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Development and Performance Evaluation of a Robot for Lawn Mowing

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Abstract

Artificial Intelligence (AI) through robotic system offer solutions to the quest for autonomous system with high cutting efficiency for lawn mowing. This work discusses the design, fabrication as well as the performance evaluation of a prototype robot for lawn mowing. The Auto-desk Inventor 2018 was used for the computer aided design and simulation of the automatic lawn mower. The electrical circuit connections between the microcontroller and the rest of the electrical systems was also designed with the aim of producing a system that can cut grass at high efficiency with little or no human intervention. The machine was incorporated with GPS, cameras, infrared and ultrasonic sensors for the detection and avoidance of obstacles. The control systems comprises of the Arduino micro-controller which controls the two geared motors alternatively in order to control the direction of the lawn mower. This is done according to the readings from the sensors governed by the C-programmed instructions fed into the micro- controller. The fabrication of the robot was done with the combination of machining and assembly operations in the machine shop and the results obtained from the performance evaluation indicated that the developed robot can autonomously avoid obstacles, make 180 degree turn and cut a lawn to an even height at high efficiency. Hence, this work provides a self-governing lawn mower that can cut grass at high efficiency and avoid obstacles thus minimizing human drudgery.

Keywords: actuators; control systems; microcontroller; robot; sensors

1. Introduction

A lawn mower is a machine which employs a revolving blades to cut a lawn to an even height. The lawn mower which employs a blade that rotates about a vertical axis are known as rotary mowers, while those which uses a blade assemble that rotates about a horizontal axis are known as cylinder or reel mowers [1-3]. Lawn mowing is the process of trimming grasses to a specific height usually for sanitation, decoration or for sport purposes. Various grasses, cutting equipment have been developed over the years, such as cutlasses, reel-blade grass cutter, spiral-rope cutter, gas powered mower and so on but they pose some challenges relating to drudgery and operational efficiency. A lawn mower is not just a tool like a cutlass or a scissors but a machine which consists of integrated mechanical and electrical systems with an effective control system. Lawn mowing machines can be powered electrically, with gas (petrol or diesel), or with the use of solar system at different levels of automation ranging from manual to semi-autonomous and fully autonomous systems. The ones powered with petrol or diesel in a combustion engine are characterized with high cutting performance but are relatively noisy with emissions which contributes to global warming. In the case of a solar powered automatic lawn mower, an additional control system is often introduced in order to automate and make it a complete mechatronics machine [4-6]. Solar powered grass cutters are machines which uses the solar energy to power an electric motor which rotates a blade that performs the cutting operation. In addition to this, a rechargeable battery is usually incorporated to save energy and reduce the

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amount of solar panels to be used because of the cost implication [7-9]. Solar energy is commonly and easily harnessed in the tropical regions because of the longer sunshine experiences compared to non-tropical regions. The main challenge however lies in the collection and conservation of the renewable energy coupled with the high and prohibiting initial costs of capital to set up a small scale solar station. But the most promising part of it all is the continued decrease in prices of solar tapping equipment over time as more technological improvements emerge with time. On the other hand, the set up cost of the electrically powered lawn mowing machine is cost effective compared to the solar powered system and it often boast of higher availability considering the fact that solar power may not be adequately harnessed for use during some period of inadequate sunshine [10-12]. Some works have been reported on the development of lawn mower. For instance, the CWRU is a grass cutter robot that captures and processes incoming images using a 1.83 GHz runs on Windows XP operating system with 4GB memory. Efficient computations and robust obstacle identification methods were used in this robot based on image hue and intensity [13-16]. Deranda *et al.* [17] developed a smart robot lawn mower which does not require boundary cable for its operation in order to reduce the cutting cycle time and operational cost. Ahamed and Ziauddin [18] developed a small scale electric lawn mower while Tanimola *et al.* [19] developed a solar powered lawn mower which can harness the potential of solar energy as a renewable source. In addition, Namoco *et al.* [20] developed a mechanical push lawn with double cylinder for blade spinning in order to increase the system's capacity and operational efficiency while Moore *et al.* [21] performed the measurement and analysis of a lawn mower in terms of its performance and noise level. Many other works have been reported on the development of autonomous lawn mower and systems which requires the installation of boundary wire around the perimeter of the lawn area to keep the machine within the predetermined area and path to be cut [22-24]. Additionally, some existing mowers use a random path which requires more time to mow with low cutting efficiency and do not produce the typical even and clean mowing lines which characterizes a well aesthetically manicured lawn. Furthermore, some existing lawn mowers operate semi autonomously relying on human intervention for some degree of operation, thus, increasing the cutting cycle time, human drudgery and labour cost. Some of the electrically or gas powered systems were developed without incorporating a solar power system for harnessing the renewable energy of sunshine thereby reducing its sustainability. This work brings about the development of a robot that cannot only mow a lawn autonomously, but also navigate in a straight parallel paths. In addition, since solar energy is green and renewable energy, the lawn mower is designed to utilize electrical energy with the solar power system as an alternative energy source which is meant to address a number of limitations of the systems that rely solely on electrical energy. Most importantly, there is a need to harness its clean and green potential while minimizing the emissions which are mostly responsible for environmental pollution and the greenhouse gases effect believed to be responsible for the worsening global warming [25]. The developed robot was also fitted with camera, GPI, IR and ultrasonic sensors to enhance its independence of operation and its ability for quick detection and avoidance of obstacles. It has the ability to make navigation decisions by spinning around its own axis in order to avoid obstacles. This robot is self-propelling, environmentally friendly, cost effective, simple to use and maintain, has high operational efficiency as well as good navigation and control abilities which makes it suitable for use in various lawns including hazardous, dangerous or difficult to reach areas for mowing. One of the peculiarities of the robot is that the user can configure the GPS to some predetermined area and can regularly probe its current location and coordinates via the android application. This enhances effective communication with the user and also makes the process of its tracking easy both within and off the site. The development of a robot for lawn mowing with the aforementioned peculiarities has not been widely reported by the existing literature.

2. Methodology

The design consideration takes into account the cutting force, blade torque, power requirement for motor, and speed of cutting amongst others. The motor which enables the robot to move around the lawn is selected based on the number of revolutions per minutes as well as the maximum and minimum torque required. High number of revolutions per minute will enhance good robot speed while high torque will be needed to sufficiently power the motor.

Due to the size of the robot ($250\ mm \times 150 \times 75\ mm$), the blade torque is calculated using Equations 1 and 2 while the power requirement of the motor was determined according to Equations 2 and 3.

2.1 The blade torque

The frictional force (F_f) on the grass is calculated as $0.04\ N$ from Equation 1.

$$F_f = W.\mu \quad (1)$$

Where W is the weight of the blade ($0.4\ kg$) and μ is the coefficient of friction (0.1).

The blade torque is calculated as $0.01\ N.m$ using Equation 2.

$$T = F_f.r \quad (2)$$

Where; F_f is the frictional force on the grass ($0.04\ N$) and r is the blade radius ($0.250\ mm$)

2.2 Power required

The power required for the motor is expressed as Equation 3.

$$P = T \times \omega \quad (3)$$

T is the torque measured ($0.01\ N.m$) and ω is the angular speed in rad/sec.

The angular speed ω is expressed as Equation 4.

$$\omega = \frac{2\pi N}{60} \quad (4)$$

For no load speed, the number of revolution per minute $N = 10000\ rpm$

$$\omega = \frac{2 \times \pi \times 10000}{60} = 1047.333\ rad/sec$$

$P = 0.01 \times 1047.333 = 10.47\ W\ \ (0.01047\ kW)$

For maximum efficiency speed, $N = 8000\ rpm$

$W = \frac{2\times\pi\times8000}{60} = 837.866\ rad/sec$

$P = 0.01 \times 837.866 = 8.37\ W \quad (0.00837\ kW)$

Using a safety factor 2.5, a $12V$ DC motor will be sufficient for the intended operation.

2.3 Robot distance from obstacle

To obtain the distance (S) of the robot from an obstacle, Equation 5 holds thus,

$$S = V_0^2 + 2a(x - x_o) \qquad (5)$$

Where; V_o *is the robot speed* (m/s), a is the acceleration due to gravity (m/s^2), $x - x_o$ is the change in distance (m).

The design of the obstacle avoiding lawn mowing robot involves different sub-systems which are necessary to enable the robot accomplish its primary task. The major sub-systems that make up this robot include; power supply unit, IR LED / receiver sensor pair, ultrasonic sensor, Arduino microcontroller (ATmega328), memory card, Raspberry Pi camera, Global Positioning System (GPS), switch and the geared DC motors. The infrared sensor is light and relatively inexpensive but its sensitivity sometimes can be influenced by external factors, hence, for precise detection of obstacles, it was used in combination with an ultrasound sensor which is also light and inexpensive but not subjected to external influencing factors.

The Raspberry Pi camera was employed to detect changes in the images within the lawn while the GPS coordinates was used to create and detect the lawn boundary as this will assist the robot in its directional movement along the predetermined area within the lawn marked for the cutting operation. In addition, it will also assist in its decision making concerning navigation and path planning. The raw image is captured and analysed through a colour algorithm in order to decide whether the objects engaged are grasses or not. This will assist the robot in taking decision on whether to cut, turn or move forward. The power supply unit consists of a 9 V volts battery inside the robot connected to the microcontroller and two rechargeable 6 V batteries connected in series to power the motors. The microcontroller provides power for the sensors which is used in accomplishing the task of obstacle avoidance and path planning of the geared DC motors. The IR LED/ receiver unit is made up of an IR LED and an IR receiver placed in parallel to each other. While the IR LED emits light in the forward direction, the IR receiver would receive the reflected IR light. If there is an obstacle ahead of the robot, the ultrasonic sensor will provide the path planning which in this case is a helix path from one end to another across the lawn until it covers the entire lawn. This is achieved with the aid of the ultrasonic sensor which detects the pavement of the boundaries of the lawn by producing a sound which is reflected back and received by its piezo speaker. This information is transmitted together with the range of the detected obstacle to the microcontroller. The motor takes its power supply from two rechargeable 6V batteries connected in series to form a 12 V power source. The microcontroller sends series of pulses from its PWM pins which determines how fast the motor would rotate. All sub-systems are connected to ensure easy flow of communication between the various subsystems of the robot designed. This robot is built using ATmega328, IR and ultrasound sensors, motor driver (L293D) and aluminium chassis. The choice of aluminum stems from the need to ensure a light weight system and energy conservation [26]. At the front, it has IR sensors to detect any obstacle ahead and send signal to microcontroller for accurate control and steering of motors. The microcontroller (ATmega328) and motor driver (L293D) are used to control the motors.

2.4 Fabrication and performance evaluation of the robot

The fabrication of the robot was done in a machine shop using the combination of machining and assembly operations involving cutting, drilling, punching, screwing and bolting. The following mechanical tools were used to fabricate the robot: 4 mm HSS drill bit, hand hack saw, screw driver, center punch, marking out tool etc.

The flow chart for the operation of the entire robotic system is shown in Fig. 1.

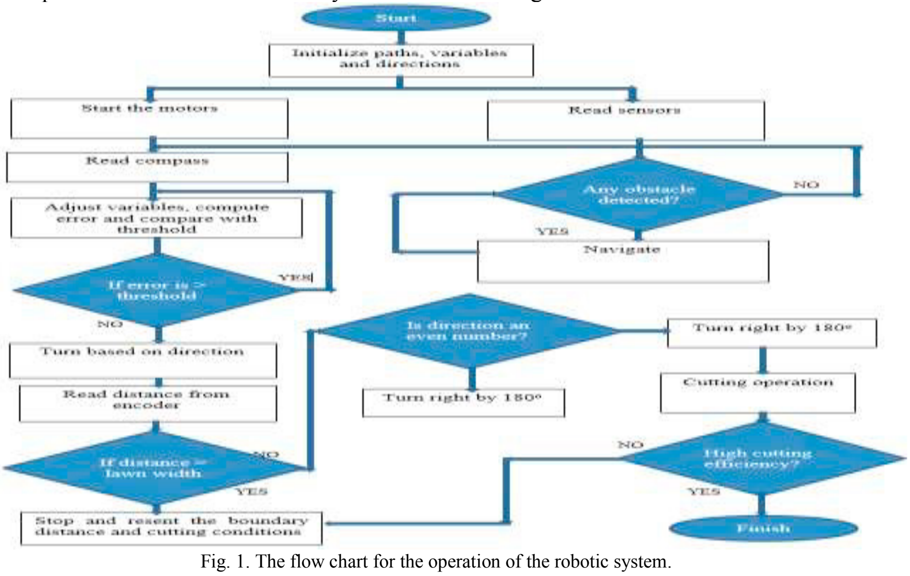

Fig. 1. The flow chart for the operation of the robotic system.

From Fig. 1, the operation of the lawn mowing robot starts by initializing the path, variables and direction it is expected to follow. The motor is powered by two rechargeable 6V batteries connected in series to form a 12 V power source. The magnetic compass takes readings relating of the turn angle and movement of the robot in order to enhance its navigation ability. The magnetic compass which consists of a magnetized pointer marked at the north end is aligned with respect to the earth's magnetic field. It also has a magnetized needle which enables it to turn freely upon a pivot. As soon as the magnetic field exerts a torque on the magnetized needle, the needle will simply move so that one end of this component is pulled toward the earth's south magnetic pole while the other is pulled towards the north magnetic pole. The compass readings is compared with the threshold on the micro controller to provide adjustment of the variables in real time once the obtained measurements falls below or exceeds the threshold values preset on the micro controller. The smart sensor also detects the presence of an obstacle and in case there is an obstacle, the sensor will provide a path planning which will assist the robot to navigate. The performance evaluation was carried out in order to determine the sensitivity of the sensors and camera as well as the accuracy of the GPS and the ability of the robot to turn at 180^o. The results obtained are explained under the results and discussion section.

The isometric view of the developed lawn mower as well as its associated part list is shown in Fig. 2 and Table 1 respectively while Fig. 3 shows the developed automatic lawn mowing robot. The choice of aluminum as the material for the robot chasis development stems from its excellent lightweight to strength ratio which reduces the power consumption of the system, thus, making it more sustainably economically and environmentally. Aluminum also boast of good ductility; corrosion resistance, high electrical conductivity and easy deformation without failure.

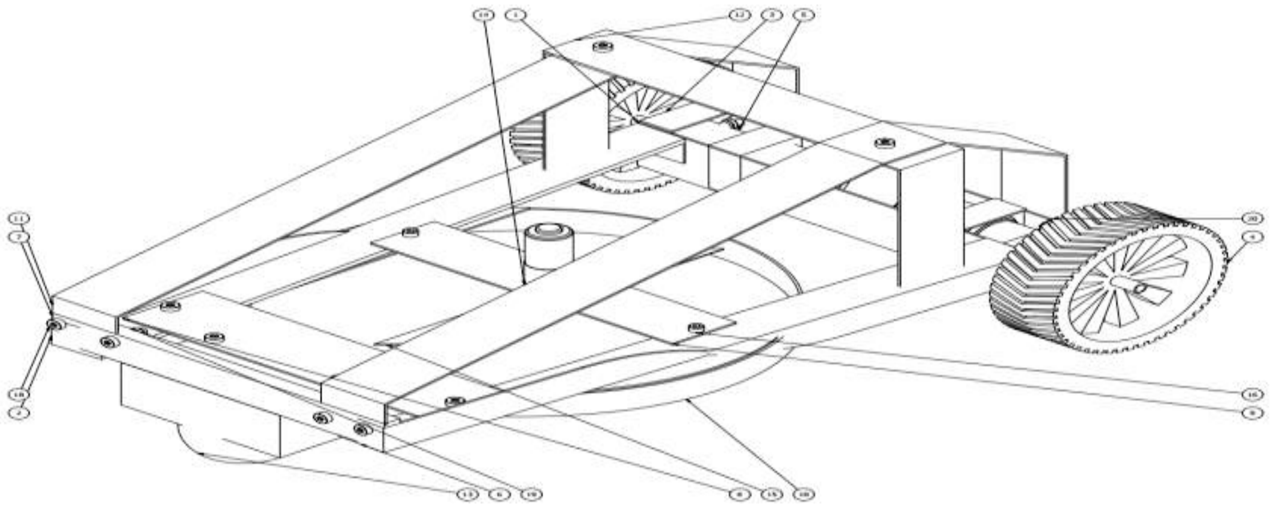

Fig. 2. Isometric view of the lawn mower.

Table 1. The component partlist.

No	Qty.	Part no	Remarks	No	Qty.	Part no	Remarks
1	1	A	Aluminium plate	11	2	I	Aluminium plate
2	1	B	Aluminium plate	12	1	J	Aluminium plate
3	4	C	Aluminium plate	13	1	Caster	
4	2	Tire		14	1	638252	116 RPM precision planetary gear motor
5	2	638255B	Planetary gear motor	15	1	K	Aluminium plate
6	1	D	Aluminium plate	16	2	BS 4168-M4×6	Hexagonal socket head cap screw
7	1	E	Aluminium plate	17	1	NF E 25-130-M5×20	Screws with conical spring, tightening washer, product grade A
8	1	F	Aluminium plate	18	13	NF E 25-130-M5×10	Screws with conical spring, tightening washer, product grade A
9	1	G	Aluminium plate	19	7	CNS 4315-M 5	Hexagonal domed cap nuts
10	1	H	Aluminium plate	20	4	CNS 4315-M4	Hexagonal domed cap nuts

Fig. 3. The developed automatic lawn mowing robot.

The fabrication of the robot was done with the combination of machining and assembly operations. The developed obstacle avoidance automatic lawn mowing robot is shown in Fig. 3 during its performance evaluations.

3. Results and Discussion

The Micro IDE software from BIPOM was used to compile 8051 based programs with the code downloaded to the microcontroller. In order to test the parameters, programs were written for each sensor separately to interface them with the microcontroller. Once the shaft encoder, proximity sensor, magnetic compass and the motor controller were interfaced with the microcontroller, the main code was written where all these sensors were combined to move the robot in a straight path and make a 180 degree turn.

To validate the performance of the robot, the sensitivity of the sensors and camera as well as the accuracy of the GPS and the ability of the robot to turn at 180° were determined. The accuracy of 180° turning was also evaluated. Ten trial runs were made iteratively with the robot which was programmed to make 180 degree turn on a lawn and the actual angle turned was measured (Table 2).

Table 2. Results obtained for the distance to obstacles avoided and the turn angle.

Trial	Distance to obstacles avoided (m)	Turn angle (deg.)
1	0.5	179.5
2	0.65	180.5
3	0.67	182
4	0.8	178.2
5	0.54	181.8
6	0.45	177
7	0.48	184
8	0.7	175
9	0.6	184.5
10	0.55	176

Fig. 4 and 5 show the results for the distance of the obstacles avoided and turn angle made by the robot respectively. The sensors were highly sensitive to obstacles causing the robot to stop and turn at an average distance of 0.6 m before an obstacle. The average turn angle obtained for the trial runs was 179.85 degrees with a standard deviation was 3.28 degrees. This implies that the developed lawn mowing robot possesses excellent navigation ability which makes it to autonomously identify an obstacle ahead and make necessary adjustment by turning to avoid the obstacle.

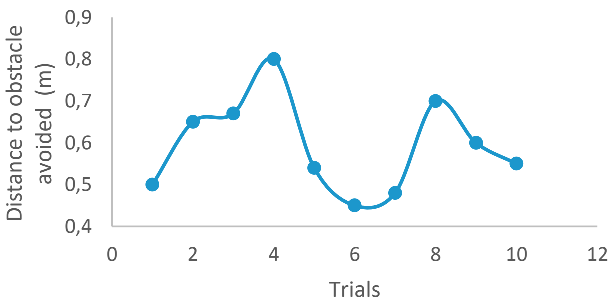

Fig. 4. Plot of distance to obstacles for 10 trials.

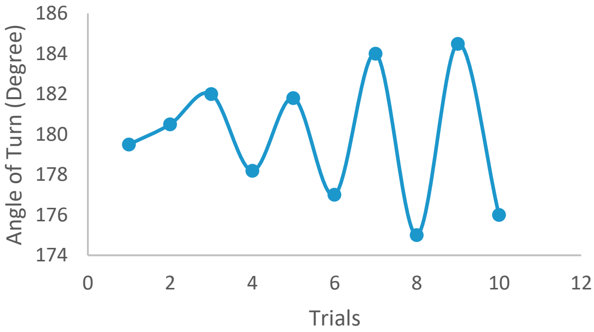

Fig. 5. Plot of actual turn angles for 10 trials.

Furthermore, 50 different images were taken and stored in the camera at different locations on the lawn. These were compared with the output of the camera algorithm and the results obtained from the comparative analysis indicate that the algorithm was very precise and accurate. The algorithm indicated the capacity to recognise 46 images and obstacles that need to be avoided out of the 50, signifying 92% accuracy while showing tendency to avoid four other images that should not be avoided (other type of grasses). This implies that the Raspberry Pi camera employed to detect changes in the images within the lawn is highly sensitive. In addition, the GPS could sufficiently detect the lawn boundary and create an artificial border by marking out a rectangular lawn using its coordinates, thus, assisting the robot in its directional movement. A GPS coordinates was mapped to identify the border of the field and its vision system was used to locate the boundary lines and provide the necessary feedback for the subsequent lines or path. This implies that the robot's vision system and the GPS is highly effective thereby contributing significantly to the independence of the system in performing the required operation. A circuit of the field was completed whenever the LRF finds the fence. A combination of LRF, GPS, and odometry data was then used to continue circuiting along the marked zone until sensor data identifies the moving obstacle or the flower bed (object not to be cut). The performance evaluation of the developed robot was further carried out in the virtual environment where the robot demonstrated excellent movement, good perception of the environment, excellent navigation ability. The cutting pattern steps of the developed robot is shown in Fig. 6.

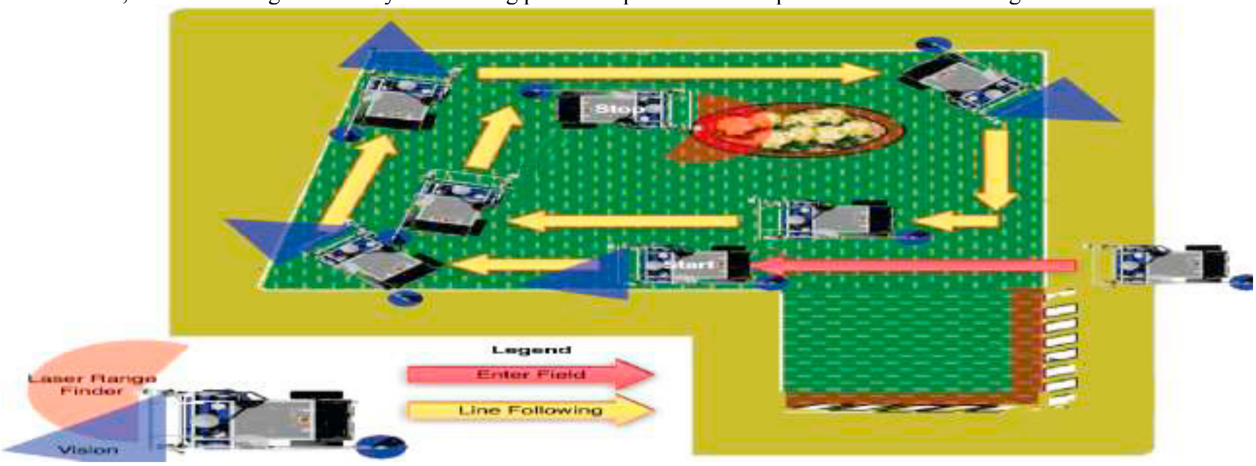

Fig. 6. Movement and the cutting pattern test.

These results indicate that the developed robot can follow a well predetermined path and autonomously make decisions regarding path planning. The robot can approximately turn 180 degree to avoid obstacles and cut a lawn to an even height with high cutting efficiency. A typical even cut and clean mowing lines which characterizes a well aesthetically manicured lawn was obtained for the different lawns having different grasses at a short cutting cycle time without human intervention during the operation. Upon proper configuration of the GPS to some predetermined area, users can regularly probe its current location and coordinates via the android application which enhances effective communication with the user off the site.

4. Conclusion

The robot developed for lawn mowing met the design criteria as well as the required service and functional requirements with its degree of automation, precision of the sensors, cameras and GPS. The results obtained indicated that the developed robot could independently identify images, avoid obstacles, make a 180 degree turn and cut a lawn to an even height. Hence, this work provided a self-governing robot that can cut grass and avoid obstacles thus minimizing human drudgery. Also, some of the materials used for the development of the robot were sourced locally which makes the system highly cost effective. Furthermore, the choice of high strength and lightweight aluminum results in significant weight reduction which reduces the power requirement of the system, thus, enhancing its economic and environmental sustainability. In addition, its ability to utilize electrical energy and solar power system as an alternative energy source is an improvement over existing designs. Future work should consider the elimination of the magnetic compass for the angle of turns measurement. Placing the shaft encoder in a more protected location would also be a good improvement over the current design which leaves it exposed and prone to damage. The findings of this research will assist robot manufacturers in the development of a robot with excellent navigation and control abilities which is suitable for use in cutting various lawns including hazardous, dangerous or difficult to reach areas.

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