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Development of Seed Sowing Robot using Shrimp Mechanism

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Abstract. Agriculture is the prime industry in India covering over most of the land and a huge portion of the economy. It is important to provide a proper advancement in this sector for the development of the nation. Agribots are introduced to automate simple, regular tasks so that we could focus on more important work thereby saving time and money. In this study, an agribot is introduced with an automated system for the seeding process in agriculture which reduces the labor cost. The system is designed from a hilly terrain perspective. It aims to increase the efficiency of the seeding process. The paper mainly focuses on implementing a Shrimp Rover mechanism for agriculture. This enables the robot to traverse on uneven terrain. The chassis of the robot is 3D printed using a FDM printer. Aluminum extrusions are used for the links. It will be capable of moving up and down the hill. The research work deals with the development of the robot and design related analysis. Moreover, a novel seeding mechanism has been implemented in this study, it enables the rover with an efficient seeding process. The proposed design is a semi-automated rover, but a fully automated robot can be put forth in the future study. Moreover, the study of developing features such as weed cutting, irrigation, soil nutrient analysis into this robot can be implemented. The proposed design of the agribot was capable of sowing seeds one at a time at equal distances, also the rover was able to traverse through uneven terrains.

INTRODUCTION

The first and foremost step of farming is soil preparation or land preparation. The very next step is the seed sowing. It is the process of placing the seed into the soil, depending upon the type of seed, soil or land there are various seed sowing methods namely broadcasting, dibbling, drilling, seed dropping behind the plow, transplanting of seedlings, hill placement and check row planting[1].The factors such as rise in labor cost and the recent development in robotics has played a vital role in the rising demand for agricultural equipment that require less human effort and time[2-4].Automation is a requirement in industries since it not only aims to improve the quality of life for humans at home and at work, but it also allows for the speedier distribution of high-quality products and services while reducing downtime and human error[5,6]. Even though humans will still be responsible for managing a farm, simpler tasks can be automated, and this can save time up to a large extent [7]. A simple mobile robot that can sow seeds which can be easily controlled using a smartphone will help the farmers automate the farming process up to some extent. A swarm

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of such robots can plant seeds in any large farms.[8] This will save the time up to great extent. Moreover, the normal mobile rovers fail to traverse up a steep inclination and an extremely rough terrain. This is where an alternative mechanism needs to be implemented in rovers used in agriculture. One such rover mechanism is the shrimp rover.

The shrimp rover, a wheeled mobile robot, is used in this study. In terms of motion, the shrimp rover robot is akin to the marine species "shrimp." Two bogies are built on the right and left sides of the robot's body, respectively, using the rhombus design [9]. There are two wheels on each bogie. The front wheel and the rear wheel, respectively, are located in the front and rear of the rover robot. The front wheel is spring suspended to ensure that all wheels are always in contact with the ground [10]. This unique shrimp rover is a six-wheeled robot with six motors driving it. It features one front four-bar that allows it to climb over obstacles of a particular height without losing stability [11]. The parallelogram bogies on the middle four wheels balance the wheel response forces when climbing. To boost climbing capacity, the single rear wheel is attached directly to the main body and is also powered by a motor [11].

Intense research has been carried out for mobile robots in farming. N. Kumar et al., developed an agribot that could minimize the time for digging and seed sowing operation [12]. Thenmozhi Devaraj et al.,designed a robotthat could travel on a 45-degree slant and identify obstacles in front and behind it[13].Pankaj Kumar along with G. Ashok designed and fabricated a seed sowing rover that completely automates the seed sowing process[14].Hussain Nor Azmi et al., was able to achieve an increase in the crop seeding efficiency of over 35% using a mobile robot[15].A Nageswara Rao et al., created a robot that calculates distance traveled using input from wheel encoders This information is utilized to activate the seeding mechanism, which keeps the crop's inter seed distance constant.[16]. Dr. Chanda V Reddy et al., built a seed-sowing robot that can move around the field and sow the seeds. It also increases the planting efficiency and accuracy rate[17] .Saurabh Umarkar and Anil Karwankar developed a robot that can Sow seeds and digging holes. It can also move along different ground contours and execute tasks such as digging, planting seed, and closing the ground [18].

In this study, the rover is inspired by the shrimp mechanism. The rover is fabricated using aluminum extrusion and the chassis of the rover is manufactured using an FDM printer with PLA. A seed storage compartment is fixed to the chassis of the rover. A novel Seed Sowing mechanism has been attached to this seed storage compartment. This seeding mechanism assures that only one seed passes through it in each seed sowing process. Moreover, it also makes sure that the seeds are placed at equal distances at equal intervals of time. The Shrimp mechanism is used for the rover to traverse on uneven terrain.

METHODOLOGY

Description of the prototype system

The conceptual agriculture robot comprises two functions: mobility for uneven terrain and a seeding mechanism attached to the robot for seed sowing application. The robot has six wheels for maneuverability, two wheels on the front and rear end, and four wheels on the sides. An operator controls the robot with the help of the Bluetooth RC controller app. The agribot is the lightweight, optimum size, and easy to use in agriculture.

Shrimp Mechanism

The shrimp mechanism rover is implemented on the agribot for mobility ease on uneven terrain agriculture fields. The shrimp mechanism provides the ability to climb over obstacles because of its unconventional wheel configuration[1].

The shrimp mechanism consists of bogies, front fork, rear fork, and steering. Wheels are connected to bogies, front fork, and rear fork. The robot uses six outdoor rubber wheels to ensure ease of movement on different field terrains such as uneven soil and rough surface etc. One wheel on each fork and two wheels on each side of bogies. The front and rear fork have rhombus configuration; its purpose is to provide a maximum vertical height to overcome obstacles and guarantee sufficient ground contact. The bogies act as a virtual suspension system that provides optimum lateral stability during mobility. The steering front and rear wheels are controlled by MG996R servo motors, which allow accurate maneuverability and can turn both right and left on the spot with minimum slip.

The parallel structure of the shrimp mechanism provides a non-hyper static configuration for the six motorized wheels by maintaining high ground clearance. It also provides maximum stability, adaptability, and excellent climbing. The steering allows the rover to carry out a pure rotation even in extreme conditions[19].

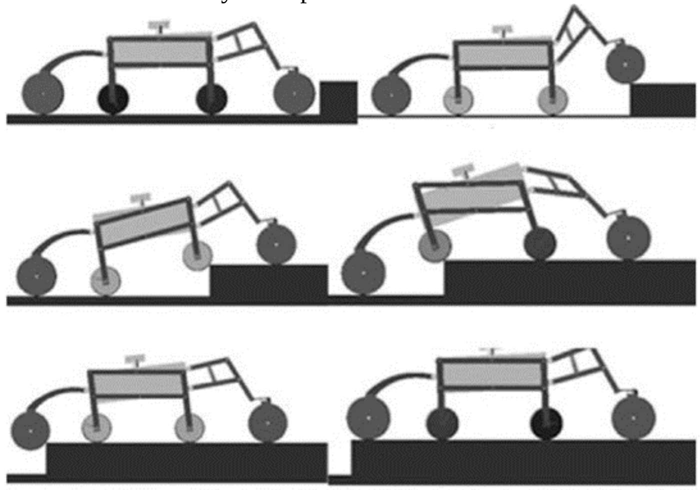

FIGURE 1 Shrimp Mechanism

Seeding Mechanism

The seeding mechanism is the most crucial function of the agribot. The construction of the seeding mechanism consists of a funnel, SG90 servo motor, lid plate, and seed compartment. Fig 2 shows the mechanism that uses the components mentioned above to effectively sow seeds one at a time and within an equal interval in the field.

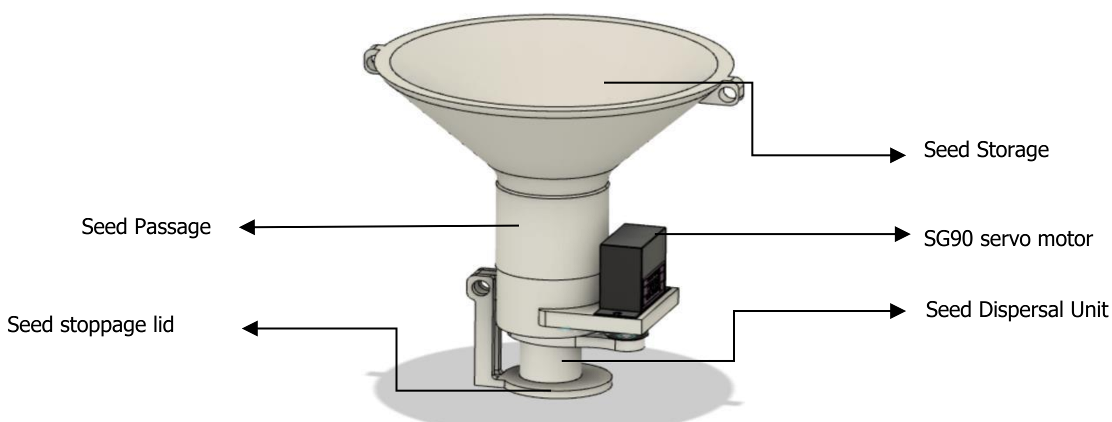

FIGURE 2 Seeding Mechanism

The funnel is the seed container where the seeds are stored, and the lid plate is attached to the funnel. The funnel has the servo mount designed where the servo is mounted. Right under the funnel, the seed compartment is placed. The seed compartment is directly joined to the servo, which acts as the main component for sowing seeds one at a time. The seed compartment has a cam profile shape lid and compartment where its volume is limited to only one seed. The purpose of thecam profile shape and seed compartment is to make the seed sowing process more efficient.

In the initial stage, the cam profile lid of the seed compartment lids the funnel to hold the seed from falling off the funnel. The servo motor provides the rotary motion to the seed compartment to perform its task. The seed compartment moves in a clockwise direction till one seed falls into the compartment.

The lid plate holds the seed till the servo moves in an anticlockwise direction. The seed falls to the field, and the process continues. With this mechanism, the seeds are sown every two seconds, and the distance between the twoseeds is 10-12cm.

The seeding mechanism was designed to accurately sow the plant seedlings one at a time, compared to the conventional seed spreaders attached to the back of tractors, thus improving the seedling germination success rate, reducing the wastage of seedlings, and achieving precision agriculture goals[21]. The agricultural robot also has two modes: an autonomous mode and a manual mode. In manual mode, the operator can control according to its preference and function. On the other hand, the automatics mode lets robots automatically perform all the preprogrammed tasks without human intervention.

Components of the Prototype System

The seed sowing robot use 6 geared D.C. motors to drive the wheels. Two motors each are connected at both sides and the front and rear arms also has one motors connected to each. The motors have an input power rating of 6 V-12 V and current rating of 2 A. These motors can produce a maximum torque of up to 5 Kg cm. The geared D.C. motors is ideal for this application as they have low speed and high torque which are the two main parameters required in this application. The D.C. motors are powered by two L298D motor driver modules. Each module can power up to 2 sets of motors. The operating voltage is 5 V and can be used to power devices of voltage rating of 5 V up to 35 V. The module receives signal from the microcontroller and these signals are used to regulate the current flow to the devices. Each module can be used to control the speed and direction of two sets of motors at a time. One module is connected to the motors at right and left side and the second module is used to control the front and rear motors.

An Arduino Uno is used as the microcontroller in this project. It is a low-cost device and is widely popular. It also supports communication using Bluetooth module. The user sends the directions via Bluetooth using a mobile application. The Arduino Uno board reads these signals with the help of a Bluetooth module. It then processes these signals and gives outputs to the driver modules and servo motors to work accordingly. The Arduino Uno can be programmed using Arduino Integrated Development Environment (IDE).

The HC05 Bluetooth module is used to receive the input via Bluetooth. The module has a 2.4GHz ISM bandwidth and in build antenna. Here the module is used in slave configuration. It is power by a 3.3 V supply from Arduino. Thereceiver and transmitter pins are connected to the Arduino.

The robot uses two types of servo motors. The first servo is MG996R. The operating voltage and current are 6V and 300mA respectively. It can produce a maximum stall torque of 15 Kg cm. This servo is used to steer the front and rear wheels.The servo turns the wheel to the desired direction by accepting input from the microcontroller. The second servo is aSG90 servo motor. The operating voltage and current are 4.8- 6V and 250mA respectively. It can produce a maximumstall torque of 1.4Kg cm. The seeding mechanism is connected to this motor. It open and close a flap at specific intervals that facilitates dropping of single seed at a time. Both the motors are connected to a 5V voltage source.

TABLE 1 Components Specifications

Components	Specification
DC motor	Voltage: 6V to 12V Current: 300mA Shaft Diameter: 6 mm Torque Range: 5 Kg-cm Speed: 30 RPM at 12V Weight: 200 g
Wheel	Diameter: 100mm Thickness: 20mm
MG996r Servo Motor	Weight: 55g Stall torque: 9.4kg/cm (4.8v); 11kg/cm (6.0v) Operating speed: 0.19sec/60degree (4.8v); 0.15sec/60degree (6.0v) Operating voltage: 4.8 ~ 6.6V Gear Type: Metal gear **Continued…….**

Components	Specification
L298N motor module	Motor driver: L298N Motor channels: 2 Maximum operating voltage: 46 V Peak output current per channel: 2 A Minimum logic voltage: 4.5 V Maximum logic voltage: 7 V Weight: 26 g
HC -05 Bluetooth Module	Bluetooth protocol: Bluetooth Specification v2.0+EDR Frequency: 2.4GHz ISM band Modulation: GFSK(Gaussian Frequency Shift Keying) Emission power: ≤4dBm, Class 2 Sensitivity: ≤-84dBm at 0.1% BER Speed: Asynchronous: 2.1Mbps(Max) / 160 kbps, Synchronous: 1Mbps/1Mbps Security: Authentication and encryption Profiles: Bluetooth serial port Power supply: +3.3VDC 50mA Working temperature: -20 ~ +75Centigrade Dimension: 26.9mm x 13mm x 2.2 mm
SG90 Servo	Torque: 2.0kg/cm(4.8V), 2.2kg/cm(6V) Speed: 0.09s/60°(4.8V), 0.08s/60°(6V) Rotate angle: 180° Operating voltage: 4.8 ~ 6V Gear: plastic. Dead band: 7us Weight: 10.5g.

Calculations

Motor Calculation

Selection of motor is very important, and this depends on the entire weight of the robot and the surface it should climb. So, the motor calculation for the 6 DC motors is given below [28]:

- Let’s assume the weight of the robot, M_R = 2.5 kg.
- Total load which could be carried by robot, M_L = 1.5 kg.
- RPM chosen for the motor is, N= 30rpm.
- Wheel diameter, D_w = 100mm = 0.1m

The rover should climb 40° on an inclined surface. So, let’s say the maximum slope incline percentage is 84%. So, the angle of incline= arctan(0.84) = 40°.

Calculation of nominal velocity (linear velocity) :

Nominal velocity,

$$Vn = \frac{\pi \times Dw \times N}{60}$$

$$= \frac{3.14 \times 0.1 \times 30}{60}$$

$$= 0.157 \text{ m/s}$$

Calculating motor power/ torque :

If we omit friction, the motor torque needed to climb on 40° inclined slope can be found out. The thrust forces needed to overcome gravity on the slope is,

$$F_T = g \times k \times (M_R + M_L)$$

where g is the acceleration due to gravity and k is the slope.

$$F_T = 9.81 \times 0.84 \times 4$$
$$= 32.69 \text{ N}$$

The mechanical power needed to move the robot uphill is,

$$P_U = F_T \times V_n$$
$$= 32.96 \times 0.157$$
$$= 5.1742 \text{ W}$$

The above power is for the entire robot. So, we have 0.86 W per one motor.
The corresponding torque for one wheel is,

$$T = \frac{1}{6} \times \frac{D_W}{2} \times F_T$$
$$T = \frac{1}{6} \times \frac{0.1}{2} \times 32.96$$
$$= 0.275 \text{ Nm}$$
$$= 2.8 \text{ Kg-cm}$$

Battery Calculation

The battery calculation for the robot is given below [29]:

1. Arduino
   Current= 200 mA
   Voltage= 5V
   Power= 200*5 = 1000 milliwatts
2. DC Motor
   Current= 300 mA
   Voltage= 12V
   Power= 300*12 = 3600 milliwatts
3. Servo Motor MG996r
   Current= 900mA
   Voltage = 6V
   Power= 5400 milliwatts
4. SG90 servo motor
   Current= 250mA
   Voltage= 6V
   Power= 1500 milliwatts
5. L298N motor module
   Current= 2A
   Voltage= 5V
   Power= 10 Watts

There are 2 motor modules, therefore $10 \times 2 = 20$ Watts

So, the total power of the whole circuit is 49.5 Watts.

Let the robot run for 30 minutes. So, if we want to run 49.5 Watts for half an hour, then we need a (49.5*0.5) Watt-hour battery. The battery will drain completely after 30 minutes. But this can damage the battery. So, let's assume that the battery should run for 30 minutes from full charge to 20%, so that the battery won't get drained completely.

Therefore, change in state of Charge×Capacity = 49.5×0.5 Watt-hours

$$\Delta SOC * Capacity = 24.75\, Wh$$
$$Capacity = 24.75 \times (1.00 - 0.2)$$
$$= 24.75 \times 0.8$$
$$= 30.94\, Wh$$

Converting Watt-hours to milliampere hour,

$$mAh = \frac{1000 \times Wh}{Voltage}$$
$$mAh = \frac{1000 \times 30.94}{11.1}$$

$$= 2787\ mAh$$

Assembly of the prototype system

The solid parts for the agribot were designed using Autodesk Fusion 360, computer-aided designing (CAD) software. The design is as shown in Fig.3 Initially the inner frame was 3D printed. The aluminum frames were cut to create the side frames. Two long links were joined by a short link in the center and the attached one side to the inner frame.

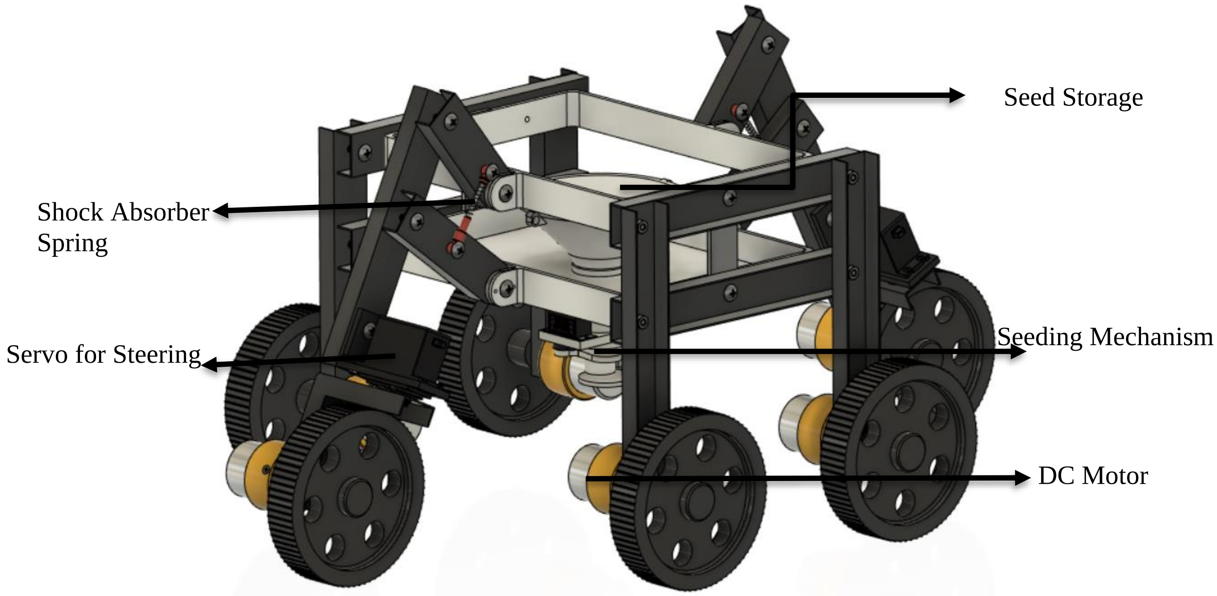

FIGURE 3 CAD Model

The ends of the long frames were attached to a long link at both the ends. All the joints were made of nut and bolts. The procedure was repeated on the next side. The wheels were attached to the free ends of the last connected links. These joints ensure that each side wheels are independent of the other side and the inner frame, with sufficientweight will remain upright.

Two aluminum links each were then joined to the extension from the front and rear end of the inner frame. A spring suspension was installed between the links. Out of those links one link is larger than the other. These links were further connected to a long link at each side. This setup ensures maximum freedom of movement for the front and rear wheels while hovering over obstacles.

A specially designed and 3D printed L-shaped clamp is used to attach the servo motors to the front and rear links. The servo motors are then connected to a gear which is fixed to another L clamp that holds the wheels. The servo motor rotates the wheel arm. This is a part of the steering mechanism. All the links are joined using nuts and bolts.

The geared D.C. motors are connected to wheel ends of the links. The wheels are then connected to the motors. The power to the wheels is regulated by two L298N motor drivers. The motor drivers receive input from the Arduino Uno microcontroller.

The microcontroller accepts the user input via using a Bluetooth module and process the input. It sends control signals to the motor driver and servo motors to move and steer the robot. The microcontroller is programmed to perform the foresaid task using Arduino IDE. The robot in manual mode can be controlled to move forward backward left and right. In the Automated mode the robot travels forward and disperses seed at constant intervals.

The Arduino is powered by a power bank. A pack of three 3.7V lithium-ion (Li-ion) batteries connected in series is used to power the motors. The total output of the battery is 11.1 V with a capacity of 2600mAh. The Lithium-ion battery is a rechargeable battery that uses lithium-ion technology using a polymer as electrolyte. The lithium-ion batteries have good battery life and are light weight.

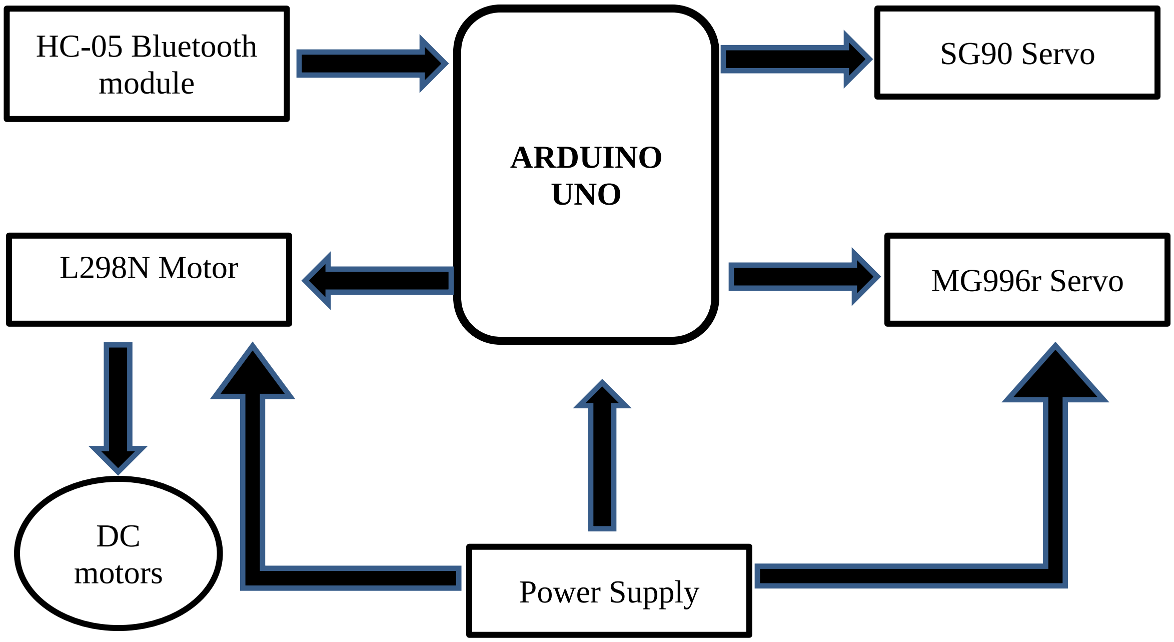

FIGURE 4 Block Diagram

Testing Procedure

The primary objective of the agribot was to disperse seed at uneven terrains. Therefore, the prototype was initially tested for its durability. It was controlled manually and hovered through different terrains. As shown in Fig.10, the robot was tested on inclined surface with slope over 45°. The robot was also tested on uneven surface where either side had to be at different slopes or heights. The robot's movement through such uneven surface is shown in Fig.5

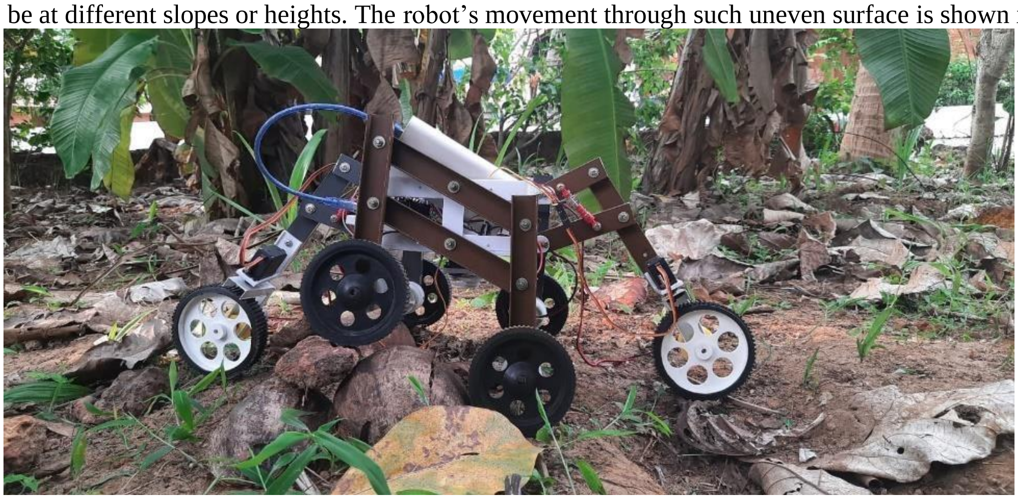

FIGURE 5 Rover on uneven Terrain

The seed dispersal is next put to test. The robot is put on automatic mode where it travels in straight line and halts after traveling for 1 sec and disperses the seed. The average speed of the robot is about 0.1m/s. Thus, every 1sec it travels over a distance between 10 cm to 12 cm. Thus, each seed is falls 10 to 12 cm away from each other. This gap is ideal for plants to ensure optimal growth and effective space management.

After a lane is completed, the robot can be changed back to manual mode. The user then directs it to next location and is again put back to automatic mode for speed dispersal.

The robot is next tested to determine its battery life. The batteries were charged to 100%. The robot was filled with seed to find the battery usage at the worst cases scenario. The robot was continuously used both in manual and automated mode till its battery was fully drained. The robot travelled through multiple terrains similar to the earlier test cases. The battery lasted for 46 minutes.

RESULTS AND DISCUSSION

Structural Analysis of Critical Components

Structural analysis of the agribot was performed to examine the strength of the structure and to ensure that the design of the rover is robust enough to withstand the payload. The chassis of the rover was made of PLA , whereas the links are of Aluminum alloy used for fabrication. The weight of each component used for the fabrication of the rover is mentioned in table 3.1. The structural analysis on the crucial components of the agribot's final model was carried out. These include each individual links and frames. out. The analysis of the model was carried out in inbuilt simulation workspace of Autodesk Fusion 360. It analyzes the deformation and stress into the model from structural loads and constraints. From the results, displacement, stresses, and common failure criteria are investigated. The results are calculated based on assumption of linear response to the stress. The relation W = mg was used to find out the Vertical Ground Reaction Force for the proposed design of the agribot. Here, 'W' is the ground reaction force, 'm' is the weight of each component, links, and the payload(here Seed) and 'g' is the acceleration due to gravity. Considering the maximum permissible payload to be 5 kg, the Vertical Ground Reaction Force was found to be 50N for the analysis purpose. Von Mises Yield Stress method was used to analyze the proposed design. The results of yield stress, along with the deformation, Reaction Force and strain, are presented in Fig.6 to Fig.8.

Fig.6 represents the safety factor of the rover.The proposed design of the agribot was able to achieve a minimum safety factor of 4.45. This ensures that therover can handle the provided payload without any failure moreover it can withstand much larger load than 4kg , but design specifications is limited to 4Kg for the smooth working of the rover and appropriate energy consumption.

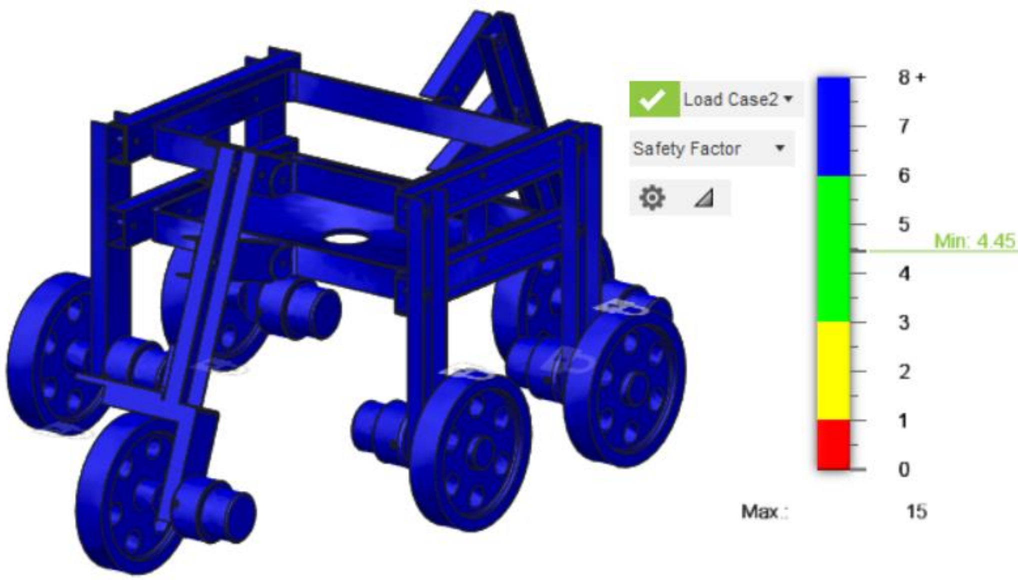

FIGURE 6 Safety Factor of the Rover

Fig 7 depicts the Von Misses stress on the proposed design for the given boundary conditions .The wheel is fixed and an overall payload of 40N acts on the chassis of the rover. The design analysis shows a safe value of stress. Maximum Von Missesstress was found out to be 33.85 Mpa.

The deformation (Fig.8) due to the applied load was also studied for the model. The deformation is negligible for the given boundary conditions and is safe. It has a maximum deformation of 0.5097 mm. This also means than it is safe with heavier payloads. The study further shows maximum reaction force of 1.131 N on the wheels.

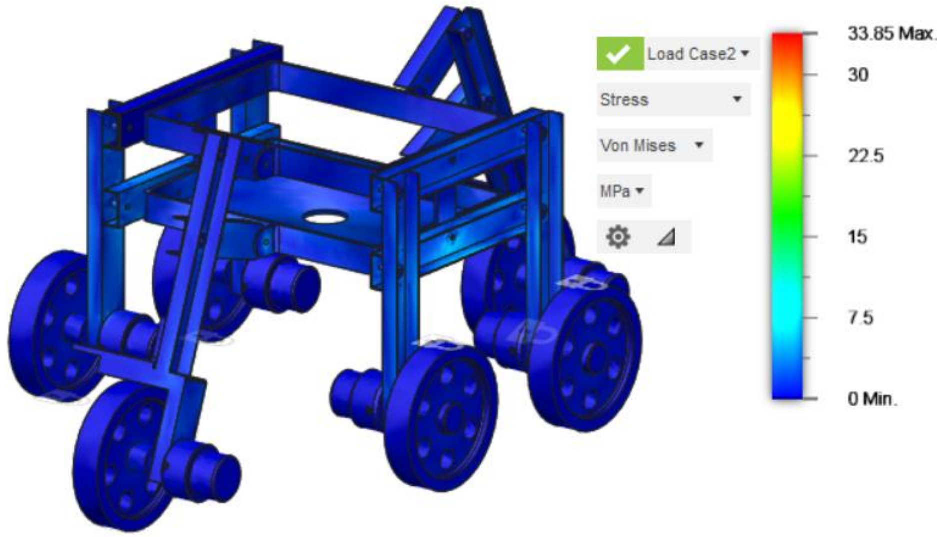

FIGURE 7 Von Misses Stress

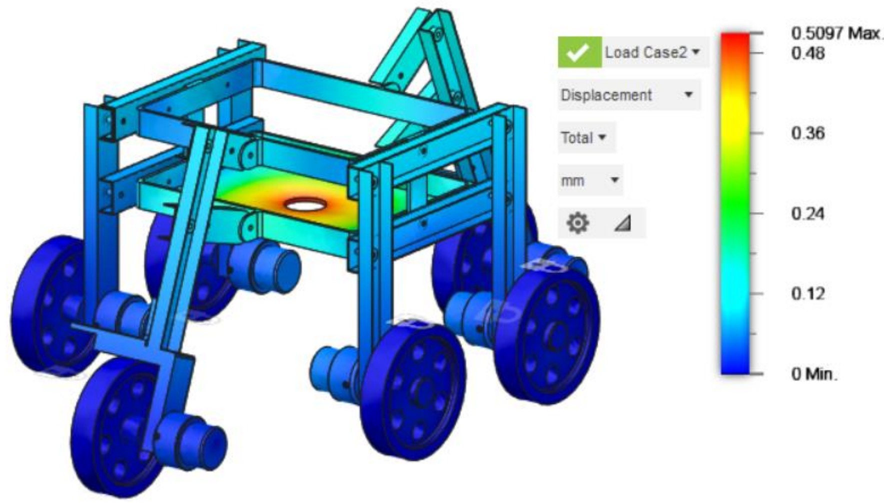

FIGURE 8 Deformation of the Rover

The properties of each material used for the fabrication of the rover is listed in Table 2.

TABLE 2 Material properties (Autodesk Fusion 360)

Properties	Aluminium	Steel	PLA Plastic
Density	2.7E-06 kg / mm^3	7.85E-06 kg / mm^3	1.14E-06 kg / mm^3
Young's Modulus	68900 MPa	210000 MPa	2100 MPa
Poisson's Ratio	0.33	0.3	0.36
Yield Strength	275 MPa	207 MPa	2.94 MPa
Ultimate Tensile Strength	310 MPa	345 MPa	28.1 MPa
Thermal Conductivity	0.23 W / (mm C)	0.056 W / (mm C)	1.6E-04 W / (mm C)
Thermal Expansion Coefficient	2.36E-05 / C	1.2E-05 / C	8.57E-05 / C
Specific Heat	897 J / (kg C)	480 J / (kg C)	1800 J / (kg C)

Crop-Seeding Test

To evaluate the performance of the seeding mechanism and to ensure that only one seed drops at a time, a seeding test was performed. For the test, coffee seeds are used as the size of the seed is considerably large so that it can be easily visible, the number of seeds that fall on the ground. Separate channels were made on ground, where theseeds are to be sown. The robot is then driven to the starting position of the channel, Fig.8, and then automatic modeis activated. Then after, the number of seeds dropped each time and distance between the seeds are noted. It was noticed that only one seed is dropped at a time and the distance between two seeds is 10cm -12cm, Fig.9.

FIGURE 8 Initial Position

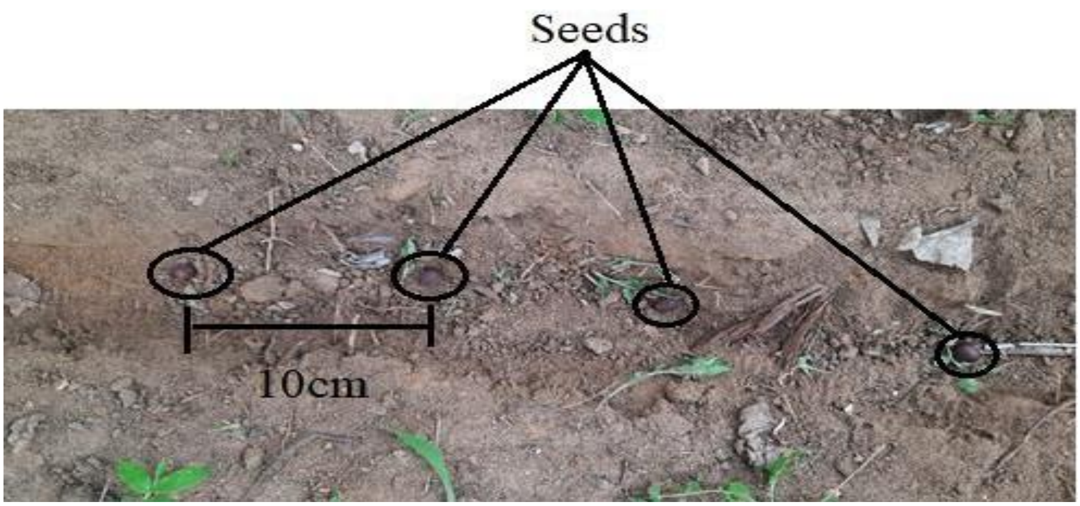

FIGURE 9 Distance between seeds after sowing

Inclined Surface Test

The robot must be able to adapt to rough terrain by climbing at least a 40-degree inclination. To ensure this, an inclined surface test is performed using the robot. For this test, a slope of around 40 degrees is created on the ground. The robot was then made to climb a slope, and it was dislided that it can readily ascend a 40-degree slope. Then, the slope angle was further increased to 45 degrees, and the test was repeated. The robot was able to effectively scale the slope, Fig.10. This is since the torque of the chosen motor is more than the predicted torque as a precaution.

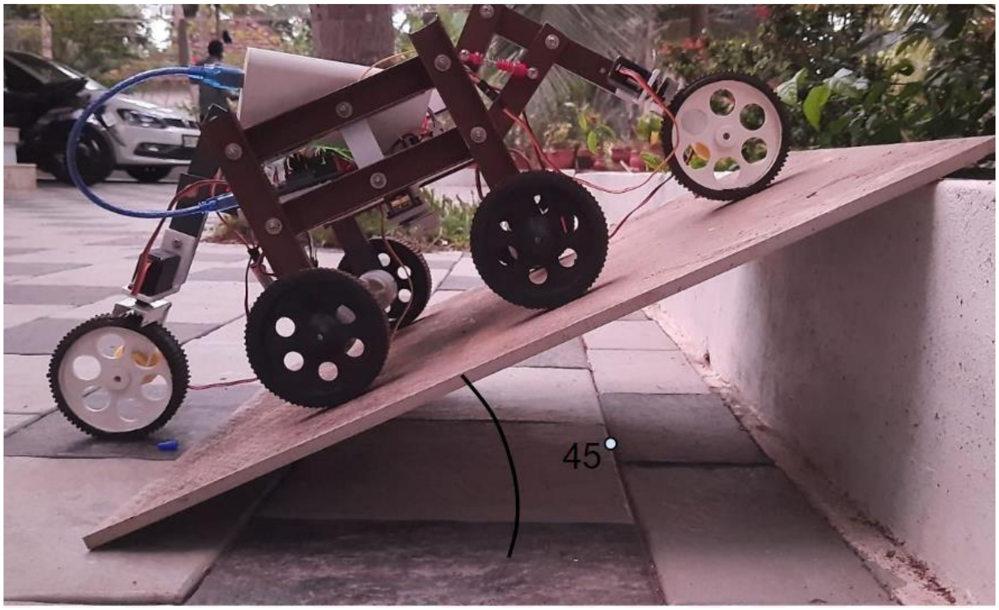

FIGURE 10 Seed sowing shrimp rover climbing a 45° inclined plain

Battery Life Test

To evaluate the robot's overall working time, a battery life test is performed. For the test, all three batteries are fully charged, and the robot is allowed to run indefinitely until the battery dies. The robot ran for 46 minutes in automated mode from full charge (100%) to 0% charge, demonstrating that the robot has a long battery life and provides adequate running time.

CONCLUSION

A remote-controlled seeding robot using shrimp mechanism has been developed in this paper. The rover part usesa Shrimp mechanism. The front, rear, right side and left side wheels are completely independent of each other and thus can hover through uneven or inclined surface with obstacles. The front wheel has a steering mechanism and a active suspension setup. A servo-based mechanism is used to separate the seed and dispense the seed at regular intervals. Further proximity sensors and accelerometers can be installed in the robot. This helps to better identify obstaclesand pass more power to the motors only when needed. It also opens a possibility for automated mode where the robotworks without human intervention and auto detects the boundaries. The accelerometer can be used to measure the distance lided and thus seeding can be dispersed at more accurate distances. The Front and Rear arms may lose ground contact at certain cases. This can be avoided by using a stiffer suspensionsetup. This ensures the arms has a larger movement arc and thus can hover through more difficult terrains. A better seeding system using pneumatic devices can be introduced to avoid wear on seed due to contact from mechanical moving parts. This increases the chance of seed germination. The range of Bluetooth communication is over 5 meters which may not be enough for all practical applications. Thus, a RF wireless communication system can be used to get a better range of communication over 100m and morein certain cases. These limitations will be resolved in the next research study.

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