Journal of Engineering and Applied Scientific Research
Volume 17, Number 1, 2025
ISSN: 2384-6569
http://www.cenresinjournals.com

Development and Comparative assessment of a Low Power Robotic Mower Using Internet of Things (IOT) against Conventional Electric Powered Mower

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ABSTRACT

The design and development of a low-power robotic lawn mower employed the user's needs-centered approach to identify the need for a low-power robotic mower. The system comprised of three build phases: mechanical fabrication, building of electrical circuit, and software development, which involved programming using C and C++. The developed system was tested by comparing it with conventional electrical mowers on mapped-out dry and fresh fields under similar test conditions. The result of the assessment showed that the developed mower completed the dried and fresh fields under 348 and 306 seconds, while the conventional mower completed the same field under 127 and 78 seconds respectively. The effective capacity, speed of operation, cutting efficiency, and performance index of the robotic mower were recorded as 0.0086 and 0.010 m^2/s, 0.0057 and 0.0049 m/s, 65 and 60%, and 0.47 and 0.50 under dried and fresh grasses, respectively. Meanwhile, the conventional mower showed operational speeds of 0.016 and 0.019 m/s, cutting efficiency of 95 and 90%, and performance indexes of 0.224 and 0.342 for dried and fresh grass conditions, respectively. The better performance of the conventional mower was a function of its higher input power of 1000 watts compared to the low power of 120 watts of the developed robotic mower.

INTRODUCTION

Lawn mowers are machines conceived and designed for the primary purpose of cutting grasses on lawns as a replacement for the laborious use of machetes (Dutta et al., 2016). This contemporary device plays a vital role in keeping our environment tidy and trimmed. It is applicable in various sectors and industries, such as agricultural fields, gardens at homes, golf fields, football fields, cricket fields, and other places where grasses are grown purposefully or as weeds. Due to various designs, lawn mowers are classified based on various parameters, such as the axis of blade rotation and the source powering the system. Based on the axis of rotation, we have the horizontal axis blade rotation mowers, which are mostly available with revolving cylinders and perform better using scissors action compared to the vertical axis blade rotation mowers, which cut grasses by rotary motion (Soyoye 2021, Dutta et al., 2016). On the other hand, power source-classified mowers are powered by hand driving, gasoline, or electricity. Previous studies show that mowers are classified by various researchers, as summarized in Figure 1.

Although Edwin Beard's lawn mowers have been popular ever since they were invented in the early 1800s (Waleed et al., 2020), some farmers in agriculture, gardening, landscaping, horticulture, and other related fields still utilize grass-cutting machines on a regular basis. This device slices grasses by shearing the action of the blade (or blades) on the bed knife, which is a stationary metal bar during its operation. Meanwhile, in mowers, cutting blades are operated and powered by either an internal combustion engine or an electric motor for cutting by rotary action. However, most rotary mowers can also be moved by hand (Chen et al., 2018; Wirtz et al., 2018; Xie and Lu, 2013; and Naranjo-Torres et al., 2020).

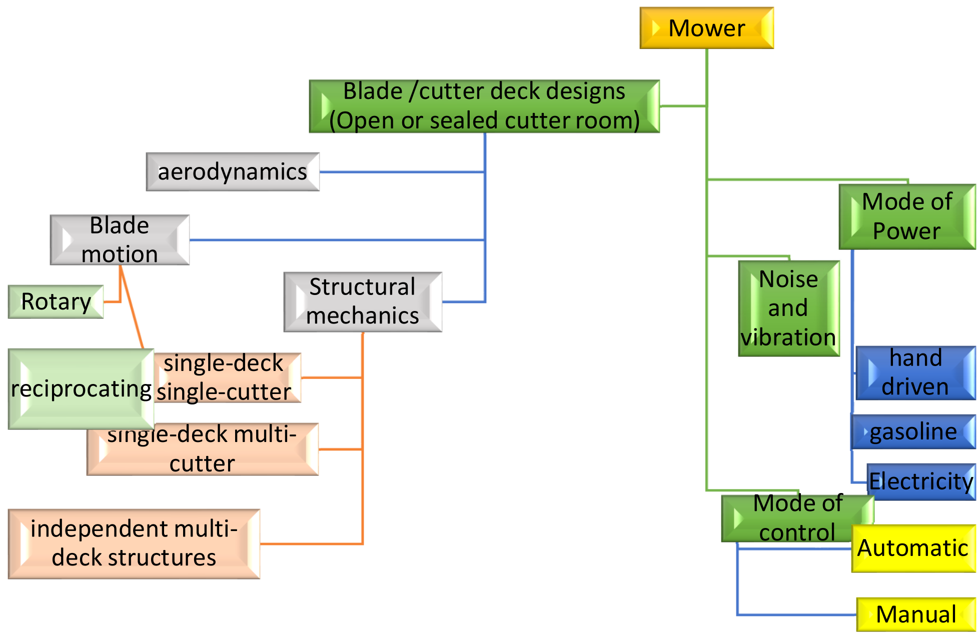


Figure 1: Classification of mowers

Traditional hand-held lawn mowers are used by the majority of farmers in the most of developing countries. These mowers are easy to use and operate in the lawn mowing area, but they have a number of drawbacks, including a heavy engine and heavy body burden; being powered by fossil fuels, which results in exhaust gas environmental pollution in addition to noise, which is harmful to both human health and the environment. Consequently, an increasing number of farmers are purchasing electric hand-held lawn mowers. These mowers have the same benefits as traditional hand-held lawn mowers, but they are quieter, produce less exhaust gas, and are lighter. In comparison, these mowers are far less complicated to operate compared to the standard mower (Belanche et al., 2020; Yusof et al., 2013).

A previous review of mowers showed that Dipin and Chandrasekhar (2014) designed an environmentally friendly robotic mower with the consideration of zero carbon emissions by developing a solar panel that charges the battery of the robot while mowing the required field. The designed robot used a microcontroller and sensors that could detect obstacles, the relative humidity of the field, and human interaction on the field. The Android phone used in this design was for the capturing of images of the field of operation as required. A similar design was developed by Tanimola et al. (2014) and tested on four different grasses, with PV cells used to power a 1.5-hp electric motor that drove the mower. Further analysis was carried out on the torque produced on the cutting blade, along with other assessments such as the impact of stress analysis on the frame and handle of the developed mower. Meanwhile, in a study by Satwik et al. (2015), which considered a different aspect of a mower design, the emphasis was on the development of an adjustable height cutting mechanism using different spur gears. The system was solar-powered by battery, with an Arduino board incorporated to control the speed of the cutting blade during operation.

However, in order to improve the technology applicable in mower designs, Newstadt et al. (2008) developed a mower with a global positioning system (GPS), a differential global positioning receiver system (DGPS), which provided details of the mower up to centimetre level, encoded wheels, a digital compass, and a more sophisticated control system. The research carried out by Mulla et al. (2016), which was similar to that of Patil et al. (2014), further involved the development of a mowing system with cordless capabilities using phone control to specify the exact desired grass cutting height and digital control for wheel speed. The developed mower could be charged dually by solar and direct electricity, which is similar to the automatic lawn mower developed by Manheche (2011), where the mower recognized its surroundings and avoided colliding with people or other objects during its operation. Furthermore, Dipin et al. (2014) designed a lawnmower that only needs human assistance when it is being set up in the work area but uses sensors and a microcontroller within the cutting region. The machine decides the path to take, evaluates its position, and then stops once the operation is completed. Chandler et al. (2000) approached the robotic design with a more technological concept in which the robotic mower is made to study its environment and operate autonomously with no obstruction using its sensors. The developed mower uses computer vision to determine cutting and non-cutting areas such as fields, walkways, flower beds, trees, etc. Although other features were added to the mower, such as automatic application of fertilizers in low-nutrient zones, insect and ant hill detection with the release of killing agents to destroy such causative organisms in the areas.

Presently, there is a problem of the availability of rural labour and an aging population in rural areas, with an increasing need to change from the use of manual labour towards the use of mechanized labour in agricultural land preparation (Chen et al., 2018). Moreover, with the steady decrease in the number of people actively seeking employment and a severe scarcity of labour that is productive, effective, and efficient in the field (Wirtz et al., 2018), the agricultural industry needs to quickly adopt the most recent technologies that are based on intelligent systems to solve its problems (Waleed et al., 2020). Moreover, various researchers have presented the risk factors that are associated with workers using different types of lawn maintenance equipment. This investigation included the noise produced by cutting blades and the noise levels at various frequencies, of which values greater than 85 decibels are detrimental to health (Bulski et al., 2008). Hence, developing an autonomous robotic mower with little or no human involvement became necessary. Although existing systems are expensive with high power consumption and chances of polluting the environment when using fossil fuels to power them (Wirtz et al., 2018; Xie and Lu, 2013; Naranjo-Torres et al., 2020; Bulski et al., 2008; Gabele, 1997).

Therefore, the research aims at designing, developing, and testing an economical autonomous robotic lawn mower using locally available materials in Nigeria to meet a clean environment with low power consumption. Present mowers use up to 1000 watts of power, but the present study seeks to provide a system with less than 125 watts of power to operate the mower in Nigeria for low-income farmers and users.

METHODOLOGY

The methodology for the project involved the identification of users' needs, data analysis, requirement specification, design, and evaluation. A user study approach was conducted to determine the needs of the product's users using a structured questionnaire and interviews to identify their needs. This was followed by data collected from the questionnaire being analyzed to establish the specifications of the product's context of use, with the requirements mapped to the needs identified. This led to the design stage, which consisted of three stages: mechanical (welding or fabrication), electronics, and firmware (hardware) programming. This is summarized in the flowchart shown in Figure 2.

Figure 2: flowchart of development procedure

2.1 Mechanical (Welding and fabrication of parts)

The mechanical design stage is comprised of the design and fabrication of various parts and other operations such as buffing, cutting, metal grinding, bending, and joining (both joint welding and screw joints). Mild steel materials such as steel plates 4′ x 8′, ¾″ pipe, ¾″ flat bar, and 2′ angled bar were procured and used for the fabrication. The materials were cut into sizes using platform cut-outs for the various sections of the machine, using an angled grinding machine for the process.

Bending processes were done on areas of continuous shaping using a bending machine. This was followed by the joining stage, where the cut-outs were welded together with a welding machine and screwing operations. Buffing was done to remove rust and prepare the body or chassis for spray painting.

2.2 Electronics

The electronics printed circuit board (PCB) was designed from the ground up, with the electronics components sourced from the local electronics market in Nigeria. Electronics design software was used in the design of the Electronics Control Unit (ECU). It was then moved to the etching stage, where all electronics traces were printed on a copper-clad board. This was followed by soldering all components to their respective positions. A diagram of the circuit box is presented in Figure 3.

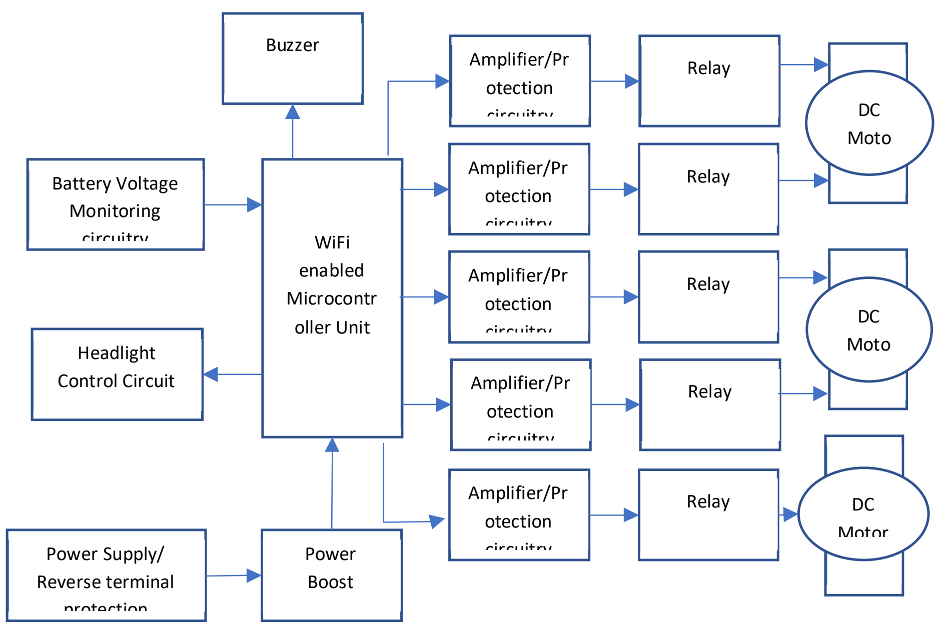


Figure 3: Diagram of the circuit block

Firmware (hardware) programming

The programming aspect controls the electronics PCB by sending appropriate signals to various units in the system through the use of signals to power and control high loads. The programming language used for the design was a combination of the C and C++ programming languages.

Cutting blade design considerations

The cutting blade is an integral component in a mower design, and the performance of the mower depends on a number of factors surrounding the cutting blade. According to Tanimola et al. (2014), the cutting efficiency of a mower is directly proportional to the power of the mower, and Atkins (1984) stated that at least 10 N of force is required to cut grasses of average height on a field. These blade parameters were evaluated using the following formula.

2.4.1 Area of the blade

This was calculated using equation 1.

$$A_b = L \times B \quad (1)$$

Where;

$A_b = Area\ of\ blade$

$L = Length$

$B = Breadth$

Volume of the blade

Equation 2 was used to calculate the volume of the mowers blade.

$$V_b = A_b \times blade\ thickness \quad (2)$$

Where;

$V_b = Volume\ of\ blade$

$b_t = blade\ thickness$

Density of the blade

$$D_b = \frac{M}{V} \quad (3)$$

Where

$D_b = Density\ of\ the\ blade$

M = Mass

V = Volume

2.4.4 Force needed to cut the grass

This is a function of the tangential force exerted of the cutting force against the resistance force of the grass under the area of consideration. This was evaluated using equation 4

$$F_b = \tau_g \times A \qquad 4$$

Where

$F_b = force\ on\ the\ blade$

$\tau_g = torque\ on\ the\ grass$

A= base area

Torque acting on the blade is represented as T and obtained using the formula

$$T = F \times R \qquad 5$$

Where R = radius of the blade

F is replaced from Equation 4 and then

$$T = \tau_g \times A \times R = \tau_g \times \frac{\pi d^2}{4} \times \frac{d}{2} \qquad 6$$

Where

A= Area of the blade

d = diameter of the blade

$$T = \tau_g \frac{\pi d^3}{8} \qquad 7$$

Power required to drive the blade

The angular rate of rotation of the blade was using the formula

$$\theta = \frac{2\pi N}{60} \qquad 8$$

Therefore power required to drive the blade is a function of the torque and the angular rotation of the blade given in equation 7 and 8 which is replaced in equation 8

$$P = T \times \theta = \tau_g \frac{\pi d^3}{8} \times \frac{2\pi N}{60} \qquad 9$$

Therefore P was evaluated using the formula

$$P = \tau_g \frac{\pi^2 d^3 N}{240} \qquad 10$$

Blade angle

The blade angle was evaluated using the formula

$$\emptyset = tan^{-1}\frac{R}{F} \quad 11$$

Speed of the blade

To determine the appropriate speed needed to cut the grass, the formula in equation 12 was used.

$$Sp_{bl} = \frac{\pi DN}{60} \quad 12$$

Performance parameters of the lawn

The various performance parameters of the lawn mower was evaluated using the following formula presented by Dogra et al., (2016).

Operating speed

$$\text{Sp} = \frac{L}{T} \quad 13$$

Where;

Sp = Speed of operation

L = Length covered

T = Time covered

Effective field capacity

$$Effc = \frac{ArC}{tt} \quad 14$$

Where:

$Effc =$ Effective field capacity

ArC = Area covered

tt = time taken

Cutting efficiency

$$\text{Cutting efficiency} = \frac{k_1 - k_2}{k_1} \times 100 \quad 15$$

Where

k_1 = Number of grasses before cutting

k_2 = Number of grasses after cutting

Performance index

$$\text{Performance index} = \frac{Ef \times CE}{Power\ input} \times 100 \qquad 16$$

Where

Equipment and material	Quantity
Electronics Parts	
Battery block 12V	2
Piezo Speaker	1
Rectifier Diode	6
Generic female header - 1 pins	6
JST-03JQ-BT	1
Generic female header - 12 pins	1
npn-Power transistor	6
220Ω Resistor	8
NodeMCU V3.0	1
RELAY	5
Boost Converter	1
Dc Gear Motor	2
DC Motor	1
Switch	1
E-Switch	1
PCB Design	1
GSM	1
Mechanical parts	
2 inches angle bar	1
1.2mm mild steel board 4'x8'	1
Allen key bolts	3
4mm plate 8"x8"	4
Flat bar	1
4inches cutting disk	20
4inches filing disk	1

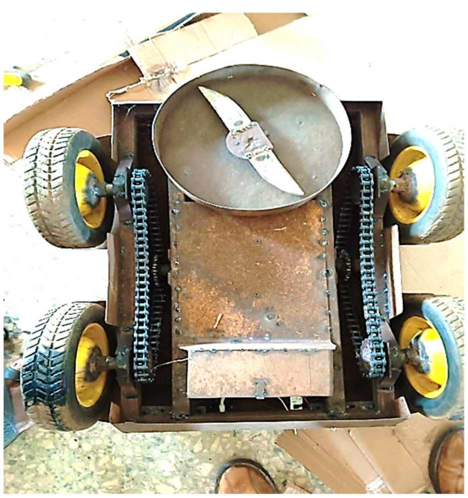
8″ back steel tyres	2
4″ front steel tyres	2
Mower blade cutting mechanism design	1

Ef = effective field capacity
CE = Cutting efficiency

Description of the developed robotic mower

The developed robotic mower is made up of a 2-inch angle bar, which constitutes the frame of the system on which other components were mounted. 1.2mm mild steel board (4′x8′) and 4mm plate (8″x8″) were used to form the cover and external body of the designed robot. A 1mm-thick cutting blade was attached to the cutting mechanism design with firm fastening using an Allen key bolt. Two 8-inch-diameter back steel tires and two 4-inch-diameter front steel tires were connected to the frame for easy movement of the robot. A 12V battery block system was used to power the electrical circuit and its components, such as the npn-power transistor, 220Ω resistor, PCB design, electric board, and switch. A summary of the various components is presented in Table 1, and views of the developed robotic mower are shown in Figure 4.

Table 1: Summary of component



a. Robotic mower cutting blade cutting blade

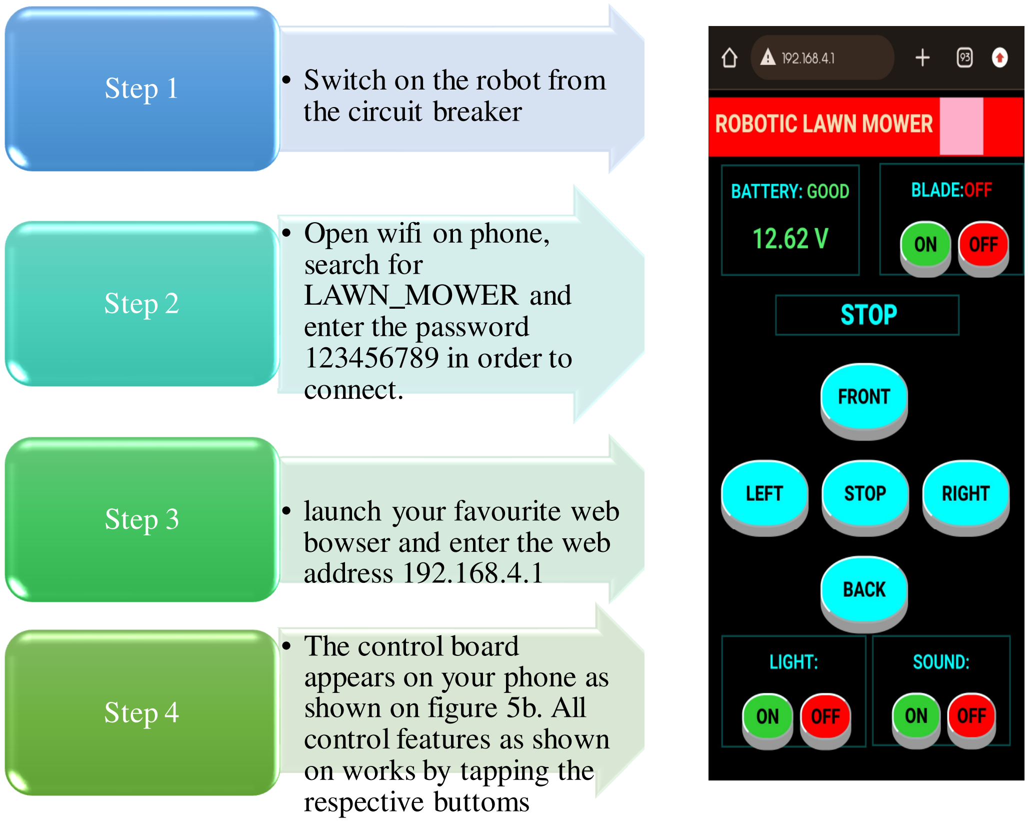
b. Conventional mower

c) Internal view d. side view e. Back view

Figure 4: Views of the robot

2.6.1 Operation of the mower

The robotic mower is operated using the following steps as presented in figure 5.



a. Operational procedure b. Phone Control dashboard

Figure 5: Operation of the robotic mower

Experimental procedure

The robotic mower and conventional mower were tested on flat fields of dried grass and fresh grass of dimensions 2m by 1.5m and 1.5m by 1.5 m, respectively. The fields were properly mapped out by measuring with tape and demarcating with pegs, as shown in figure 6 and 7. Twenty (20) representative samples of the grasses were observed spotted in the mapped area, and heights were measured with tape before and after the mowing operation. The two mowers were placed in their respective fields to be cleared. A digital stopwatch was used to monitor the duration it takes each mower to clear its field completely. The fields were observed for uncut grasses after the mowing operation.

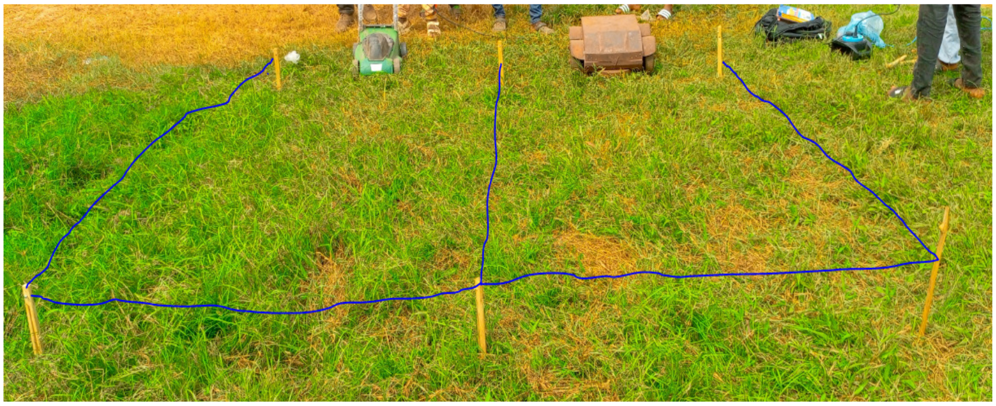
a. Demarcated dried grass fields before mowing

b) Dried field before clearing

c) Cleared by Robotic mower

d) cleared by Conventional mower

Figure 6: Showing dried fields operation under robotic and conventional mower



a. Demarcated fresh grass fields before mowing

b. Fresh grass before clearing

c. Cleared field by mower

d. Cleared field with conventional

Figure 7: Showing fresh fields operation under robotic and conventional mower

Result and discussion

Performance parameters

3.1.1 Speed of operation and effective field capacity

The developed robotic mower was tested under various performance conditions and compared with the conventional mower. The results of the field test as shown in Table 3.1 indicated that, for a field length of 2m and a breadth of 1.5m of dried grasses, it took the robotic mower 348 seconds to clear the field with an average operation speed of 0.0057 m/s, while under a fresh grass condition with a field length of 1.5m and a breadth of 1.5 m of coverage, it took about 306 seconds for the robotic mower to clear the field with a resulting operational speed of 0.0049 m/s. On the other hand, conventional mowers on similar dried grass of field length 2m and breadth 1.5m coverage distance and fresh grass of 1.5m by 1.5m coverage used 127 seconds and 78 seconds, respectively, with operational speeds of 0.016 and 0.019 m/s. This shows shorter clearing duration and higher operational speed with the conventional mower over the designed robotic mower. This is due to the lower input power of the designed mower (120 w) compared to the higher input power (1000 w) of the conventional mower. In addition, the field capacities of the two mowers under a similar mapped area of 2m by 1.5 m of dried grass and 1.5m by 1.5 m of fresh grass showed the robotic mower field capacities of 0.0086 m^2/s and 0.010 m^2/s for the dried and fresh grasses, respectively. Meanwhile, the effective field capacity of the conventional mower in similar conditions was 0.0236 m^2/s and 0.038 m^2/s, respectively.

Table 3.1: Showing operational speed and field capacity parameters

Mower type	Robotic mower		Conventional mower	
Grasses under test	Dried grass	Fresh grass	Dried grass	Fresh grass
Length covered (m)	2	1.5	2	1.5
Time taken (sec)	348	306	127	78
Speed of operation(m/s)	0.0057	0.0049	0.016	0.019
Area cleared (m^2)	2 x 1.5	1.5 x 1.5	2 x 1.5	1.5 x 1.5
Effective field capacity (m^2/s)	0.0086	0.010	0.0236	0.038

Cutting efficiency and performance index

The cutting efficiency of the developed mower was compared to that of the conventional mower. This was evaluated from the 20 representative samples identified before and after clearing a mapped dried and fresh grass area. After the mowing operation, an average of 7 dried grasses and 8 fresh grasses were found after mowing the field with cutting efficiencies of 65 and 60%, respectively, when operated with the robotic mower, while only 1 dried and 2 fresh grasses were found with cutting efficiencies of 95 and 90% after mowing the field with the conventional mower. This resulted in a performance index of 0.47 and 0.50 for the robotic mower under dried and fresh grass conditions, and 0.22 and 0.34 for dried and fresh grasses under conventional mower operation. Again, the low cutting efficiency of the robotic mower is a result of low power input, although other factors were identified, such as the low rpm of the cutting blade and the angle of the cutting blade. The impact of these parameters in addition to the aerodynamic effect of the blade was emphasized in a three-blade mower design by Hagen et al. (2002) of which there was significant effect of these parameters on cutting efficiency. In a research by Amer et al., (2014) better cutting efficiency was achieved at blade angles of 30° of inclination, which is close to the blade angle of the conventional mower at 35° while the designed robotic mower's blade was at 0° angle of inclination. Although Li et al. (2011) obtained optimum cutting at a blade angle of 5°, which is far from that of Amer et al., (2014), that of the conventional mower, but close to that of the robotic mower. This discrepancy gives room for further study on the optimum blade angle. In addition, the performance indices showed that, at 120W of power input, the robotic mower performed better with the little power at the same field size, field capacity, and cutting efficiency compared to the conventional mower with 1000W of power at the same condition. Therefore, the value of the performance index shows the underperformance of conventional mowers compared to the fair and average performance index of the robotic mower.

Table 3.2: Showing cutting efficiency and field power index parameters

Mower type	Robotic mower		Conventional mower	
Grasses under test	Dried grass	Fresh grass	Dried grass	Fresh grass
Number of grasses before cutting (k_1)	20	20	20	20
Number of grasses after cutting (k_2)	7	8	1	2
Cutting efficiency (%)	65	60	95	90
Power input (W)	120	120	1000	1000
Performance index	0.47	0.50	0.224	0.342

CONCLUSION

The low-input-power robotic lawn mower was designed and developed using locally available materials. The build process involved three phases, such as the design and fabrication of the mechanical components, the installation and building of the electrical components, and the programming of the robotic mower to operate under specific instructions. The developed robotic lawn mower under similar test conditions as a conventional electrically powered mower was evaluated in terms of effective field capacity, speed of operation, cutting efficiency, and performance index. The result of the comparative assessment showed that the high input power of the electrically powered conventional mower contributed to the higher performance of the mower when compared with the low-power developed robotic mower. Hence, improvements in the blade cutting angle, blade speed, and input power of the robot will improve its performance.

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