Unmanned Automated Lawn Mower

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Abstract – *This paper presents an automatic lawn mower which is a device or robot that help human to cut grass automatically. Due to rapid development, many conventional lawn mowers have turn into robotic mowers. But they are expensive and have certain demerits. Hence, we designed autonomous lawn mower that fulfills the requirement of a robotic mower, which is economically feasible and environmentally friendly. Sensors are used to provide feedback from outside world. Arduino UNO and Motor Drive Controller microcontrollers controls the entire system. Every action of the Lawn Mower is monitored by the microcontroller with the help of the sensor. Furthermore, Siemens NX as CAD software used to design the structure of the lawn mower. Also, this lawn mower will be self-guided without a need of human directional control due to ultrasonic sensor and the microcontroller that helps in the movement of the machine. The discharge type of this lawn mower is of bagging type. The overall conclusion of this paper is to select proper components with proper designing calculations and also analysis the structure by using Ansys as Engineering Simulation software.*

***Key Words*: Robotic Mowers, Arduino Uno, Bagging type, Rapid Development, Siemens NX, Ansys**

1. INTRODUCTION

A lawn mower is a machine that uses one or more revolving blades to cut a lawn to an even height. The blades may be powered either by hand; pushing the mower forward to operate the mechanical blades, or may have an electric motor or an internal combustion engine to spin their blades. There are several types of mowers, each suited to a particular scale and purpose. The smallest types are pushed by a human user and are suitable for small residential lawns and gardens. Riding mowers are larger than push mowers and are suitable for large lawns. The largest multi-gang mowers are mounted to tractors and are designed for large expanses of grass such as golf courses and municipal parks. But with advancement in technology and things being converted to mobile and automated these days, the transition from traditional hand guided or ride on mowers to robotic lawn mowers has begun to replace. This has made the mowing experience very fast, hassle free and comfortable for the customer

Our "Unmanned Automated Lawn Mower" is a machine that cut grass automatically and collect the mowed grass simultaneously without any human intervention. It can be stated as a machine or robot that helps people to do cutting grass work. Unlike other lawn mowers on the market, this design requires no perimeter wires to maintain the robot within the lawn. Through an array of sensors and motor controller, the robot will not only mow the lawn, it will also avoid collision with objects and human. It is a device that can fit into just about everyone's lifestyle, therefore having a device that costs less, accomplishing the same task as the higher end models is a great advantage in order to compete with the current market.

Robotic lawn mowers have been in the market to the general public from the late 20th century to public use. On the other hand, it has been limited mainly due to:

- Its expensive cost.
- Less Adaptation to such lawn mowers for the aged people and to disabilities.
- High Power Consumption of these gadgets
- For Non automatic lawn mowers, it's difficult to users with a busy schedule and rarely find time to mow, etc.

But now, we expect that this device will fit into just about everyone's lifestyle, therefore having a device that costs less, whilst accomplishing the same task as the higher end models is a great advantage in order to compete with the current market where the end consumer will benefit from.

1.1 Current Trend in Market:

Existing lawn mowers have this working principle, for instance the Robomow from Friendly Robotics (2011) [1] requires the user to perform a onetime set up where the garden perimeter is set. The perimeter is set using a battery powered wire that is laid around the outer edges of the garden and any area where the robot is not to cover. Special sensors inside Robomow enable the wires to be recognized and the robot is therefore kept within the designated area. The robot travels on the garden in a systematic criss-cross or irregular pattern, several times from side to side to ensure that the entire area is covered and that the grass is cut from different angles. Similar technologies are implemented by LawnBott and Husqvarna as shown in Fig 1 (Friendly Robotics, 2011).

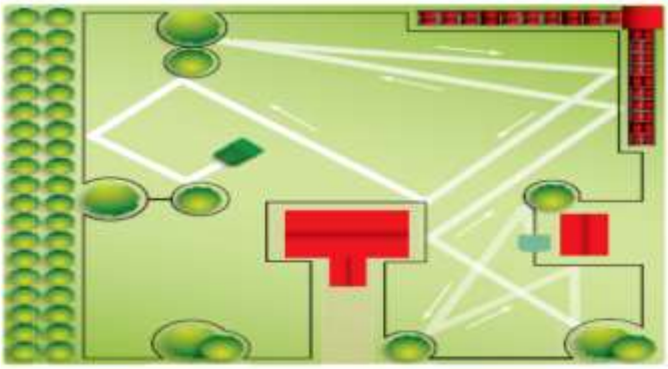

Fig1: LawnBott random cutting pattern (LawnBott,2011) [2]

Other technologies work is the implementation of the mulching process from the bagging process for discharging of mowed grass. It differs from region to region. In India, as the monsoon season comes, heavy rainfall and water clogging is the main issue observed. Hence when mulched, the mowed grass particle either float or make the lawn marshy, not favorable to any residential or industrial lawn. Hence bagging technique is an important aspect.

1.2 Identification of Merits and Demerits:

The working methodology of the Robotic Lawn Mower although its effective, but to a certain degree its inefficient and contribute to high cost and maintenance to the end product. The main advantages of these design include, virtually any size or shape of garden can be specified, it is flexible and it can work without requiring the user intervention at any stage, can operate at surface areas with slopes, smaller in size than the previous lawn mowers, usability of these lawn mower, these points can also constitute a disadvantage. The system design has the following disadvantageous aspects:

Irregular area of lawn – As wires have to be placed in the garden perimeter to be covered by the robotic mower; the cost of the entire system is considerably higher depending on the size. In the case of plants being in the middle of the garden area, the setup can become cumbersome [2].

Damage or faults on wires – The wires are set on the grass and although the company mentions the fact that they would typically be covered by grass and become unnoticeable in a matter of 2 to 3 weeks (Friendly Robotics, 2011) [1], the wires are prone to damage. The damage can be from any origin for example, pets can dig up and damage the wire, over time due to weather it can wear off, amongst others. A fault on the wire can provide incorrect information to the device and as consequence the device will not work as expected.

Cutting pattern inefficiency – the criss-cross pattern for these robotic lawn mowers are all not very efficient due to the fact that it is required that the robot crosses the same location more than once, or may leave a certain portion of area of lawn, consequently more energy is dissipated and the overall completion time is extended or an inconsistent mowing occurs, which is undesirable for a lawn mower.

Sticking to Manual/Semi-Automatic Mower – As these Robotic Lawn Mower is expensive especially in India and when they compare the product cost with its requirement, people find it difficult to invest a big cost on such advanced product. Hence, they prefer Semi-Automatic or Manual Lawn Mower that fits in their budget, but it increases their work load, requires human interaction, lower working efficiency and time loss as concluded.

2. PRINCIPLE OF OPERATION:

In this "Unmanned Automated Lawn Mower", 4 components play a vital role for the overall working of this system namely:

- Cutter
- Fan
- Arduino and Motor Drive Controller
- Battery

The cutter performs the mowing of the lawn. We have also provided a height adjusting mechanism for the cutter to provide an additional feature of mowing the lawn at your required height. Since our system is in a close environment (provided with the coverings) the fan plays a vital role as it throws the mowed grass to the collector bag provided at the end of the lawn mower, the air flow is been ensured that it can overtake the swirling effect made by the cutter.

Arduino and Motor Drive Controller (Motor Control Module) is the brain of the system as it carries out the algorithm and provides the required signals and perform the necessary action as per the program coded in Arduino. Motor Control Module will help in the motion of the machine as per the signals of Arduino. Ultrasonic Sensors are also there to check out the obstacles in front of the Mower. The signals received from the sensors passes to the Arduino so as to perform Its execution procedures as per the algorithm.

Battery is the major power source of our entire system. Hence its important that the Power to Weight ratio must be high so that our machine runs for longer time and less maintenance, hence Lithium Ion Battery is taken as it fulfills our requirements.

3. FLOWCHART OF MODEL

From Dutta P.P et al, we understood the initial phase of our work process flow. But we want to ensure that the lawn mower completes its path till there is no obstacle and to avoid travelling the same path again. Hence in our lawn mower, when it comes in the contact region of any obstacle, it takes 180^0 turn travel and after completing this turn, it moves forward unlike taking a single left turn as shown in fig 2. These turns changes from left to right at every successful turn. Hence, the path is more of S-shape, than the square shape. This ensures that the lawn mower will not travel the same path again, resulting in less energy loss. Its important to have the knowledge of different types of sensors, electrical components with the Arduino and Arduino programming.

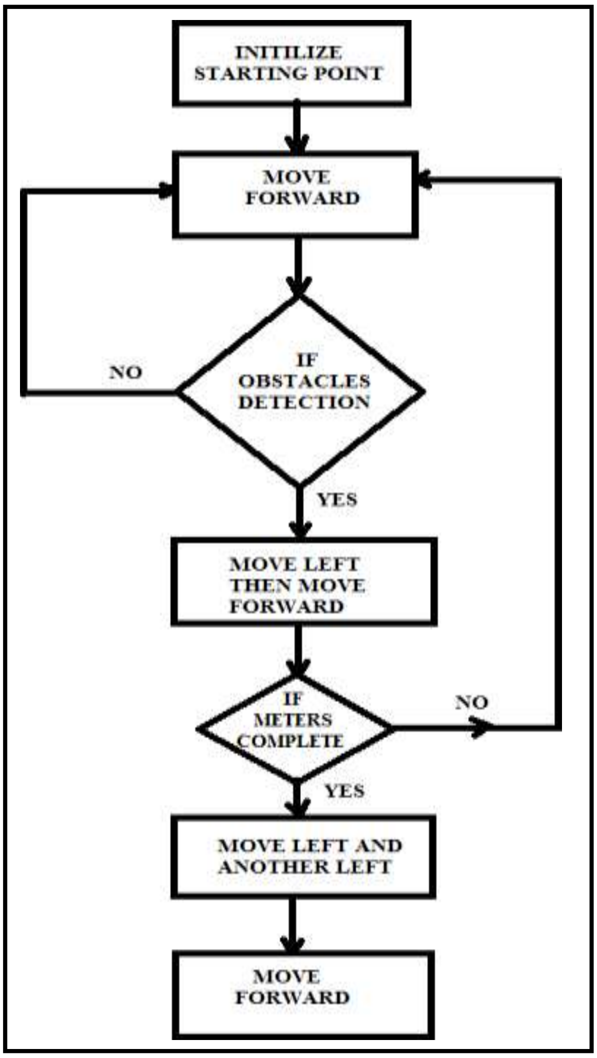

Fig 2. Flowchart of Model [3]

4. MAJOR COMPONENTS

After going through the field study, related works and research related to this topic, we concluded the major components that constitutes this Unmanned Automated Lawn Mower, which makes it economically viable and user friendly are as follows:

1. Ultrasonic Sensor: It is a sensor that uses ultrasonic sound to detect range or distance of an object. This sensor can also act as a sensor to detect present or absent of an object. Due to ultrasonic is in the form of sound, a sort of energy, it can be used to calculate distance of the sound travel from the emitter to an object and reflect back to the receiver. Sound wave travel at speed of 340m/s.

2. Arduino UNO: The Arduino UNO is an open-source microcontroller board based on the Microchip ATmega328Pmicrocontroller and developed by Arduino.cc. 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. The board has 14 Digital pins, 6 Analog pins, and programmable with the Arduino IDE (Integrated Development Environment) via a type B USB cable.

3. Cutter: This will be used for the primary function of the mower i.e. to cut the grass. Depending on the design, more than one cutter can be used in synchronization as well. Also, cutters with different shape or number of blades can be used for the purpose of the getting the required cutting speed.

4. Motor Drive Controller: This gives the required signal to the geared motor for actuation of the wheel rotation. It also provides the required signals when there is any change in the direction with the help of the motor drive controller.

5. Buck Converter: A buck converter (step down converter) is a DC to DC power converter which steps down voltage (while stepping up current) from its input supply to its output (load). Its required for Arduino.

6. Battery: It will provide the energy for the working of the robot Use of Lithium-Ion Battery results in the environment friendly model.

7. Wheels: These will be required for the cause of the motion of the body of the robot. The choice of the wheels largely depends on the shape and size of the grass. It will also depend on the required ground clearance of the robot. As trends of the tires can contribute significantly to the performance of the mower, great caution is needed during the decision to choose the particular tires.

8. Metal Gear Motor and Cutter Motor: To drive the wheels we need metal gear motors and to rotate the cutter at high speed we need high speed motor.

9. PVC Pipes: While designing the weight and cost are the important factors. So, to minimize the weight of the whole setup and to minimize the cost, PVC pipes, used for making the structure (chassis of the model) of setup as it can handle the weight of the battery.

10. Grass Collector Bag: Taking reference to the commercial grass bags we are going to use grain sacks which are light in weight. Advantage of this is that these bags are light in weight, moisture proof and recyclable.

4.1. CAD Model Design

With the help of Siemens NX as CAD software we have design of the model as per the calculations and the specifications as in shown in Fig. 3 and Fig. 4.

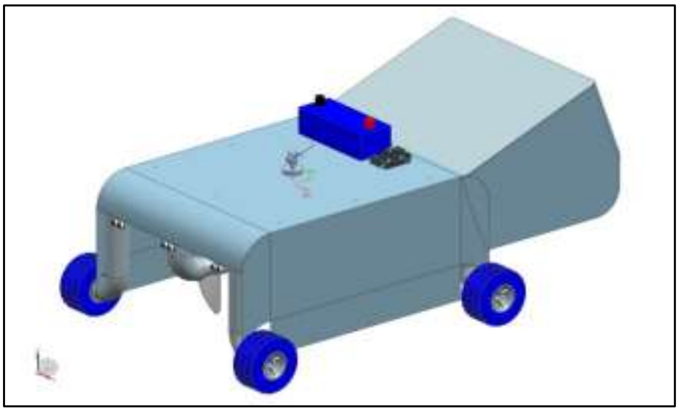

Fig 3. Design of Model (Isometric view)

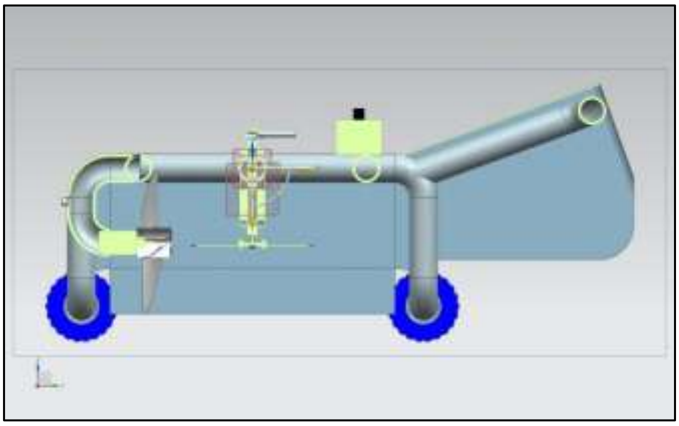

Fig 4. Cross section of model (Sectional-Side View)

5. DESIGN PROCEDURE AND CALCULATIONS

5.1 Design Analysis of Cutter and Cutter Motor Selection:

In designing the cutting blade, the force required to cut the lawn as well as the force acting on the blade was considered. The force required by any sharp object to have impact on the grass is less than 10 Newton [4]. It is also dependent on the height, density and the area covered by the object. A stainless steel is used in the construction of the cutting blade because of its strength and weight which can transmit same speed as that of the DC motor or a little less cause of friction [5].

Now, as our Assembly supports both blades and the wooden block as shown in Fig 5.

Length of blade: 100mm

Width of Blade: 18mm

Thickness of Blade: 1mm

Number of Blades: 4

Density of Stainless Steel: 7800kg/m^3

Density of Plywood Block (Hardwood): 900kg/m^3

Speed of the Cutter: 3500rpm

Acceleration due to Gravity: 9.81m/s^2

Now,

Volume of the Blade: L*B*H

$100*18*1=1.8x10^{-6}m^3$.

As No of blades is 4, hence total blade volume=

$1.8x10^{-6}*4=7.2x10^{-6}m^3$.

Mass of Blade: Density of Blade*Volume=$7800*7.2x10^{-6}$= 0.05616kg

Weight of Blade: Mass *Acceleration due to Gravity=0.05616*9.81=0.551N

Volume of Block is: L*B*H=$3.4x10^{-5}m^3$.

Mass of Block: Density of Block*Volume=$900*3.4x10^{-5}$= 0.0306kg

Weight of Block: Mass* Acceleration due to Gravity

0.0306*9.81=0.3N

Total Weight of Cutter= Weight of Blade + Weight of Block

0.551+0.3=0.831N

We take the Total Weight as 1N

Now, Angular Velocity ω = 2ΠN/60 = 366.52 rad/sec

Torque=r*W =0.15*1=0.15N-m.

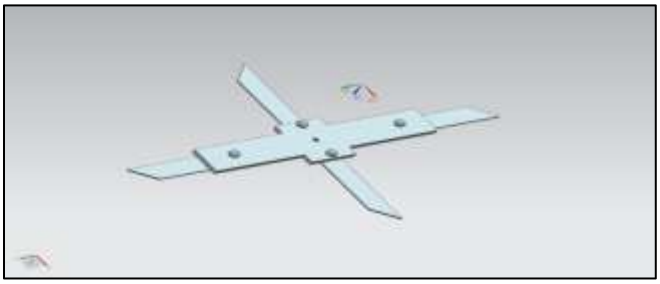

Fig 5. CAD model of Cutter Assembly

Power=T* ω

P1= 0.15*366=**54.9 Watt.**

Thus, power required to motor for driving the blade at selected speed and dimensions is 54.9 watt.

Hence, 775 DC motor is most suitable as it provides the following specifications:

Specification:

Model	775
Shaft Diameter	5mm
Mounting hole size	M4
Mounting hole	2

Motor Power(W)	Rated Voltage(V)	Maximum Current(A)	Maximum Torque(KG)	Maximum Speed(RPM)
80W	12	6A	1.8	4000
	24			8000
150W	12	12A	3.2	7500
	24			15000
288W	12	12A	3.8	6000
	24			12000

Table 1. Specifications of the 775 DC motor [6]

5.2 Selection of Metal Gear Motor To drive the wheels:
Gross vehicle weight (GVW): 5kg = (5*9.81) = 49.05N
Weight on each drive wheel (W_W) : (6*9.81)/4 = 14.715N
Diameter of wheel/tire (Rw) :125mm = 0.125m
Speed of the wheel: 30 RPM
Desired top speed (Vmax) : (0.0625*2*3.14*30)/60= 0.196 m/s
Maximum incline angle (α) : upto 15 degree
To choose motors capable of producing enough torque, it is necessary to determine the total tractive effort (TTE) requirement for the vehicle:

TTE = RR + GR + F_a

Where,

TTE = total tractive effort

RR = force necessary to overcome rolling resistance

GR = force required to climb a grade

F_a = force required to accelerate to final velocity

Step One: Determine Rolling Resistance

Rolling Resistance (RR) is the force necessary to propel a vehicle over a particular surface. The worst possible surface type to be encountered by the vehicle should be factored into the equation.

RR = W_{GV} x C_{rr} = 49.05 * 0.055 = **2.69775 N**

Where,

RR = rolling resistance

W_{GV} = gross vehicle weight

C_{sf} = surface friction coeff. (value from Table 2)

Table 2. Surface Friction Coefficient for Plastic Wheels

Contact Surface	Csf
Concrete (good / fair / poor)	.010 / .015 /.020
Asphalt (good / fair / poor)	.012 / .017 / .022
Wood (dry/dusty/wet)	.010 / .005 / .001
Snow (2 inch / 4 inch)	.025 / .037
Dirt (smooth / sandy)	.025 / .037
Mud (firm / medium / soft)	.037 / .090 / .150
Grass (firm / soft)	.055 / .075
Sand (firm / soft / dune)	.060 / .150 / .300

Step Two: Determine Grade Resistance

Grade Resistance (GR) is the amount of force necessary to move a vehicle up a slope or grade. This calculation must be made using the maximum angle or grade the vehicle will be expected to climb in normal operation.

To convert incline angle, α, to grade resistance:

GR = W_{GV} x sin(α) = 49.05 * sin (15) = **12.695 N**

where:

GR = grade resistance

W_{GV} = gross vehicle weight

α = maximum incline angle [degrees]

Step Three: Determine Acceleration Force

Acceleration Force (F_a) is the force necessary to accelerate from a stop to maximum speed in a desired time.

F_a = W_{GV} x $(Vmax)^2/r$ = 5*(0.196)²/0.0625 = **3.07328 N**

Where,

Fa = acceleration force Vmax = maximum speed

WGV = gross vehicle weight

Step Four: Determine Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2& 3.

TTE = RR + GR + Fa = 2.69775 + 12.695 + 3.07328 = **18.46603 N**

Step Five: Determine Wheel Motor Torque

To verify the vehicle will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (Tw) based on the tractive effort.

Tw = TTE * Rw * RF = 18.46603 * 0.0625 * 1.1 = **1.2695 N m**

Where,

Tw = wheel torque

TTE = total tractive effort

Rw = radius of the wheel/tire

RF = resistance factor

The resistance factor accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

Step Six: Reality Check

The final step is to verify the vehicle can transmit the required torque from the drive wheel(s) to the ground. The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

MTT = Ww x μ x Rw

= 14.715 *0.36 * 0.0625 = 0.3310 Nm

Where,

Ww = weight (normal load) on drive

μ_s = static friction coefficient between the wheel and the ground (From Table no)

Rw = radius of drive wheel/tire

Material	Against Material	Static Coefficient of Friction	
		Dry Contact	Lubricated Contact
Silver	Silver	1.40	.52
Skin, Human	Metals (63 Ra)	.9	-
Steel	Steel	.80	.16
Teflon	Steel	.04	.04
Teflon	Teflon	.05 - .20	.04
Tin	Cast Iron	.31	-
Tire, Rubber	Asphalt	.71	-
Tire, Rubber	Grass	.36	-
Tungsten Carbide	Steel	.40 - .60	.10 - .20
Tungsten Carbide	Tungsten Carbide	.20 - .25	.12
Wood	Wood	.25 - .50	.20
Wood	Metals	.20 - .60	.20 (wet)
Zinc	Zinc	.60	.04

Table 3. Selection of Static Coefficient of Friction(μ_s)

Now for no of wheels, 0.26487 * 4 = 1.32435 N m

Total Tractive Effort is the net horizontal force applied by the drive wheels to the ground. If the design has four drive wheels, the force applied per drive wheel (for straight travel) is ¼ of the calculated TTE.

The Wheel Torque calculated in Step Five is the total wheel torque. This quantity does not change with the number of drive wheels. The sum of the individual drive motor torques must be greater than or equal to the computed Wheel Torque.

The Maximum Tractive Torque represents the maximum amount of torque that can be applied before slipping occurs for each drive wheel.

The total wheel torque calculated in Step Five must be less than the sum of the Maximum Tractive Torques for all drive wheels or slipping will occur.

Now, for the selection of the motor,

Twe = 1.2695 N m = (1.2695*100)/9.81 = 12.94 kg. cm

Hence, from above table the first motor selected with 30 RPM.

Power required to drive the all four wheels,

Power = P2= Tw * w = (1.2695 * (2 * 3.14*30))/60 = **3.988W**

Product	Specification	Application
Johnson Motor High Torque DC Geared	Voltage – 12V Rated Current – 1.2 A Stall Current – upto 7.5A (max) Torque – 5.2 to 120 kgcm Power – 15W RPM – 10 to 900 RPM	• Gear box diameter 37mm • High Quality Spur gear box • Used for prototyping and hobby purpose applications • 30mm long round shaft with 6mm diameter
DC Geared IG32 Motors	Voltage – 12V Rated Current – 1.2 A Stall Current – upto 7.5A (max) Torque – 3 to 140 kgcm Power – 20W RPM – 10 to 800 RPM	• Gear box diameter 32mm • All metal sturdy construction • Suitable for small machinery industrial use • Silent operation • 15mm long d shaft with 6mm diameter and M3 tapped hole for coupling bolt
Mega Torque DC Geared Motors	Voltage – 18V Rated Current – 14A Stall Current – upto 30A(max) Torque – 39 to 650 kgcm Power – 250W RPM – 25 to 750 RPM	• Gear Box Diameter 42mm • High Torque Motor For Heavy Duty Applications • Planetary gear box with all metal Construction • Compact powerful driving system • 18mm long d shaft with 8mm/12mm diameter
DC Geared IG52 Motors	Voltage – 24V Rated Current – 4A Stall Current – upto 30A (max) Torque – 10 to 380 kgcm Power – 100W RPM – 10 to 750 RPM	• Gear box Diameter 52mm provides sturdy and reliable performance • Industrial grade continuous use motor • Suitable for heavy load in compact size • Silent operation even under heavy load • 25mm long shaft with 12mm diameter and keyway slot for positive coupling

Table 4. Comparison of Different DC geared motors

5.3 Design of Height Adjustable Screw for cutter assembly

As the purpose of the Height Adjusting Screw is to Lift Up and Down the Cutter Assembly as per our requirement, it can be referred to as a micro "Screw Jack". Hence the calculation will be based on Screw Jack.

Step 1: Material Selection

Application of screw	Material		Safe bearing pressure in N/mm²	Rubbing speed at thread pitch diameter
	Screw	Nut		
1. Hand press	Steel	Bronze	17.5 - 24.5	Low speed, well lubricated
2. Screw jack	Steel	Cast iron	12.6 – 17.5	Low speed < 2.4 m / min
	Steel	Bronze	11.2 – 17.5	Low speed < 3 m / min
3. Hoisting screw	Steel	Cast iron	4.2 – 7.0	Medium speed 6 – 12 m / min
	Steel	Bronze	5.6 – 9.8	Medium speed 6 – 12 m / min
4. Lead screw	Steel	Bronze	1.05 – 1.7	High speed > 15 m / min

Table 5. Limiting Value of Bearing Pressure

For Screw: Carbon Steel is taken for which;

Ultimate Crushing stress (σ_{cu}) is 320 MPa

Yield stress in Tension or Compression is (σ_y) 200MPa

Shear stress is (τ_y)120 MPa.

Allowable Bearing pressure between screw and nut is (p_b)15 N/mm².

Young's modulus for steel is (E) 210 kN/mm².

For Nut: Phosphor Bronze for which;

In tension, Elastic limit is ($\sigma_{et(nut)}$)100 MPa.

In compression, Elastic limit is ($\sigma_{ec\,(nut)}$)90 MPa.

Shear stress is ($\tau_{e(nut)}$)80 MPa.

Coefficient of Friction:

S.No.	Condition	Average coefficient of friction	
		Starting	Running
1.	High grade materials and workmanship and best running conditions.	0.14	0.10
2.	Average quality of materials and workmanship and average running conditions.	0.18	0.13
3.	Poor workmanship or very slow and in frequent motion with indifferent lubrication or newly machined surface.	0.21	0.15

Table 6. Coefficient of Friction under different conditions

Hence the Coefficient Between the Screw and Nut is taken as (μ) 0.13

Step 2: Selection of Screw Dimension

The Table below shows the dimension for Square Threads of Normal Series.

Nominal diameter (d_1)	Major diameter		Minor diameter (d_c)	Pitch (p)	Depth of thread		Area of core (A_c) mm²
	Bolt (d)	Nut (D)			Bolt (h)	Nut (H)	
10	10	10.5	8	2	1	1.25	50.3
12	12	12.5	10				78.5

Table 7. Dimensions for Square Threads

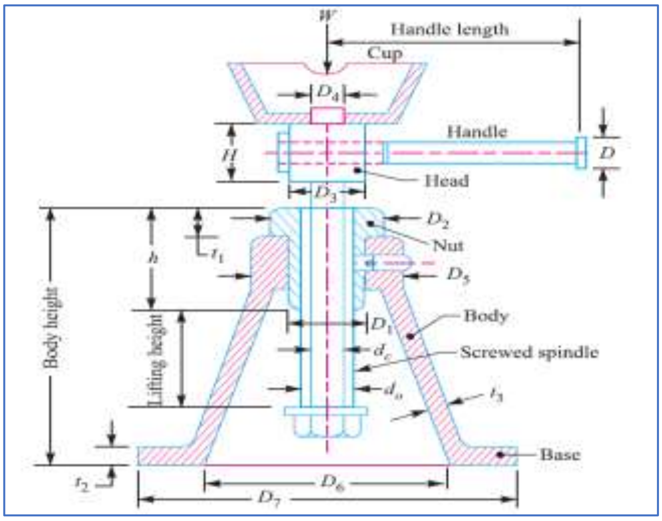

Fig 6. Cross Section Of Screw Jack

Step 3: Load Selection

Considering all the forces acting on the screw such as the weight of the load, the ergonomist consideration of the user feasibility and the standard one available at market, we take load W=1kN.

Step 4: Lifting Height of Screw

Taking into consideration of the ground clearance and the height of the cutter assembly, the lifting height is 105mm.

Step 5: The Design Calculation

Design of screw for spindle:

Let d_c = Core diameter of the screw.

Since the screw is under compression, therefore load (W),

$W = \frac{\pi}{4} \times d_c^2 \times \frac{\sigma_c}{FOS}$

(Taking factor of safety, F.O.S. = 5)

Implies $1000 = \frac{\pi}{4} \times d_c^2 \times \frac{200}{5}$

Therefore d_c =5.64 ~ 7mm

For square threads of normal series, the following dimensions of the screw are selected from the above table as;

Core diameter, d_c = 8 mm

Nominal or outside diameter of spindle, d_o = 10mm.

Pitch of threads, p = 2 mm

Now let us check for principal stresses:

We know that the mean diameter of screw,

$$d = \frac{d_o + d_c}{2}$$

Therefore, $d = \frac{10+8}{2}$= 9mm

And $\tan\alpha = \frac{p}{\pi\times d} = \frac{2}{\pi\times 9}$=0.0707

As coefficient of friction=0.13

$$\mu = \tan\emptyset = 0.13$$

Now, Torque Required to rotate the screw in the nut, $T_1 = P \times \frac{d}{2} = W \times \tan(\emptyset+\alpha)\frac{d}{2} = W \times (\frac{\tan\emptyset+\tan\alpha}{1-\tan\emptyset\times\tan\alpha}) \times \frac{d}{2}$

Therefore, $T_1 = 1000 \times (\frac{0.13+0.0707}{1-0.13\times 0.0707}) \times \frac{9}{2}$ ∴ T_1= 911.53 N-mm.

Now, compressive stress due to axial load,

$$\sigma_c = \frac{W}{A_c} = \frac{1000}{50.3} = 19.88\ N/mm^2$$

As, Shear Stress due to torque,

$\tau = \frac{16\times T_1}{\pi\times d_c^3} = \frac{16\times 911.53}{\pi\times 8^3}$= 9.06 N/mm^2

Maximum principal stress (tensile or compressive) is;

$$\sigma_{c(\max)} = \frac{1}{2}[\sigma_c + \sqrt{(\sigma_c^2 + 4\tau^2)}]$$
$$= \frac{1}{2}[19.88 + \sqrt{(19.88^2 + 4\times 9.06^2)}]$$

$$\sigma_{c(\max)} = 23.39\ N/mm^2$$

The given value of σ_c is equal to $\sigma = \frac{\sigma_{ec}}{F.O.S} = \frac{200}{5} = 40\ N/mm^2$

We know that Maximum Shear Stress is;

$\tau_{(\max)} = \frac{1}{2}[\sqrt{(\sigma_c^2 + 4\tau^2)}] = \frac{1}{2}[\sqrt{(19.88^2 + 4\times 9.06^2)}] = 13.44\ N/mm^2$

The given value of τ is equal to $\tau = \frac{\tau_e}{F.O.S} = \frac{120}{5} = 24\ N/mm^2$

Since these maximum stresses are within limits, therefore design of screw for spindle is safe

Design for nut:

Let n = Number of threads in contact with the screwed spindle

h = Height of nut = n × p

t = Thickness of screw = p / 2 = 2 / 2 = 1 mm

Assume that the load is distributed uniformly over the cross-sectional area of nut.

We know that the bearing pressure (p_b);

$$p_b = \frac{W}{\frac{\pi}{4}\times[d_o^2 - d_c^2]\times n}$$

$$\therefore 15 = \frac{1000}{\frac{\pi}{4}\times[10^2 - 8^2]\times n}$$

∴ n=2.35~ 5 threads

And height of nut , h = n × p = 5x2 = 10mm.

Now, let us check the stresses induced in the screw and nut.

We know that shear stress in the screw;

$$\tau_{(screw)} = \frac{W}{\pi \times n \times d_c \times t} = \frac{1000}{\pi \times 5 \times 8 \times 1} = 7.96\ N/mm^2$$

And Shear stress in nut is;

$$\tau_{(nut)} = \frac{W}{\pi \times n \times d_o \times t} = \frac{1000}{\pi \times 5 \times 10 \times 1} = 6.36 N/mm^2$$

Since these stresses are within permissible limit, therefore design for nut is safe.

Let D_1 = Outer diameter of nut,

D_2 = Outside diameter for nut collar, and

t_1 = Thickness of nut collar.

First of all, considering the tearing strength of nut, we have;

$$W = \frac{\pi}{4} \times [D_1^2 - d_o^2] \times \frac{\sigma_{et(nut)}}{F.O.S}$$

$$\therefore 1000 = \frac{\pi}{4} \times [D_1^2 - 10^2] \times \frac{100}{5}$$

Therefore, D_1=12.79~ 15mm.

Now considering the crushing of the collar of the nut, we have:

$$W = \frac{\pi}{4} \times [D_2^2 - D_1^2] \times \frac{\sigma_{ec(nut)}}{F.O.S}$$

$$\therefore 1000 = \frac{\pi}{4} \times [D_2^2 - 15^2] \times \frac{90}{5}$$

Therefore, D_2=17.19~ 20mm.

Considering the shearing of the collar of the nut, we have:

$$W = \pi \times D_1 \times t_1 \times \frac{\tau_{e(nut)}}{F.O.S}$$

$$\therefore 1000 = \pi \times 15 \times t_1 \times \frac{80}{5}$$

Therefore, t_1=1.32~ 3mm.

Design for handle:

The diameter of the head (D_3) on the top of the screwed rod is usually taken as 1.75 times the outside diameter of the screw (d_o).

∴ $D_3 = 1.75\ d_o = 1.75 \times 10 = 17.5$~ 20mm.

The head is provided with two holes at the right angles to receive the handle for rotating the screw. The seat for the cup is made equal to the diameter of head, i.e. 20 mm and it is given chamfer at the top. The cup is fitted to the head with a pin of diameter $D_4 = 0.5 \times d_o = 0.5 \times 10 = 5$mm.

Now let us find out the torque required (T_2) to overcome friction at the top of the screw.

Assuming uniform pressure conditions, we have;

$$T_2 = \frac{2}{3} \times \mu \times W \times [\frac{R_3^3 - R_4^3}{R_3^2 - R_4^2}]$$

$$\therefore\ T_2 = \frac{2}{3} \times 0.13 \times 1000 \times [\frac{10^3 - 2.5^3}{10^2 - 2.5^2}]$$

∴T_2= 910 N-mm.

∴ Total torque to which the handle is subjected,

$T = T_1 + T_2 = 911.53 + 910 = 1821.53$ N-mm.

Assuming that force of 50 N is applied by a person intermittently, therefore length of handle required = 1821.53/50 = 36.43~ 50mm.

A little consideration will show that an excessive force applied at the end of lever will cause bending. Considering bending effect, the maximum bending moment on the handle,

M = Force applied × Length of lever

= 50 x 50 = 2500 N-mm

Let D = Diameter of the handle

Assuming that the material of the handle is same as that of screw, therefore taking bending stress $\sigma_b = \sigma_t = \sigma_{et} / 2 = 100\ N/mm^2$.

We know that the bending moment (M); $M = \frac{\pi}{32} \times \sigma_b \times D^3$

$$\therefore 2500 = \frac{\pi}{32} \times 100 \times D^3$$

∴ D = 6.33~ 10mm.

The height of head (H) is taken as 2D.

∴ H = 2 x D = 2 × 10 = 20mm.

Now let us check the screw for buckling load. We know that the effective length for the buckling of screw,

L= Lift of Screw + (0.5 x Height of Screw)

= 105 + (0.5 x 10) = 110mm.

When the screw reaches the maximum lift, it can be regarded as a strut whose lower end is fixed and the load end is free. We know that critical load;

$$W_{cr} = A_c \times \sigma_y \times [1 - \frac{\sigma_y}{4 \times C \times \pi^2 \times E} (\frac{L}{k})^2]$$

For one end fixed and the other end free, C = 0.25.

Also, k = 0.25 x d_c = 0.25 × 8 = 2 mm

$$\therefore\ W_{cr} = 50.3 \times 200 \times [1 - \frac{200}{4 \times 0.25 \times \pi^2 \times 210000} (\frac{110}{2})^2]$$

$\therefore W_{cr}$ = 7123.47 N

Since the critical load is more than the load at which the screw is designed (*i.e* 1000 N) therefore there is no chance of the screw to buckle.

Design of body:

`The various dimensions of the body may be fixed as follows:

Diameter of the body at the top;

$D_5 = 1.5\ D_2$ = 1.5 × 20 = 30 mm

Thickness of the body;

$t_3 = 0.25\ d_o$ = 0.25 × 10 = 2.5~ 5mm

Below, fig. shows the cad model of mechanism of adjustment screw for cutter assembly

Fig 7. Mechanism of Adjustment Screw for Cutter Assembly

5.4 Analysis and Selection of Fan

As the cutter speed is 3500 RPM, so the speed of the fan which is going to work as blower is must be greater than 3500 RPM.

So, from Table, selecting the motor of RPM 4000 RPM for the fan of 25 cm (9.84 inch) based on design.

Now,

Flow rate of fan = Q = Area * Velocity = (3.14 * 0.25* 0.25 * 2 * 3.14 *4000 * 0.127))/(60 *4)=2.57 m^3/sec = 5445.52 cfm

Now, for this cfm we got the 12V DC fan with the nominal RPM of 2400 which is sufficient to allow the cut grass thrown into the collector.

Step 1: Go to site of ComairRotron

Step 2: Next put values of needed voltage and cfm.

Step 3: Select the required fan for the given purpose.

Fig 8. Process of Selection of Fan

Now considering the weight and cost optimization we made the fan with plastic material.

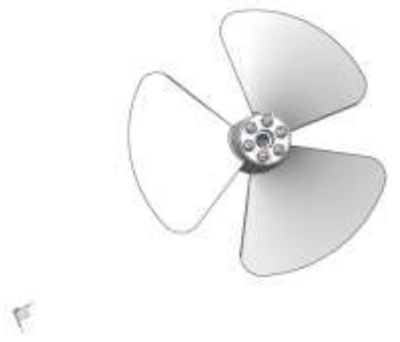

Fig 9. Cad Model of the Fan

5.5 Total power calculation & Selection of Battery
Total Power required to drive the whole setup
$= P_1 + P_2 + P_3 = 54.9 + 3.988 + 64.3 = 123.188$ Watts
P_T = 123.188 Watts
Total Current = I_T = 123.188 /12 = 10.26 A
So, we required 10.26 A to drive the total setup.
Based on the experimental analysis, if we select 12 V 'X' Ah Battery, 30 % power is consumed by itself and it only works on 70 % of the remaining Ah.
So, we are selecting the **12 V DC Battery of 15 Ah** to drive the whole setup.

6. ANALYSIS OF MODEL STRUCTURE

To understand the strength and load capacity of structure it is necessary to perform static structural analysis and to determine the location for maximum deflection and stress induced for the structure and to ensure that the material selected, the geometry structure and the load bearing capacity are safe enough for manufacturing.

6.1Problem Description:
Perform stress & deflection analysis of the structure using ANSYS software.
The material Selected is Polyethylene as its properties matches with the PVC (in the software data). Then plot the following results:

1. Max Deflection
2. von-Mises Stress

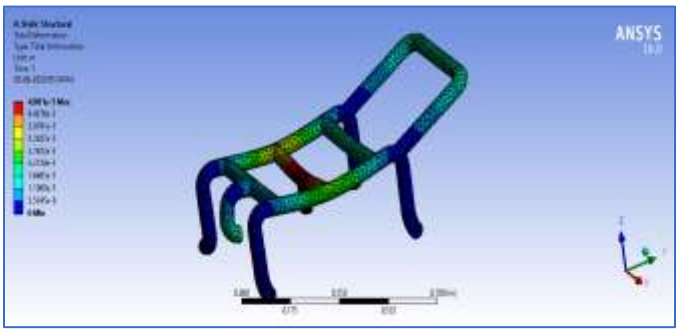

Fig 10. Total Deformation Plot

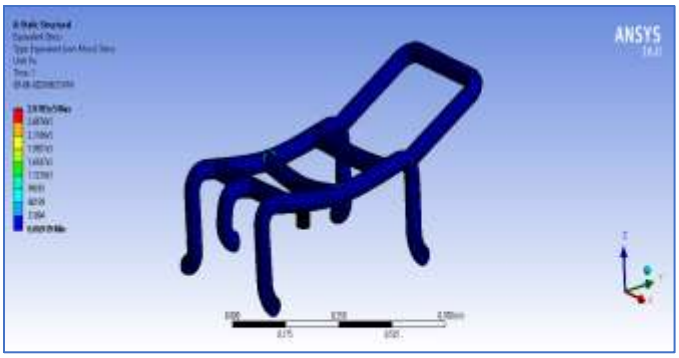

Fig 11. Von-Mises Stress

6.2 Results of analysis

Table 8. Results of analysis

Sr no	Result	Maximum
1	Total Deformation	4.981×10^{-5}m.
2	Equivalent Stress	0.3 MPa

8. CONCLUSIONS

Here we concluded the study of UNMANNED AUTOMATED LAWN MOWER with proper selection of components, analysis and design calculations. The major advantage of this project is that it not only cut the grass but also it will throw the mowed grass into the grass collector and can adjust the height as per our requirement. Our system ensures that the cost is minimized as well as it provides all those necessary features that the customer prefers. Hence its budget as well as easy to use. There is no harmful impact on the environment because the whole setup works on the Lithium Ion Battery with charger and also the grass collector which is used here is also recyclable.

This project can further be improved with Automatic blade changing warning can be provided by the Lawn Mower to the user, using geo-fencing technology the Lawn Mower can be made capable of tackling more complex boundary shapes with higher precision. boundary area calculations can be made more precise by more complex algorithm designs and estimates of time and energy required can be displayed, the Lawn Mower can be designed to complete multiple lawns in same session by travelling to the next lawn automatically using satellite tracking. Also vision based lawn mower will provide real-time view and can help in proper navigation of the lawn mower.

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