Design and Implementation of Remote-Controlled Lawn Mower Using Dual-Tone Multi-Frequency Technology

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Abstract – *One of the most important machines that assist with retaining the physical shapes and beauty of lawns is lawn mower. There are ranges of styles and shapes for commercial use of heavy-duty mowers to residential use of push mowers. Lawn mower can operate on solar power, electricity or diesel. Some lawn mowers have the capabilities to gather the cut grasses into bags and spread the grasses on the surfaces of the soil to help reduce loss of moisture in the soil. Lawn mowing requires the operator to move to the various locations that the weeding would take place. This causes fatigue to the operator since the operator would have to be standing and moving in the sun for a long time and also could be hit by a stone during the cutting of the weeds. This could lead to injuries to the operator and staying in the sun for long can likewise cause migraine. Furthermore, the exposure to noise from the mower and dust may also be harmful to the health of the operator. To overcome these challenges associated with lawn mowers, their operation can be automated. This paper aims to design and construct a prototype of a remote-controlled lawn mower using dual-tone multi-frequency technology to control the directions of a lawn mower. This research was designed using Arduino Uno, which is based on the ATmega328P microcontroller, 6 VDC geared stepper motor, a 700- HB relay that serves as a motor driver, a sim8001 DTMF module integrated circuit (IC) and a mobile phone.*

Keywords: *Dual-tone Multi-frequency, Hybrid Stepper Motor, Lawn Mower, Permanent Magnet Stepper Motor, Variable Reluctance Stepper Motor*

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I. Introduction

Lawn mower is a simple machine that is used for trimming grounds that are covered with grasses. The rotating blades of a mower makes its finishing looks beautiful as compared to the use of cutlass to weed. Applications of mower range from residential, commercial to industrial purposes. The market projection is valued to increase from USD 23.5 billion in 2022 fiscal year to USD 33.6 billion in 2027 fiscal year [1]. On the market, the available lawn mowers include the robotic mower. These types of mowers function automatically without or with less human involvement. Such mowers make use of sensors and technologies like the global positioning system (GPS) to guide their working activities [2]. Also, the next available mower is the riding mower. These types of mowers are provided with facilities such as steering wheels and sitting seats for operators to sit on during the mowing of the lawn [3]. In addition to the existing mowers on the market are the self-propelled mowers. These types of mowers are suitable for large size lawns and they can function without human involvement by the use of powered motors [4]. Finally, the oldest types of mowers, known as push mowers are also available for customers to choose from. It is one of the first designs of mowers that uses direct human effort to operate it from one place to another. They are suitable for working on small lawns because of the fatigue that is associated with its use [5].

There are different features that distinguish one type of mower from the other. One of the key features is the power source that the mower uses to work. The power sources can be derived from solar energy, batteries, gasoline or electricity [6]. Another feature that makes mowers unique from one another is its ability to adjust its blade to match the grass cutting height of the lawn. The blade cutting width is another feature of mower. With every single pass, the amount of grass that the mower cuts is determined by the blade cutting width [7]. Modern mower has the ability to spread the grass that is

cut over the surface of the soil to help minimize loss of moisture from the soil and also as another form of fertilizer for the soil. This feature is used for the process known as, Mulching [8]. Lastly, added feature of mowers is the inclusion of bags to gather the cut grass for next process of disposal [9].

The use of mower for cutting lawn has numerous advantages including making the lawn look tidy and neat in appearance [10]. Besides the cutting of grass, regular mowing can serve as a source of exercise for its operator [11]. In comparison to other means of lawn cutting, the use of mower can reduce air and noise pollution. Furthermore, energy, time and physical efforts that are exerted by the operator of lawn mower is less compared to the use of other means of grass cutting such as the use of cutlass [12]. Because of the reduced effort exerted on the use of lawn mower, it encourages regular keeping of lawn in good shape.

For effective and efficient use of lawn mower, proper maintenance practice should be observed. Among the maintenance practice are cleaning and storing the lawn mower in its designated location after use [13]. In addition, periodic changing of spark plugs and air filter help to keep lawn mower in shape [14]. Furthermore, the oil of the mower machine must be changed as prescribed by the manufactures [15]. Also, constant monitoring of the fuel level is necessary as this will prevent the mower from running dry [16]. For the lawn mower to be able to cut grass neatly, its blades should be sharpen enough before using it to perform a task [17]. Likewise, trapped grass debris on the blades and the engine of mower should be removed intermittently during mowing.

II. Stepper Motors

A. Permanent Magnet Stepper Motors

In most industrial applications that require precision control of movement, stepper motor is employed [18]. Stepper motor derives its name from its ability to give exact steps of increment or decrement [19]. Electrical pulses are converted into mechanical motion with accurate steps by stepper motor, a unique characteristic that differentiates it from the other motors [20]. With this type of motor, the rotor is a permanent magnet with alternating north and south poles positioned in a straight line parallel to the rotor shaft [21]. These magnetized rotor poles provide an increased magnetic flux intensity and because of this, the permanent magnet stepper motor exhibits improved torque characteristics when compared with the variable reluctance stepper motor type. Unlike the other stepping motors, the permanent magnet stepper motor rotor has no teeth and is designed to be magnetized at a right angle to its axis. Fig. 1 shows a simple, 90º permanent magnet stepper motor that employs a cylindrical permanent magnet as the rotor and possesses four poles in its stator carrying four phases [22].

Fig. 1. A Permanent Magnet Stepper Motor

B. Variable Reluctance Stepper Motor

This motor has the simplest design amongst the three types, with a soft iron, non-magnetic, toothed rotor and a wound electromagnetic stator [23]. Because the rotor is not magnetized, there is no attraction between the rotor and the stator when the windings are not energized hence no decent torque is produced. It has four rotor teeths, 90º apart and six stator poles, 60º apart. Electromagnetic field is produced by activating the stator coils in sequence. It attracts the metal rotor. When the stator windings are energized in a reoccurring sequence of 2, 3, 1, and so on, the motor will rotate in a 30º step angle, and this energizing sequence shall also determine the rotation direction of the rotor as shown in Fig. 2 [24].

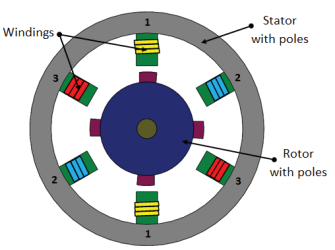

Fig. 2. A Variable Reluctance Stepper Motor

C. Hybrid Stepper Motors

Among the stepper motors, the most generally used one that also incorporates the actions of the static motor and variable reluctance is the hybrid stepper motor [25]. With respect to cost, the permanent magnet stepper motor is less costly as compared to the hybrid stepper motor. Furthermore, it provides higher performance with respect to relevancy step resolution, speed and

torque capabilities. The hybrid stepper motor has its rotor being multi-toothed such as the variable reluctance motor having axially magnetized and aligned magnet encompassing its shaft [26]. Movement of magnetic flux within the air gap is aided by the tooth on the rotor. In addition, the detent, holding and dynamic torque behaviour is enhanced as compared to the variable reluctance and permanent magnet motor types as depicted in Fig. 3 [27].

Fig. 3. Hybrid Stepper Motor

III. Dual-tone Multi-frequency

Dual-tone multi-frequency (DTMF) is a method that is used by telephone set to send messages over voice channels in telecommunication system [28]. The tones that are generated when the numbers on a phone are pressed is called, dual-tone multi-frequency and are conveyed with the voice channel for communication. Each tone is generated at definite frequency. Anytime a number is pressed, two tones at certain frequencies are generated and transmitted over the communication channel. One tone corresponds to column that the key is located whilst the other tone likewise corresponds to the row [29]. Whenever the keys on a phone are pressed to make calls, corresponding tones are generated and sent over the channel. The receiving end equipment listens to these tones and decodes them into commands. These commands are the results of what we see anytime our phones receive calls. Since DTMF is a set of commands, it can be used to control equipment remotely. Bell Labs developed the DTMF for faraway calls. Telephone handset and switching centers are some of the applications of DTMF [30]. DTMF can be deployed in automated teller machines (ATMs), voice interactive response systems, telephone devices, home and industrial security systems and other remote control systems [31].

IV. Brief Literature Survey

A. Solar powered lawn mower models

There is a force that is exerted on the body due to solar manually operated mower that is controlled by a level system. This work includes a blade cutting device based on rising and falling system [32]. The system comprises of two spur gears of distinct appearance in dimensions with adjustable rotor height lever. The lever regulates the movement of the minor spur gear over the surface of the large spur gear. Also, in another research work cited [33], a lawn mower that depends on robotic vision and solar power is developed. The system includes a sensor and a microcontroller. The battery used for this mower machines gets charged in the sun during its mowing process or alternatively, can be charged manually. The mower uses humidity and ultrasonic sensors to check for the surrounding humidity level as well as to avert collision with obstacles respectively. Human movement around the mower when it is cutting grasses is detected by Passive Infrared Sensors (PIR)**.** Likewise, there is an electrically powered mower machine that works on solar panels and solar cells. The mower's cutting blade is attached to the electric motor [34].

B. Automatic Lawn Mower Models

Construction and utilization of a mechanized solar powered grass cutting machine is the research conducted on a lawn mower [35]. The aim of the research is to minimize the involvement of human effort in the use of lawn mower. The rotation force of the cutter is provided by solar power source. Arduino ATmega328p and IR sensors are the major components that are used to achieve the successful operation of the lawn mower. Also, there was a design and construction of an Automated Lawn Mower robotic car that used Ackermann steering device [36]. To prevent the mower from getting into contact with objects, a proximity sensor is used. The researchers make the design such that it can be operated in full autonomous mode or semi-autonomous mode. Another lawn mower is designed for cutting grasses based on smart technology [37]. The mower machine uses of linear blades that are operated by a motor. The supply voltage to the motor is a rechargeable battery that can be charged by mains electricity or solar energy. To prevent possible damage to the mower during it operation, infrared sensors are used to sense obstacles within the working area.

C. PLC Based Lawn Mower Models

There is a design of a PLC based lawn mower by using a collision detection mechanism, grass cutting mechanism and a motor controller [38]. The smart grass cutter system puts forth a completely automated lawn mower mechanism. The robotic vehicle is equipped with a blade that allows for grass cutting at high rpm. This system uses a PLC based circuit in order to achieve its functionality. The PLC operates the vehicle movement by dc motor as well as the grass cutter at the same time while monitoring the ultrasonic sensors. The PLC smartly operates the DC motors using the motor driver IC to achieve desired movement based on ultrasonic inputs. There is another lawn mower design that is based on using PLC systems [39]. The researchers use a solar panel, battery, DC motor and sensors which are controlled by a compact PLC system. The PLC acts as the brain of the entire system. In their development, solar panel charges the battery as well as supplies power to the system if the user wants to use the mower during the day time. When the user switches on the system, it starts the cutting motor blades that are already attached. Furthermore, it will begin to move forward when no obstacles are found on its route. If an obstacle is found by the sensor, the mower will stop moving forward and will move few seconds backwards and move towards right hand side of the lawn. Afterwards, the mower will begin moving in the forward direction when it does not encounter any barrier or obstacle. If an operator wants to use the mower during the night, the system will get electrical power from the battery that is charged by the solar panel during the day time.

V. Research Gap

The surveyed literatures do not report on the use of DTMF technology to control the movement, that is left, right, forward and reverse movements of lawn mower. Therefore, this research proposes the use of DTMF technology to control the movement of lawn mower.

VI. Materials and Methods

A. Design concept and criteria

Fig. 4 shows the basic design concept of the remote controlled system using dual tone multi frequency.

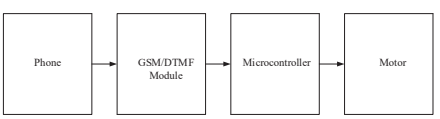

Fig. 4. Conceptual Diagram of the Proposed Design

A mobile phone sends a signal to a DTMF module. When the DTMF module receives the signal, it decodes the signal into sets of instructions for the microcontroller to process. The instructions are processed by the microcontroller to control the direction of the motor.

The design criteria of the DTMF control are:

- A 220 VAC power source is needed to supply power to the mower;
- Transformer will be used to step down the 220 VAC to 12 VAC;
- A diode will be needed to rectify the 12 VAC to 12 VDC;
- A voltage regulator will regulate the voltage from 12 VDC to 6 VDC;
- The microcontroller will process the decoded signal received from the DTMF module; and
- The relay will energize and control the motor's direction.

B. The Proposed Design

Fig 5 shows the block diagram of the remote controlled lawn mower using DTMF. The DTMF module, microcontroller and relay are supplied with a 6 VDC voltage from a voltage regulator. The voltage regulator receives it supply voltage from 220/12 VAC transformer. A mobile phone sends a signal to the DTMF module. The signal received is decoded and is sent to the microcontroller. The microcontroller would process the decoded signal and send it to the transistor. The transistor amplifies the signal and forward it to the relay. The relay serves as a motor driver and controls the directions of motor A, B and C representing the various movement.

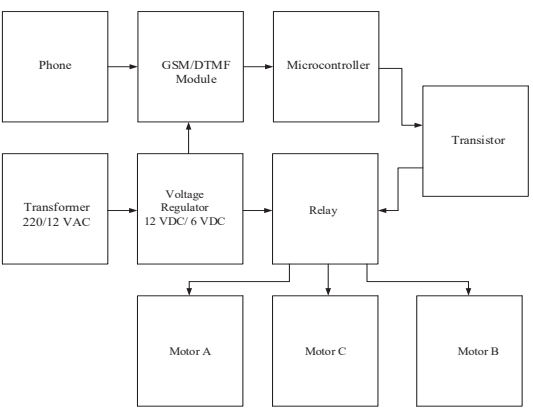

Fig. 5 Block diagram of the remote controlled lawn mower

C. Selection of components

The components employed in the construction of the lawn mower are: DTMF module, microcontroller, transistor, transformer, diode, capacitor, voltage regulator, resistor, light emitting diode (LED), motor and relay. The value of the diode was selected based on (1).

$$I = Io\left(e^{\frac{qV}{\eta KT}} - 1 \right) \quad (1)$$

where I is the current flowing through the diode, I_o is the dark saturation current, q is the charge on the electron, V is the voltage applied across the diode, η is the (exponential) ideality factor, K is the Boltzmann constant = $1.3\times10^{-23}JK^{-1}$ and T is the absolute temperature in Kelvin.

The transformer was chosen based on (2).

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1} \quad (2)$$

where N_1 is the primary windings number of turns, N_2 is the secondary windings number of turns, V_1 is the primary voltage, V_2 is the secondary voltage, I_1 is the primary current, I_2 is the secondary current.

The values of resistors were selected based on (3).

$$\text{Re}sistor = \frac{Voltage}{Current} \quad (3)$$

where voltage is in volts, current is in amperes, and resistor is in ohms.

The capacitors were chosen based on (4).

$$Capacitor = \frac{Charge}{Voltage} \quad (4)$$

Also, the transistors were based on (5).

$$I_e = I_b + I_c \quad (5)$$

where I_e is the emitter current, I_c is the collector current and I_b is the base current.

D. Component Specification

Table I shows the specification of the components used to design the lawn mower.

TABLE I
COMPONENTS AND THEIR DESCRIPTIONS

SN.	Component	Specification	Qty
1.	DTMF module	Sim800l	1
2.	Transformer	240 VAC/12 VAC	1
3.	Diode	1N4007	4
4.	Capacitor	100 uf	2
5.	Voltage regulator	lm7805	1
6.	Resistor	470 Ω	4
7.	LED	5 mm	4
8.	Stepper Motor	6 VDC	3
9.	Relay	700-HB	2
10.	Microcontroller	ATMEGA 328P	1
11.	Transistor	NPN	4

E. Construction of A Prototype of the Lawn Mower

Fig. 6 presents the schematic diagram of the remote controlled lawn mower using DTMF technology. The selected components were thus connected as:

- connect primary winding of the transformer T1 to sw1;
- connect one terminal of the secondary winding of the transformer to the input of the diode;
- connect another terminal of the secondary winding of the transformer to BR1 input and output of BR1 to capacitor C1;
- connect positive and negative terminal of the GSM to the power supply;
- connects resistor R1 in series with the LED D1;
- connects resistor R2 in series with the base of transistor Q1;
- content one coil of the relay to the positive terminal of the power supply;
- connect the other coil of the relay to the collector pin of the NPN transistor;
- connect the base resistor to the base of the transistors;
- connect the Motor 1 in series with the normally open side of the relay 1;
- connect the motor 2 in series with the normally open side of the relay 2; and
- connect the motor 3 positive terminal in series with the switch labelled SW3.

F. Operation of The Remote Controlled Lawn Mower Prototype

For the lawn mower to work effectively and efficiently, firstly it has to be connected to a power source. Then, pressing the switch on the mower will cause its blades to start rotating. A ten digits arbitrary number is used to program the microcontroller where in this case is 0237699446. The number is dialed on the phone and the lawn mower is ready for operation. The inbuilt DTMF/GSM module in the mower will

automatically answer the call and the mower will move according to the number pressed as follow:

- press 2 for forward direction
- press 0 for reverse direction
- press 6 to move to the left
- press 4 to move to the right
- press 5 to stop operation

In every movement of the lawn mower, there are sets of LED lights that light up to show the indication of that particular movement, either forward movement, reverse movement, left movement, right movement or even when the lawn mower comes to a stop. The LEDs are used for indication purposes.

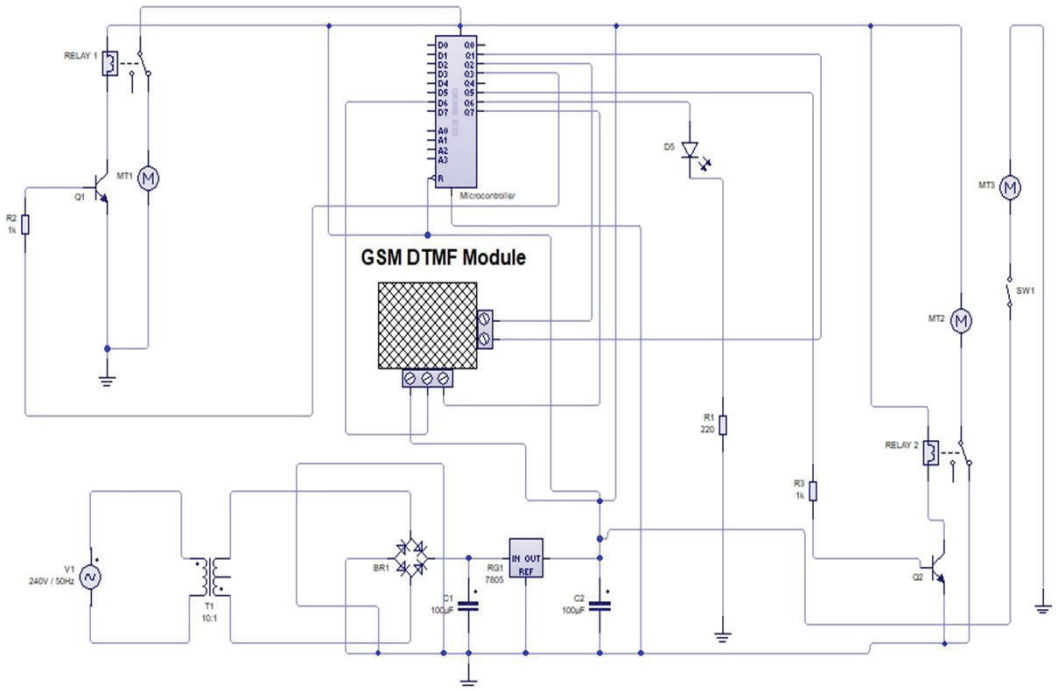

Fig. 6. Schematic diagram of remote controlled lawn mower

VII. Results and Discussion

1. Simulation Results of the DTMF Mower

Programming of the microcontroller chip was done using Arduino IDE. Likewise, simulation of the circuit was done using circuit wizard software because of its flexibility and easy to operate features. Fig. 7 shows the simulated result from the microcontroller output when power is not supplied to the microcontroller. It is observed that the voltage stays at 0 VDC meaning the microcontroller will not function although the microcontroller is active.

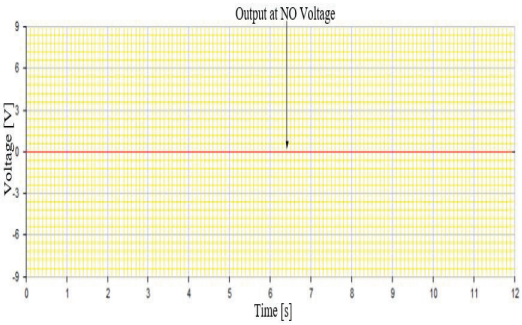

Fig. 7. Output of Stepper Motor at No Supply Voltage

While Fig. 8 shows the simulation results when power is being supplied to the stepper motor. The waveform

showed the output voltage at 6 VDC when power is being supplied to the stepper motor. This made the motor to function at that output voltage. This is the output waveform for all the various movements of the lawn mower.

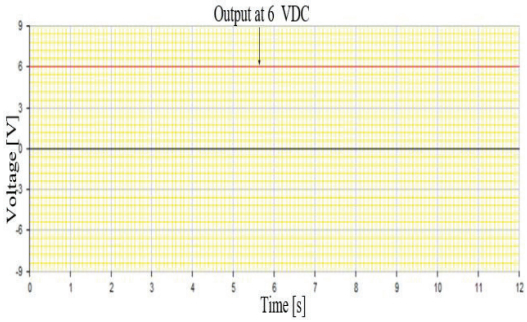

Fig. 8. Output of Stepper Motor at 6 VDC Supply Voltage

2. Test Results of the Mower Prototype

Scenario 1

Fig. 9 shows the test results when power is supplied to the lawn mower and the switch for the mower blade is turned on. The LED indicator on the casing represents power on for the lawn mower and one LED represents the mower blade is switched on.

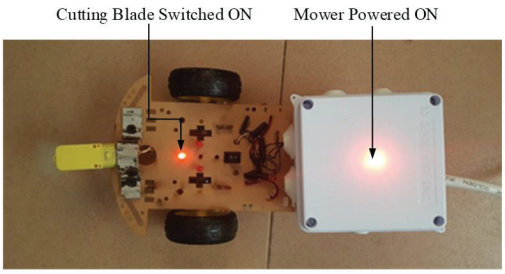

Fig. 9. Mower blade turned ON

Scenario 2

Fig. 10 shows the test results when power is supplied to the lawn mower and the switch for the mower blade is turned off. The LED on the casing remains on but no other LED is switched on.

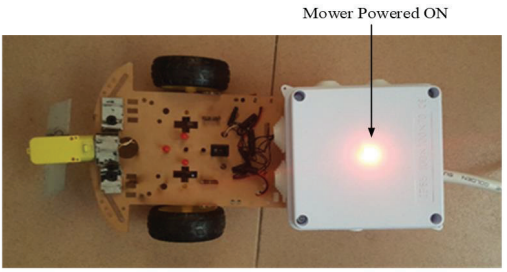

Fig. 10. Mower blade turned OFF

Scenario 3

Fig. 11 shows the test results when power is supplied to the lawn mower, the mower blade is turned on, number 0237699446 is dialed, and number 2 is pressed on the phone keypad. All the LED indicators light up and the mower moves in the forward direction.

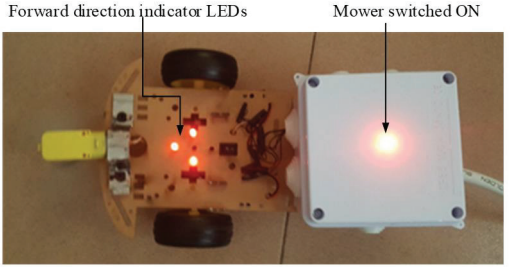

Fig. 11. Forward direction of the mower

Scenario 4

Fig. 12 shows the test results when power is supplied to the lawn mower, number 0237699446 is dialed, and number 4 is pressed on the phone keypad. The two LEDs on the casing light up in that manner and the mower moves to the right direction.

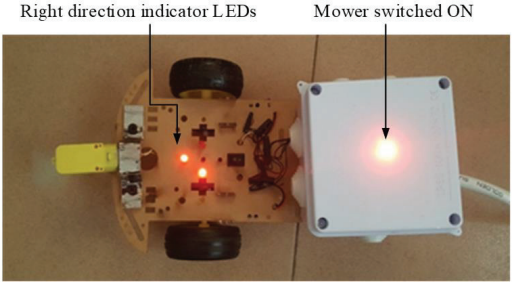

Fig. 12. Right direction of the mower

Scenario 5

Fig. 13 shows the test results when power is supplied to lawn mower, number 0237699446 is dialed, and number 6 is pressed on the phone keypad. The LEDs on the casing light up in that manner and the mower moves in left direction.

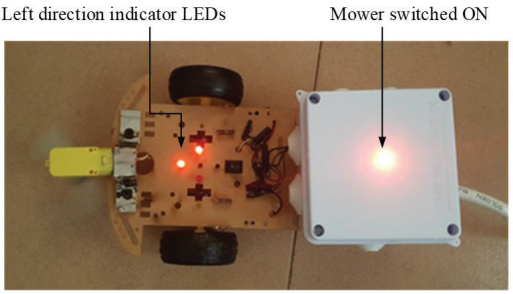

Fig. 13. Left direction of the mower

3. Summary of findings

Findings from this research are summarised as follows:

1. The lawn mower can be operated with minimal human effort.
2. The lawn mower can be operated remotely from a distance using DTMF technology.
3. The lawn mower can be operated at a reduced noise and speed levels.
4. DTMF technology with the help of a microcontroller can be employed to control the directions of stepper motors.

VIII. Conclusion

The purpose of the research is to design and construct a remote controlled lawn mower using DTMF technology. The outcome of this research is the successful design and construction of a prototype lawn mower that can be controlled in all directions using a mobile phone. Also, the use of DTMF technology with the Arduino Uno microcontroller and the relay has made the design of the remote controlled lawn mower possible. Equally, the dangers and hazards associated with the user are reduced because the mower can be operated from a distance through DTMF, creating a distance between the user and the mower. More significantly, the research has showed that:

1. DTMF technology is applicable in the precise positioning and control of stepper motors.
2. Control of lawn mower is achieved.
3. There are different types of motor control strategies that can be implemented for motor control.
4. The system is environmentally friendly and cost effective due to the availability of the components in local markets.
5. The lawn mower is limited to only the use of mobile phones.
6. The proposed design will help in reducing operator fatigue.

IX. Recommendations

Based on the successful undertaking of the research, the following recommendations are made:

1. The mower can be redesigned to be solar powered since it would be used in the sun most often.
2. DTMF technology can also be used to control other devices such as lighting system in our homes.
3. Due to the call charges by network providers, the mower can be redesigned to so that radio frequency can be used to replace the GSM.
4. Further work should look into the ability to increase and decrease the speed of the lawn mower.
5. Likewise, further research can be conducted to so that the lawn mower can be control by other available devices apart from the mobile phone.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1: Data collection, analysis and original draft preparation; Author 2: Supervision, draft review and editing and investigation. Author 3: Conceptualization and review.

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