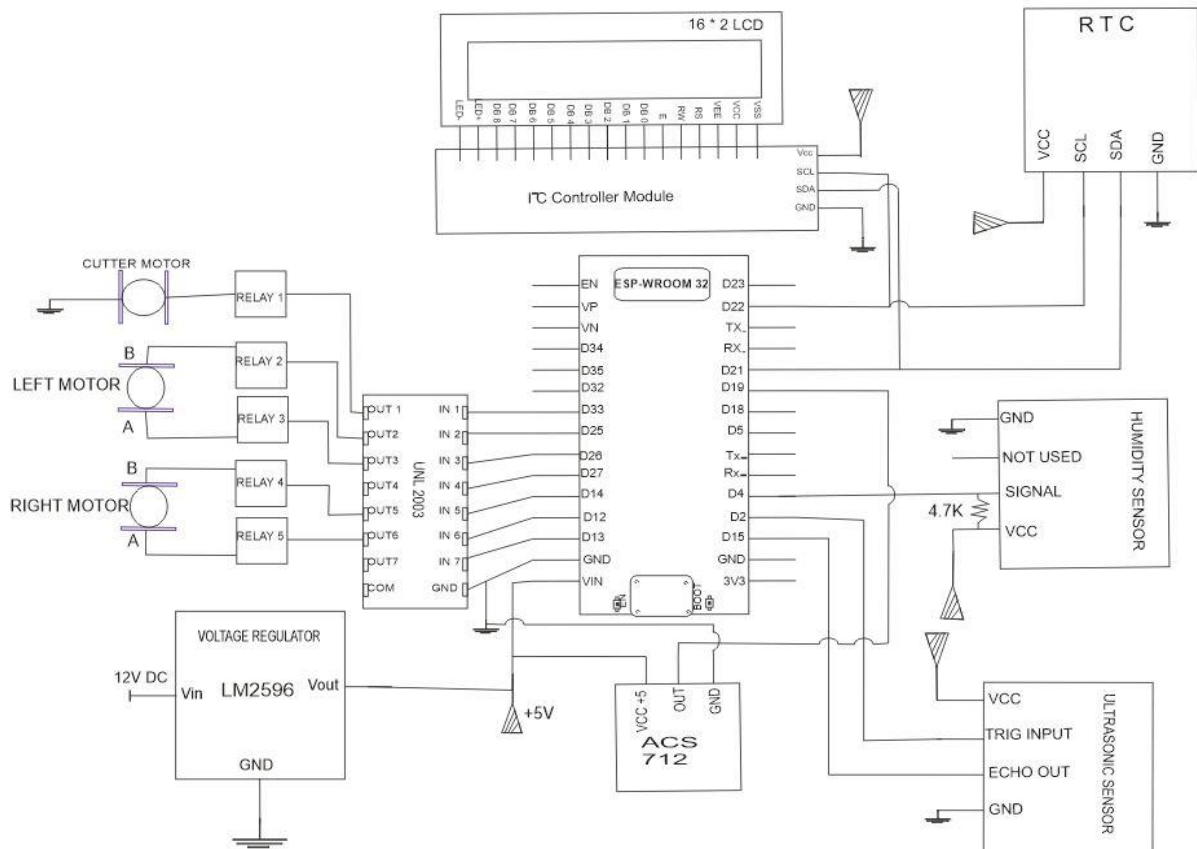
The UNL2003 digital amplifier IC and the relays constitute the driver circuitry. The 12 V supply relay with a coil resistance of 400 Ω passes a current of 30 mA. It therefore requires 30 mA to be switched on. A GPIO pin exposes a signal level that is either 3.3 V or 0 V. The maximum amount of current allowed to flow out of the GPIO pin is 12 mA (Expressif, 2019). A UNL2003 amplifier IC is therefore used to amplify the current that will eventually switch the relay on. Consequently, the two rear wheels receive the electrical impulse to move according to preset algorithm. But pulse width modulation control becomes impossible and unrealistic with the relays and UNL2003 amplifier IC constituting the motor driver circuit. The absence of pulse width modulation control makes the rear wheel motor to run too fast making it practically impossible to do any meaningful cutting.

The pin assignment is in two phase: firstly, the input pins of UNL2003 are interfaced with esp32 as follows:

- UNL 2003 <-----> ESP32**  
 In 1<-----> D 33  
 In 2<-----> D 25  
 In 3<-----> D 26  
 In 4<-----> D 27  
 In 5<-----> D 14

In 6<----->D 12  
 In 7<----->D 13  
 Gnd<----->Gnd

Secondly, the central circuit connection as shown in figure 3 assigns outputs of UNL2003 IC via relays as follows:



**Figure 3:** Central Circuit of the Mower

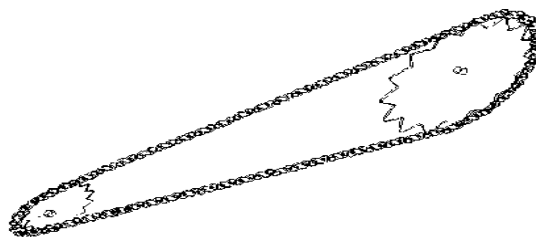
The output pins of UNL2003 IC are connected to the DC motors via relays as follows:

**UNL 2003 <----->DC MOTORS**

- Out 1<----->relay 1
- Out 2<----->relay 2
- Out 3<----->relay 3
- Out 5<----->relay 4
- Out 6<----->relay 5

**GEAR REDUCTION TECHNIQUE**

In the context of the research work and to ensure there is higher torque, a boxer motorcycle gear with 14 teeth, its timing chain, the rear sprocket of a bicycle wheel with 28 teeth were employed as shown



**Figure 4:** Timing chain with 14 teeth gear and 28 teeth bicycle sprocket for torque increment

The arrangement above provided a gear ratio of 2:1 with a very high torque. With this, the speed is drastically reduced. However, wiper motor of 12 VDC 50 rpm was chosen for the design.

### **MOTOR AND WHEEL SELECTION**

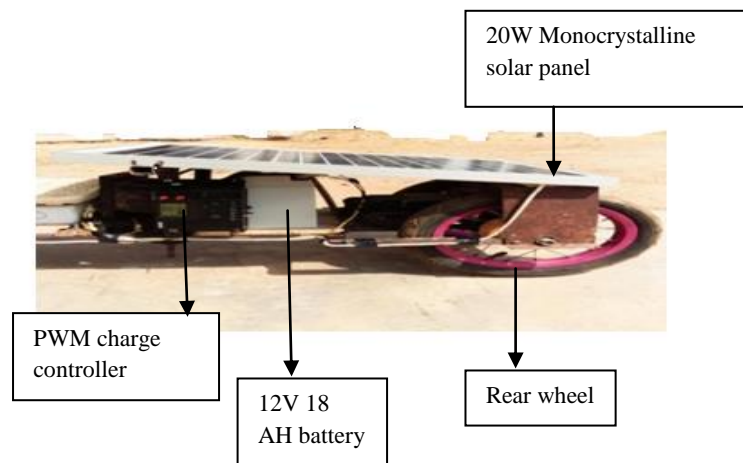
In order to choose a fitting motor for the project, a two-speed wiper motor was selected. It employs a worm gear system. The wiper motors combines two mechanical technologies to perform their task:

1. A combination of electric motor and worm gear reduction providing power to the wipers, but this time to the two rear wheels of the lawn mower.
2. A neat linkage converts the rotational output of the motor into the back- and- forth motion of the wipers.

However, the rear wheels that were chosen to go with the motors have a radius of 17.5cm each. As for the front wheel, a castor wheel that is Omni directional (ability to turn 360<sup>0</sup>) was chosen to enable the prototype to turn in narrow spaces. The radius of the castor wheel is 11cm.

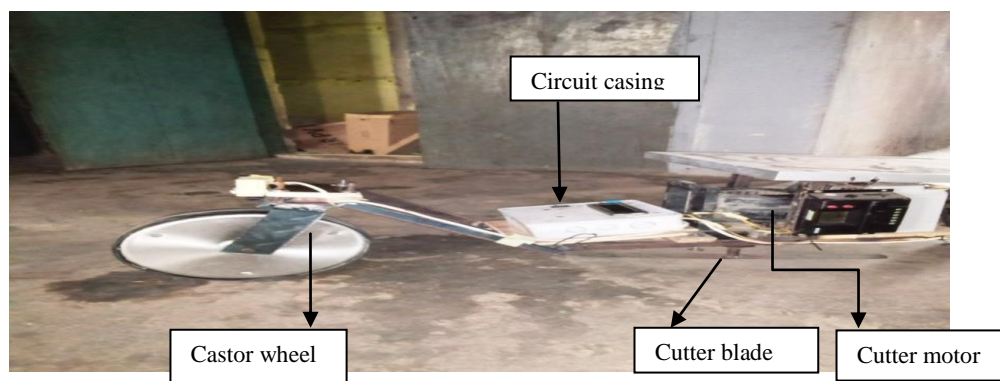
### **THE FINISHED DESIGN**

The side view of the robotic solar powered lawn mower designed is shown in Figure 7.



**Figure 7:** Side View of the Mower showing Major Components Labeling

Figure 8 is further revealing the side view of the mower design by showing the castor wheel, cutter motor and circuit casing.



**Figure 8:** Castor Wheel, Cutter Blade and Circuit Casing of the Mower

As seen in Figure 8 the bottom part of the mower is the cutting deck. The design actually replicated the original blade of a gasoline type grass cutter. The blade is mounted on the inside centre of the mower. Its length is 31 cm and width 3.5 cm.

The timing chain coupling as shown in Figure 9 reveals the rear view of the mower



**Figure 9:** Rear View of the Mower Showing the Timing Chain

### FUNCTION TESTING

Each component/ method used was tested for three cycles that is thrice in order to know the final output. The function control test was a vigorous process pursuant to the connection and writing of the algorithm (programme). Table 1 is the function control test table

**Table 1:** Function Control Test

| Test                        | First cycle | Second cycle | Final observance |
|-----------------------------|-------------|--------------|------------------|
| Obstacle detection          | ✓           | ✓            | ✓                |
| Obstacle avoidance          | ✓           | X            | ✓                |
| Path maintained             | X           | ✓            | ✓                |
| Android phone control (GUI) | ✓           | ✓            | ✓                |
| Humidity sensor             | ✓           | ✓            | ✓                |

### Motor Control Test

The motor control must be responsive making sure that the system works properly.

The system comprise of five set of relays (four for the driving motors: two attached per wheel and one for the cutting motor).

The UNL2003 amplifier IC module has seven direction control pins. The **IN1** controls the cutter motor. **IN2**, **IN3** and **IN4** pins control the spinning direction of the left motor A while **IN5**, **IN6** and **IN7** control right motor B. The spinning direction of a motor can be controlled by applying either a logic HIGH (12 Volts) or logic LOW Ground) to these input.

### Motor Truth Table

The process of testing was done using the truth table (Table 2) as an illustration.

**Table 2:** Logic Interpretation of Direction of Spinning

| A (left turn) | B (right turn) | AB (combined operation) | Result/Action                       |
|---------------|----------------|-------------------------|-------------------------------------|
| 0             | 0              | --                      | Stop                                |
| 0             | 1              | - +                     | Right turn (clockwise direction)    |
| 1             | 0              | + -                     | Left turn (Anticlockwise direction) |
| 1             | 1              | ++                      | Forward/reverse                     |

## III. RESULTS AND DISCUSSION

Tables 3, 4, 5, and 6 shows the results of the experiment carried out on different species of grass using the robot lawn mower. As can be seen from the tables, the downloaded data via wi-fi were divided into four categories of different species of common grasses namely: *Sida acuta*, commonly referred to as stubborn grass; *Sida rhombifolia*, referred to as arrowleaf sida; *Axonopus compressus*, referred to as carpet grass; and *Setaria palmifolia*, commonly called palmgrass. An area of 3m x 3m was covered by the mower per grass specie.



*Sida acuta*

Table 3: Logged Data for *Sida acuta* (Stubborn Grass)

| Date & Time           | Voltage (V) | Current (A) | Temperature (°C) | Humidity (%) |
|-----------------------|-------------|-------------|------------------|--------------|
| 4/30/2021/15:30:00 PM | 12.6        | 4.98        | 32               | 71           |
| 4/30/2021/15:31:00 PM | 12.5        | 5.16        | 33               | 70           |
| 4/30/2021/15:32:00 PM | 12.1        | 5.35        | 32               | 71           |
| 4/30/2021/15:33:00 PM | 11.98       | 5.55        | 32               | 70           |
| 4/30/2021/15:34:00 PM | 10.62       | 6.7         | 33               | 70           |
| 4/30/2021/15:35:00 PM | 10.45       | 6.8         | 32               | 69           |
| 4/30/2021/15:36:00 PM | 10.3        | 6.84        | 31               | 70           |
| 4/30/2021/15:37:00 PM | 10.2        | 6.9         | 33               | 62           |
| 4/30/2021/15:38:00 PM | 10.15       | 7.08        | 34               | 60           |
| 4/30/2021/15:39:00 PM | 10.1        | 7.12        | 44               | 35           |
| 4/30/2021/15:40:00 PM | 10.08       | 7.35        | 46               | 29           |
| 4/30/2021/15:41:00 PM | 10.02       | 7.6         | 46               | 29           |

The table shows that *Sida acuta* (stubborn grass) with an average voltage of 10.93 V and an average current of 6.45 A consumed 70.5 Watts in terms of power requirement from the power.

*Sida rhombifolia*

Table 4: Logged data for *Sida rhombifolia*

| Date & Time           | Voltage (V) | Current (A) | Temperature (°C) | Humidity (%) |
|-----------------------|-------------|-------------|------------------|--------------|
| 4/30/2021 13:41:00 PM | 13.9        | 4.78        | 30               | 69           |
| 4/30/2021 13:42:00 PM | 13.5        | 4.85        | 30               | 70           |
| 4/30/2021 13:43:00 PM | 13          | 4.9         | 30               | 70           |
| 4/30/2021 13:44:00 PM | 12.45       | 4.98        | 30               | 70           |
| 4/30/2021 13:45:00 PM | 12.3        | 5.42        | 30               | 70           |
| 4/30/2021 13:46:00 PM | 11.96       | 5.5         | 30               | 70           |
| 4/30/2021 13:47:00 PM | 11.5        | 5.55        | 30               | 70           |
| 4/30/2021 13:48:00 PM | 11.09       | 5.62        | 30               | 70           |
| 4/30/2021 13:49:00 PM | 10.9        | 5.75        | 30               | 70           |
| 4/30/2021 13:50:00 PM | 10.69       | 6.45        | 30               | 70           |
| 4/30/2021 13:51:00 PM | 10.3        | 6.6         | 30               | 70           |
| 4/30/2021 13:52:00 PM | 9.98        | 7.02        | 30               | 70           |

As seen in table 4, trimming *Sida rhombifolia* requires an average current of 5.62 A and an average voltage of 11.80 V. This makes the mower power consumption to be 66.3 Watts on this specie of grass.

*Axonopus compressus*

Table 5: Logged Data for *Axonopus compressus*

| Date & Time          | Voltage (V) | Current (A) | Temperature (°C) | Humidity (%) |
|----------------------|-------------|-------------|------------------|--------------|
| 5/1/2021 14:20:00 PM | 13.3        | 2.5         | 31               | 73           |
| 5/1/2021 14:21:00 PM | 12.8        | 2.8         | 31               | 73           |
| 5/1/2021 14:22:00 PM | 12.04       | 3.1         | 31               | 73           |
| 5/1/2021 14:23:00 PM | 11.92       | 3.5         | 31               | 70           |
| 5/1/2021 14:24:00 PM | 11.86       | 3.75        | 31               | 70           |
| 5/1/2021 14:25:00 PM | 11.3        | 4.16        | 33               | 65           |
| 5/1/2021 14:26:00 PM | 10.95       | 5.75        | 38               | 62           |
| 5/1/2021 14:27:00 PM | 10.46       | 5.87        | 40               | 37           |
| 5/1/2021 14:28:00 PM | 10.1        | 5.95        | 40               | 37           |
| 5/1/2021 14:29:00 PM | 9.94        | 6.4         | 46               | 30           |

|                      |      |      |    |    |
|----------------------|------|------|----|----|
| 5/1/2021 14:30:00 PM | 9.4  | 6.55 | 46 | 30 |
| 5/1/2021 14:31:00 PM | 9.29 | 6.7  | 34 | 60 |

The *Axonopus compressus* with an average voltage of 11.11 V expended an average current of 4.75 A as seen in table 5. Hence 53 Watts in terms of power consumption from the machine

***Setaria palmifolia***

**Table 6:** Logged Data for *Setaria palmifolia* (Palmgrass)

| Date & Time          | Voltage (V) | Current (A) | Temperature (°C) | Humidity (%) |
|----------------------|-------------|-------------|------------------|--------------|
| 5/1/2021 13:06:00 PM | 12.8        | 2.6         | 32               | 70           |
| 5/1/2021 13:07:00 PM | 12.5        | 2.98        | 32               | 70           |
| 5/1/2021 13:08:00 PM | 12.3        | 3.82        | 32               | 70           |
| 5/1/2021 13:09:00 PM | 12.08       | 4.15        | 32               | 71           |
| 5/1/2021 13:10:00 PM | 11.9        | 4.3         | 32               | 70           |
| 5/1/2021 13:11:00 PM | 11.74       | 4.5         | 32               | 70           |
| 5/1/2021 13:12:00 PM | 11.4        | 4.72        | 32               | 70           |
| 5/1/2021 13:13:00 PM | 11.09       | 4.85        | 31               | 70           |
| 5/1/2021 13:14:00 PM | 10.9        | 5.52        | 33               | 65           |
| 5/1/2021 13:15:00 PM | 10.4        | 5.69        | 34               | 60           |
| 5/1/2021 13:16:00 PM | 10          | 5.75        | 44               | 33           |
| 5/1/2021 13:17:00 PM | 10.05       | 5.82        | 46               | 29           |

The average current drained trimming palmgrass is 4.56 A at an average voltage of 11.4 V. Hence, 52 Watts in terms of power consumption by the mower was expended.

**IV. Summary of findings**

1. Palmgrass and carpet grass with an average power consumption of 52 Watts and 53 Watts respectively can be easily trimmed compared to stubborn grass and arrowleaf sida which use 70.5 Watts and 66.3 Watts respectively.
2. The implication is that the lower the power consumption requirement of a grass the easier it is to cut the grass.
3. There is voltage drop as current drained increases.
4. Stability in temperature increase owing to sunlight energy ensures relatively better charging voltage.
5. The higher the temperature, the lower the humidity, meaning that on warm day grass trimming condition is excellent vice versa.
6. The nature of toughness of grass specie and trimming duration are a factors as per current drained.
7. Height specific and sprawling nature of a grass such as Sida species is another contributory factor to excessive power consumption.

**V. Conclusion**

The main goal of this work is to develop a machine that uses current sensor to detect the current consumption of the cutter motor, log environmental data, voltage, current, time, electrical power and be able to detect and avoid obstacle by using obstacle avoidance sensor. A well-developed algorithm used to this extent ensured that the requirements for the robotic lawn mowing system were met. The robot can mow better if the type of lawn grass is carpet grass and palmgrass, and when the lawn is dry. The possibility of cutting and trimming grasses autonomously without the use of fuel to power its engine is a viable economic alternative, especially in the era of fossil fuel extinction, in addition to mowing with lesser human effort. It differ from the available lawn mowers on the basis of additional technology used due to its capabilities to log battery voltage, current drain, humidity, temperature, time and date; being controlled through Wi-Fi direct android application interfaced with ESP32 microcontroller thereby enabling power consumption and performance appraisal of the robot.

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