

# Design of a Solar-assisted lawnmower with an Arduino-based Mobile Application control system

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## ABSTRACT

The design objectives is to come up with a solar-assisted lawn mower with an arduino-based control system which runs with the support of a mobile application which renders the mowing task to be independent of fuel engine as source of power supply and manpower. The device consists of linear blade which is operated with the help of two rear motor as the power supply for the motor is by using battery. The battery can be charge by using power supply and solar panel. Design and simulation of the machine was also carried out to reveal the assembly stress analysis with regards to the stability of the mower, while maneuvering a turn during the task execution to know how the machine would function in real life situation. Also, an Android software app has been designed and developed which enables convenient operation and control of the lawn mower without hassle. The machine has been built and experiments performed in the workshop and on field which adequately indicates that the lawn mower is power autonomous i.e. it is self-dependent with regard to the operation, control and power requirement for carrying out the mowing task. Solar power and electricity can be exploited to provide the required power for automated control of the mower, vehicle motion and mowing the lawn..

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## Introduction

The world we live in is a digital world. Man is developing more refined and technical ways of tackling his everyday problems. One of the key ways to differentiate between an urbanized environment and a rural one is its cleanliness - ranging from absence of physical dirt down to well-trimmed lawns. Lawn maintenance and landscaping remain the most important constraints to keeping a clean and fresh looking gardens and yards. Traditionally, machetes, hoes, cutlasses, hand scissors, and many other hand tools are used to cut grass. In developing countries, these tools are still in use. Better techniques for grass cutting have evolved with technological advances. This gave birth to the invention of the lawn mower (Okafor, 2013). A lawn mower is a machine utilizing one or more revolving blades to cut grass surface to a desired height. The elderly and the young cannot easily accomplish cutting grass. Engine lawn mowers create noise pollution due to the loud engine, and local air pollution due to the combustion in the engine. In addition, an engine powered-motor lawn mower requires periodic maintenance such as changing the engine oil. Even though electric solar grass cutter is environmentally friendly, they too can be inconvenient. Along with motor powered grass cutter, electric grass cutters are also hazardous.

In the time where technology is merging with environmental awareness, consumers are looking for ways to contribute to the relief of their own carbon footprints. Nowadays, everything is going under automation to reduce the human effort for the mowing job. Green technology initiatives

are supported by both the government and cooperates businesses. Hence, the need for an automated solar-powered lawn mower or grass cutter exists. To save cost, time and energy to ease the process of cutting grasses with less labor intervention, there is a need to design and fabricate a cheap, portable energy efficient and easy to operate lawn mower that can be used to cut grass on a large area of land within a short period.

Victor and Verns, (2003) designed and developed a power operated rotary cutter which was environmental friendly, because it does not emit carbon monoxide into the environment, the noise level was drastically reduced and the machine was more efficient in a soil with low moisture content. The problem with this design was complex nature of the machine and its major disadvantage because its maintenance and operation were difficult for the peasant farmers.

Amrutesh *et al.*, (2014) designed a solar lawn mower which could maintain and upkeep lawns in gardens, schools, college's etc. They made some changes in the previous machines existing to make its application easier at reduced cost. The design was also made simple so that unlearned or unskilled individuals could use it, but there was a major challenge with this design for it was too expensive for the common man.

Nkakini and Yabef, (2014) designed, fabricated and tested a manually operated apparatus for grass cutting. The apparatus was designed with an internal spur gear system which transfers the torque to the mower spiral mechanism. The cutting mechanism is made of a flat blade rigidly fixed to the frame

behind the spiral arrangement that is configured to contact at least one-reel bar of the spiral blades during the rotation of the spiral mechanism. The machine’s performance evaluation was conducted in the River State University of Science and Technology, RSUST research farm. The field capacities of 0.00115 km<sup>2</sup>/hr. and field efficiency of 63.2% were obtained. The cutting effectiveness was achieved with a total power of 934.3 W at a rotary speed of 1500 rpm of shaft. The major disadvantage was that it was manually operated and manpower was required at one point or the other.

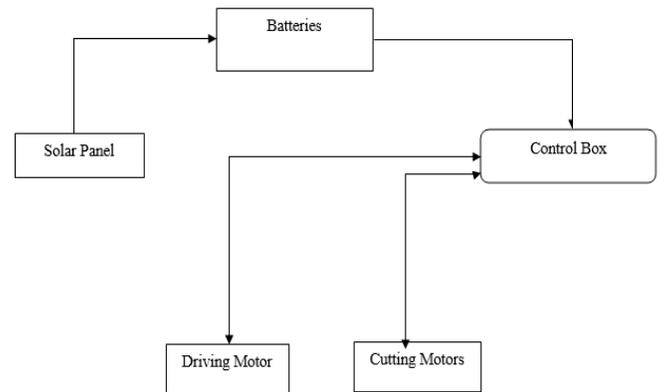
Ashwani and Karan, (2015) designed a mower that was portable, durable, easy to operate and maintain. The heart of the machine was a battery powered DC engine, it comprised of a system of speed multiplication pulleys which drive the cutting blades and the height of cut. The only let down in this design is the inability for the battery to charge itself during use, but needs to be carried back to be charged whenever the battery runs down.

**Description of the Lawnmower**

This new design would be able to operate independent of manpower during operation due to automation. Also, this design should be less noise pollutant, air pollutant and zero carbon monoxide emission. The automation of the lawn mower would be achieved by the process of hardware programming using Arduino platform. The lawn mower is controlled using a mobile application developed for android devices. The development of this mobile application was done using the software, ‘Android Studio’. Android Studio is the official Integrated Development Environment (IDE) for Google’s Android operating system. This is to enable a convenient and easy control without intensive manpower. The lawn mower will operate with less noise due to the absence of internal combustion engine which will be substituted with a DC electric motor-powered with a battery. Zero green gas emission is achieved during energy transformation throughout the system as a result of usage of clean energy.

The machine consists of the cutting motor, cutting motor housing, the wheels, driving motor, 12 V batteries, solar panel, etc. The front and rear wheels carry the entire components of the machine with the rear wheels fastened to the driving motor. The cutting motor housing carries the fabricated frame upon which the rechargeable 12 V batteries sits. The batteries supply electrical energy to the motors, electrical and automation components. Solar grass cutter are based on the use of small but powerful motors that provides enough torque to spin a very sharp horizontal blade that cuts the grass upon contact. It uses the photovoltaic panel to generate the energy needed to power the mower. It is assumed that a lawn mower using solar as the energy source will address a number of issues that the standard

internal combustion engine. A lawnmower with solar energy will be easier to use, it eliminates down time by frequent trips to the gas station for fill-ups and danger associated with gasoline spillage. The dangerous emissions generated by the gasoline spillage and that of the internal combustion engine into the atmosphere are eliminated. The solar-powered lawnmower will help to reduce air pollution as well as noise pollution produced by other types of lawnmowers. In addition, it will help to reduce the running cost of using and maintaining the lawn mower. The block diagram of the operational cycle of the lawnmower is shown in Figure 1. Table 1 shows a list of the materials used and their descriptions.



**Fig. 1: Block Diagram of Operational Cycle**

Figure 2 shows a schematic diagram of the hardware setup and Figure 3 the circuit board of the lawnmower.

**Table 1: The Materials used and their descriptions**

| Materials                       | Description   |
|---------------------------------|---|
| <b>Cutting Motor Housing</b>    | The motor housing is a metallic, rectangular shaped metal with a circular expansion to the left and right in the middle with an opening in the middle to which the cutting motor and its peripherals are fitted into. This housing has the tires fastened to it with the use of bolts and nuts and is the base upon which the battery sits.   |
| <b>360-degrees front wheels</b> | The two front wheels are made of 360° rotating wheels. As the name implies, it is capable of maneuvering the direction of a machine during of motion to the direction of applied force or momentum. The two front wheels in conjunction with the rear wheels carry the entire load of the lawn mower. The design and fabrication of 360° wheel is done to reduce time to turn from one direction to another. This component can move in all directions at the same position by used of steering, sprocket, DC motor, bearing and chain drive. It is used to ease movement maneuver of a machine in all directions.  |
| <b>Rear driving wheels</b>      | The rear driving wheels are riveted to the driving motors to propel the lawn mower for movement during cutting operations. The treads of the tires are designed to increase friction during movement. The turf tires feature small lugs and narrow void that prevent damages to the soil and vegetation. The grooves in-between the treads are used to let out water during operation in a wet lawn.  |
| <b>Driving motor</b>            | These are two DC motors rotating at a combined speed of 2400 rpm. The motors are responsible for the rotational motion of the tires for the forward or backward and turning motions of the lawn mower. There are two easily controllable parameters of a DC motor, direction and speed. To control the direction, the input voltage is varied for one of the motors using pulse width modulation. For example, to turn right, the input voltage of the right tire is varied (lowered or turned off) while the left wheel is rotated at full voltage supply until the required degree of turn is achieved then. When the turn is achieved, the voltage of the right wheel is flicked back on in full. This means that you pulse the motor on and off at varying rates. It is used to introduce rotational motion for movement. |
| <b>Aluminum angle iron</b>      | The Aluminum angle bars were specifically chosen because of its light weight and capability to still function in its place of operation. They were used to fabricate the frame of the lawn mower upon which the front wheels and driving motors are bolted. It is also used to create a housing space for the batteries. The frame constructed of the Aluminum angle bar was harnessed to the motor housing.  |
| <b>Bolts, nuts and washers</b>  | These are fasteners that were used to fasten several components like front wheel tires, cutting motor housing, driving motors, cutting motor and metal angle bars to one another. They were chosen to ease coupling and decoupling of the components.   |
| <b>Relays</b>                   | A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a separate low-power signal, or where several circuits must be controlled by one signal. A total of seven relays were used of which six were for the driving motors and the other for the cutting motor. It is used as a switch for the operation of the driving and cutting motors.   |
| <b>GPS Module</b>               | The GPS module for Arduino is a small electronic circuit that allows you to connect to your Arduino board to get position and altitude, as well as speed, date and time on Universal Time Coordinated (UTC). It uses the standard NMEA protocol to transmit the position data via serial port. It is used to measure distance, which is the length and breadth of the lawn/field.   |
| <b>6-Axis Compass</b>           | The Compass Module 6-Axis is a low-field magnetic sensing device with a digital interface. The compass module converts any magnetic field to a differential voltage output on 6 axes. This voltage shift is the raw digital output value, which can then be used to calculate headings or sense magnetic fields coming from different directions. The module is designed for use with a large variety of microcontrollers with different voltage requirements. It is a gyroscope that is used can be used to provide stability or maintain a reference direction in navigation systems.   |
| <b>Wi-Fi Module</b>             | The ESP8266 Wi-Fi Module is a self-contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to Wi-Fi network. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. Each ESP8266 module comes pre-programmed with an AT command set firmware, meaning, you can simply hook this up to your Arduino device and get about as much Wi-Fi-ability as a Wi-Fi Shield offers. The ESP8266 module is an extremely cost effective board. This module has a powerful enough on-board processing and storage capability that allows it to be integrated with the sensors and   |

|                      |  |
|----------------------|--|
| <b>Cutting motor</b> | <p>other application specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry, including the front-end module, is designed to occupy minimal PCB area. It is used to connect devices (Android app) to send and receive commands during operation.</p> <p>A DC cutting motor is a class of rotary electrical machines that converts direct current supplied by battery into mechanical energy (rotational motion). The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor. The high speed cutting motor has the cutting blade clamped to it to rotate the blade at high speed for cutting. The cutting motor provides the high rotational motion to the blade for cutting grass of a lawn or field.</p> |
| <b>Resistors</b>     | <p>Resistors are electronic components which have a specific, never-changing electrical resistance. The resistor's resistance limits the flow of electrons through a circuit. They are passive components, meaning they only consume power (and can't generate it). Resistors are usually added to circuits where they complement active components like op-amps, microcontrollers, and other integrated circuits. Commonly used resistors are used for limiting current, divide voltages, and pull-up I/O lines. All resistors have, two terminals, one connection on each end of the resistor.</p>   |
| <b>Transistors</b>   | <p>A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of semiconductor material with three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals controls the current through another pair of terminals. This is because the controlled (output) power can be higher than the controlling (input) power.</p>   |
| <b>Veroboard</b>     | <p>Veroboard is a brand of stripboard, a pre-formed circuit board material of copper strips on an insulating bonded paper board. It is a general-purpose material for use in constructing electronic circuits - differing from purpose-designed printed circuit boards (PCBs) in that a variety of electronic circuits may be constructed using a standard wiring board.</p>   |
| <b>Jumper wires</b>  | <p>A jumper wire (also known as jumper, jump wire, jumper cable, DuPont wire, or DuPont cable) is an electrical wire, or group of them in a cable, with a connector or pin at each end, which is normally used to interconnect the components of a Vero board or other prototype or test circuit, internally or with other equipment or components, without soldering. Individual jumper wires are fitted by inserting their end connectors into the slots provided in a breadboard, the header connector of a circuit board, or a piece of test equipment.</p>  |
| <b>Jumper wires</b>  | <p>The battery has been the most popular source of electricity in many daily life applications. Nowadays, more electrical energy is converted to mechanical energy, solar energy, and chemical energy etc. A battery is a device that converts chemical energy to electrical energy. The 12 volts 62Ah battery in use is rechargeable by solar energy which means it can be used multiple times by recharging it externally.</p>   |
| <b>Solar panel</b>   | <p>Also known as photovoltaic solar panels. It absorbs sunlight as a source of energy to generate electricity. A photovoltaic (PV) module is a packaged, connect assembly of typically 6x10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications but for the sake of the project, the photovoltaic system generates and supplies electric charge to the 12 V batteries. Each module is rated by its DC output power under standard test conditions (STC). The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 W module will have twice the area of a 16% efficient 230 W module.</p>  |
| <b>Arduino Uno</b>   | <p>Arduino Uno is a widely used open-source microcontroller board on the ATmega328P microcontroller. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. It has 14 digital input/output pins of which 6 can be used as PWM outputs, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller when it is connected to a computer or power source of voltage range 7-20 volts.</p>   |

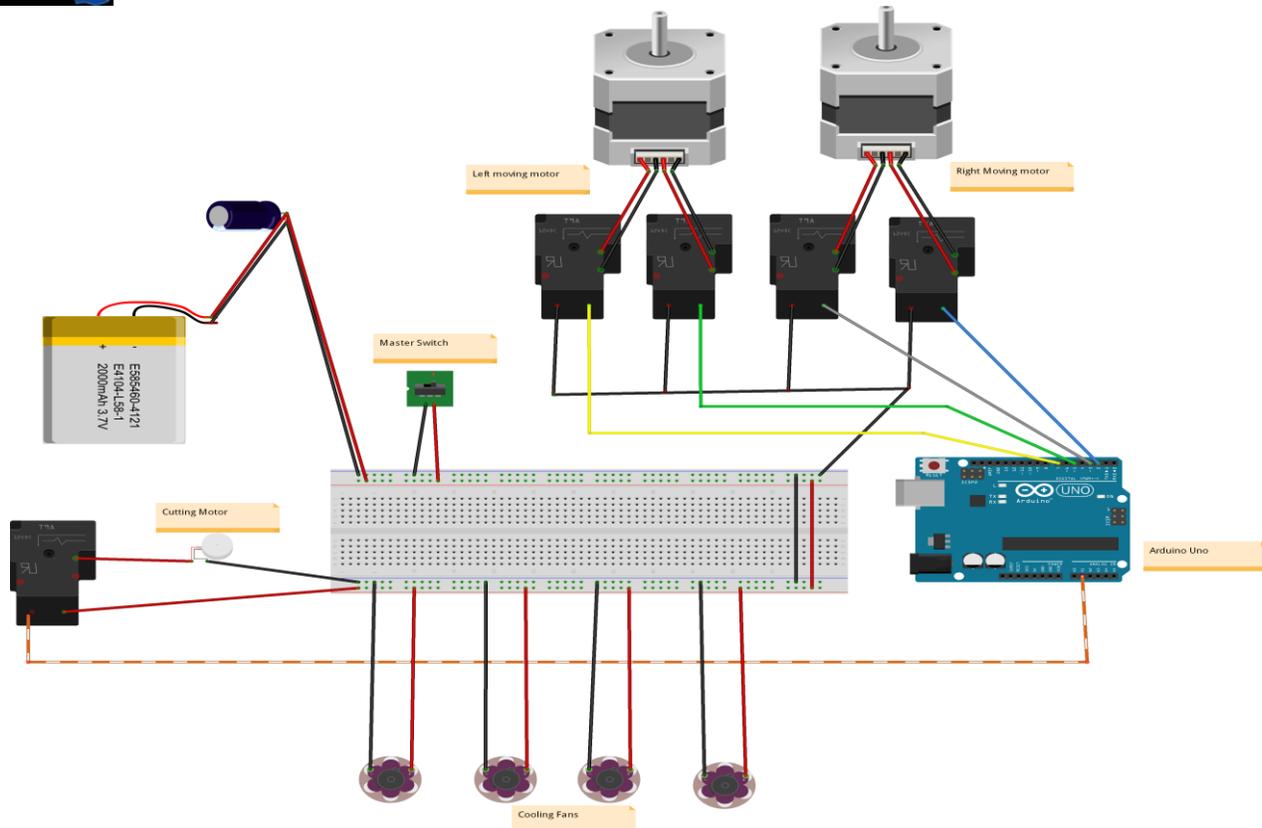


Fig. 2: Schematic Diagram of the Hardware Setup



Fig. 3: The circuit board of the Lawnmower

### Mechanical Design Analysis

This section presents the design of the basic mechanical components of the lawnmower.

#### i. Rolling Resistance

Rolling Resistance (force required to keep the wheels rolling) is given by equation 1.

$$R_f = WC_{rr} \quad (1)$$

where,  $R_f$  = Rolling Resistance (N),  $W$  = Total Weight of vehicle (N) and  $C_{rr}$  = Coefficient of Rolling Resistance. The standard weight for a powered lawn

mower has been considered as 105 pounds (47.62 kg) (Chouhan *et al.*, 2017).

The entire components of the mower weigh 50.3 kg (493 N). The coefficient of rolling resistance ( $C_{rr}$ ) is selected as 0.075 (corresponding to grass surface and soft interaction).

The computed value of  $R_f = 37 N$ .

#### ii. Grade Resistance

Grade Resistance (force due to gravity which causes resistance to the drive of a vehicle up a slope) is given by equation 2.

$$R_g = W \sin \theta \quad (2)$$

where  $R_g$  = Grade Resistance (in N) and  $\theta$  = Inclination Angle. Assuming Slope is  $1^\circ$ ,  $R_g = 8.6 N$ .

#### iii. Acceleration Force

The acceleration force (force that supports the vehicle to attain a decided speed from zero in a definite span of time) is given by equation 3.

$$F_a = ma \quad (3)$$

where  $F_a$  = Acceleration Force (N),  $m$  = mass of vehicle (kg),  $a$  = acceleration of vehicle required ( $m/s^2$ ), and  $g$  = gravitational acceleration ( $9.81 m/s^2$ ).

The safe mowing speed of a walk-behind mower is 3 miles/hour or 4.82 km/h and of an electric lawn mower is

3.3 miles/hour or 5.31 km/h (Klutho, 2001). Taking 5.31 km/h as the constant velocity to be achieved in the first 5 seconds of starting the mower, the acceleration of the mower for that time period will be equal to  $0.295 \text{ m/s}^2$  and  $F_a = 14.83 \text{ N}$ .

**iv. Total Tractive Force**

The total tractive force (force needed to provide motion to the vehicle) is given by equation 4.

$$F_t = R_f + R_g + F_a \quad (4)$$

where,  $F_t$  = Total Tractive Force (N) and the values of  $R_f$ ,  $R_g$  and  $F_a$  are computed from equations 1 to 3. Hence,  $F_t = 60.43 \text{ N}$ .

**v. Actuator Torque required at a Wheel**

Actuator torque ( $\tau$ ) required for driving the wheel can be calculated using equation 5.

$$\tau = F_t r_w \quad (5)$$

where,  $F_t$  = total tractive force,  $r_w$  = radius of driving wheel (selected as 4 inches or 0.1016 m due to availability in the local market). Hence,  $\tau = 6.14 \text{ N-m}$ . Hence, two motors each to producing approximately 4 N-m torque are required. Due to availability motors producing 6 N-m torque for each wheel are selected.

**6. Selection of Cutting Motor, Mowing blade and Actuator for the mowing blade**

The section below presents the selection of the cutting motor, mowing blade selection considerations and computation of actuator torque required for actuating the mowing blade.

According to Yong and Chow (1991) the shearing force of most annual and perennial grasses found on most lawns is usually between  $9.2 \text{ N} \sim 11.51 \text{ N}$ . The force required by the cutting blade to shear the grass is given by equation 6 (Khurmi, 2003).

$$F = \frac{\tau_s}{R} \quad (6)$$

where  $\tau_s = \frac{P}{2\pi N}$  shaft torque,  $P$  = power developed by the shaft,  $N$  = shaft speed in rev/min and  $R$  = Radius of cutting blade.

For smooth grass cutting, a motor power of not less than 628.3 W (0.84 hp) having a rotational speed of not less than 3,000 rev/min and producing a shear force of about 10.5 N is recommended (www.lawnmowerguide.com). However, due to non-availability of wide range of DC motors in the market, two radiator fans of about 1200 rpm each were used (combined speed of 2400 rpm). The shear force produced was sufficient when used with a synthetic wire blade. This is because torque was traded for speed used with a blade with a small surface area.

**7. Sizing of the Solar Power System to Vehicle**

The following steps for sizing for a 12 V system were obtained from Selectsolar.co.uk.

**i. Wattage per week:**

Considering two driving motors of 12 V and 23 A each, Wattage = 552 W.

**ii. Daily Watt-hour requirement:**

For 2 Drive Motors –  $552 \times (1/7) = 78.9 \text{ Wh}$ . Hence, total daily requirement = 78.9W-h.

**iii. Panel size:**

This can be determined by dividing the daily total Watt-hour requirement by the hours of available light expected in an average day. This gives = 8.77W or more, taking an average daily available sun light to be 9 hours.

**iv. Battery size:**

Multiplying the daily Watt-hour requirement by 7 to get the weekly requirement and dividing by 12 it is converted back to Ah in terms of which batteries are rated in. Multiplying this by 2, the correct battery size is obtained as approximately 92 Ah. This can be achieved by using two 62 Ah batteries. That is,  $62\text{Ah} \times 2 = 124 \text{ Ah}$ .

**Principle of Operation**

The principle of operation the lawnmower is achieved by conversion energy by different components that has been used in the course of this project. The electrical energy of the battery is converted to mechanical energy through the three D.C. motors to the cutting blade for grass cutting operation and the other two for driving the rear wheels. The electric circuit ensures power transfer from the battery to run the D.C. motor, whilst the solar panel power to continuously recharge the battery while in operation. The cutting blade and rear wheels tap power from the D.C. motors. When the power switch is on, the electrical energy from the battery powers the motors which in turn rotates the wheels and actuates the blade. The solar panel generates current to recharge the battery, thereby compensating for the battery discharge. The rotating blades continuously cut the grass as the mower is propelled forward.

The direction of cut is done in a clockwise direction in a rectangular-concentric form. This tends to throw the excess clippings away from the edges and into the center of the lawn. Figure 4 shows the CAD drawing of the lawnmower while Figure 5 shows the assembled mower.



**Fig. 4: AutoCAD drawing of the Lawnmower**



**Fig. 5: The Assembled lawnmower**

As a result of this development, an easier, faster and a more reliable way for controlling a lawnmower is available for everyone. This has contributed to the general environmental cleanliness of the society. Children, as well as old persons can carry out the task of mowing a lawn, without much effort. An average sound level of 68 decibels was obtained by an Android Application recorded 68 decibels. This is greatly less than that of an engine lawnmower. The cutting pattern and direction of cut is perfect for a rectangular based lawn which most of the lawn found around consists of.

This project presents a complete control system of an automated solar-powered lawn mower that is simple, easy and independently operated. Experimental results prove that the integration of automation and solar power supply system to the lawn mower makes it independent of labor and external power supply.

### Conclusion

An android app has been developed which controls the motion, direction maximum length and breadth of the lawn or field. The work emphasizes on proving that the control of a lawn mower can be entirely automated, that is, independent of labor force, solar panel supply system and electricity for battery recharge can be successfully used for making lawn mowing independent. This machine is still being developed to achieve results such as cutting different grass heights and grass types, and provision of multiple modes of motion and cutting styles that suits various shapes of lawns.

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