DEVELOPMENT OF AUTONOMOUS LAWN MOWER FROM LOCALLY SOURCED MATERIALS

BY

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SUBMITTED TO

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CURRICULUM VITAE

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I hereby declare that this project has been carried out by **Oluniyi Kehinde Tobi,** and submitted to the Department of Mechatronics Engineering, Federal University Oye-Ekiti in partial fulfilment for the award of Bachelor of Engineering (BEng) degree in Mechatronics Engineering.

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CERTIFICATION

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DEDICATION

We dedicate this report to God almighty the maker of heaven and earth who had granted us the enabling grace for the successful completion of our internship and also to our families, lecturers, staffs, fellow pioneering students and logistic course mates whose love, moral support, valid and quick information helped me make it through the rough times.

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The satisfaction that accompanies the successful completion of this project would be incomplete without mentioning the names of those who made it possible. It is evident that without the constant guidance and encouragement received from these great personalities, all efforts would have gone in vain. I thank God Almighty, the creator of the universe for the privilege given to me during the course of my studies.

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My profound gratitude goes to ***Mr and Mrs Oluniyi,*** who have always supported me especially in my academics. I pray that God will grant all of your heart desires, thank you very much. Also to my siblings and well-wishers, God bless you all.

ABSTRACT

A lawnmower is a machine that uses a revolving blade or blades to cut a lawn grass. Many designs have been made, each suited to a particular purpose. Manual grass cutter has environmental issues regarding pollutions and also require the need of man power to operate and has a great maintenance to its engine. This robot is design to be environment friendly and operated by a rechargeable battery and can be describe as an intelligent robot because the microcontroller receives information from several sensors (PIR, Humidity and Bumper switches) connected to it in avoiding obstacle to ensure a neat pattern of cut and use the information to actuate the left and right motors driving the wheels and the center motor driving blade and at the same time it obeys all parameters of work and its program database. The result obtained from the test and analysis carried out shows that our ***development of the autonomous lawn mower from locally sourced materials*** is highly recommended because it is safer to use, environmental friendly, easy to operate, and fully automated.

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CHAPTER ONE

1.0 INTRODUCTION

A mower is defined as a machine used to cut down grass or grain with a scythe or a mechanical device. It was invented in ***1830 by Edwin Beard Budding***. Basically, a lawnmower is a type of grass cutter designed to trim and maintain overgrown lawn grass. Each of them have their own style of operation, and it could be manual or automatic. In addition to this, they differ on the type of material for cutting such as using the rotational blade or nylon strips. The advantage of using rotational blade is the fine output , smooth cutting, and has more efficient, it enable the neatness of landscape particularly in residential establishment, sports fields, gulf course, and some other places that has lawn area. In some other way, disadvantage of using blades was the portion of the lawn such as grass near the center island, big trees, and grass grown beside the rock were untrimmed since the blade may damage if this part reach the blade. On the other hand, using nylon strips has an advantage such as leaving the lawn fully trimmed. Reaching those grasses that can't be cut by a blade. Unfortunately, nylon strips get dull and break away and should be replaced. The output was untidy since trimmed grass are thrown anywhere and also the strong impact of this nylon strips to a stone or other object may cause injury to the user and people nearby.

Lawn mowing is an important part of the process to keep terrain with grass well-manicured and tidy. Places such as soccer field, garden, home lawn, golf course and many others require constant lawn mowing and grass cutting. One of the complicated tasks is mowing, with large amount of time and effort needed to complete it. Depending on geographical location and weather trends such as rainfall and temperature, it is generally necessary to move a lawn on a weekly basis. The duration to complete the task takes from minutes to hours, depending on the size of the particular lawn and the moving equipment available. The required long hours and the complicated job would make the operator to succumb to fatigue. It is a fact that humans have some physical limitations regarding environmental factors such as weather conditions, including temperature, pressure, humidity and so on which causes low blood pressure and poor fluid intake.

In committed situations, robots can do and should do the job for us. Robots are not only used in outer space, but, there are many places on earth where it is too dangerous for man to work at like in the deep sea, nuclear plants or waste dumps. Hence, there is also a growing need for robots in supporting human beings in their daily life at home or at work. These are also reasons for the limited workforce available in this sector. The operation of a lawn is a skill and labor intensive task and furthermore the shortage and aging workforce in agriculture results in a decrease of skilled machine operators. Therefore, the development of driverless lawn mower and tractor is of commercial significance and societal importance.

There has been a need for some time for a lawn mower that is truly autonomous. Although many types of autonomous lawn mowers have been proposed in the past, none have met with any real degree of commercial success. One of the reasons being that the proposed systems cost too much, that many small landscaping operators would not be able to afford. For those in developing countries where the cost of labor is low, the investment against return would not be favorable. Besides that, systems that apply technology such as Global Positioning System (GPS) and motion-sensor are too sophisticated for any ordinary employee to operate. This paper reviews the previous inventions done by other researchers in finding the various automated mowers and tractors and the newly proposed cost effective method for the simple and useful automated lawn mower.

The advancement of technology has changed the usual way of implementing task in terms of lawn maintenance. Some other manufacturers designed their machines to be more efficient, reliable, and robust suitable for several lawn area. Nowadays, the use of a simple lawnmower turns into modern applications such as autonomous system. The usual machine evolves into robots and was designed to execute lawn mowing without human intervention. In connection to this, the proponent will design an autonomous lawn mowing mobile robot that can navigate itself within a predefined area without boundaries using digital compass. The proponent decided to innovate recent lawnmower technology making it more practical to use. Moreover, the design of the robot is divided into several major subsystems namely: Navigation System, Obstacle Detection System, Microcontroller Network System, Mechanical System, and Power Control System.

The mobile robots need direction sensors for their guidance to be able to move from one place to other place in a straight path. However, another popular technology readily available for this purposes the GPS. With GPS, the robot can determine its absolute position and headings. But there are couples of cautions attached to it that may severely limit the usefulness of the project. GPS is accurate to within +/- 5 meters at best, and does not work indoors. During initial design planning, a global positioning system (GPS) was considered as an attractive navigation system but this idea was abandoned due to high cost of materials needed in the system. Electronic Compass on the other hand, won't give the robot its absolute location but it can approximately guide to a known target location relative to its present position. It will work both indoors and outdoors. This usually matters more than the robot absolute position. If a location fix is essential, GPS and electronic compass maybe installed to work together. Moreover, Digital Compass-aided Autonomous Lawn Mowing Robot is a centralize system able to maintain small scale lawn areas. It is equip with digital sensors for obstacle avoidance and programmed to track its bearing using Electronic Compass Zilog z8F042AP sensor developed by e-gizmo. In addition, the robot will follow spiral direction as defined in the program.

1.1 Statement of the Problem

With so many utility tools arising today and because of the advancement of technology, there is a need for a development of semi-automated device that will mow lawn grass autonomously. Innovations of existing technology may decrease air pollutions to environment. Optimizing the use of gasoline powered grass cutter and replace it with electric powered grass cutter.

The specific problem sought to be addressed of this study are:

1. How to minimize time and ensure safety.
2. How to minimize power consumption using alternative source
3. How to trim lawn grasses autonomously, safe and environment friendly

1.2 Objectives of the Study

The general objective of this project is to design and evaluate an autonomous lawn mowing robot in trimming lawn grass in safe and sanitary way.

The following are the specific objectives of the project:

1. To determine the materials and the electronic components that will be needed in the design.
2. To design and fabricate an autonomous lawn mower from locally sourced materials.
3. To be able to use electricity in recharging a battery as a power source of the system.
4. To develop an autonomous automated system that cuts down lawn grass safely and its environment friendly.

1.3 Significance of the Study:

This intelligent autonomous lawn mowing robot aims to help the people to maintain and fully manicured residential and building lawn with small scale area in a safer and sanitary way. The usual way of grass cutting takes higher cost, time and effort on the part of the user in spite of the fact of the risks of accidents that may happen. The use of this device decreases the emission of gas elements contributing air pollutions from previously designed lawn mowers that could damage our environment. Thus, innovating the usual process by implementing the autonomous and battery rechargeable powered lawnmower will decrease the user's effort, help to preserve environment, able to do multi-tasking, with lesser cost.

1.4 Scope and Limitation

The researcher aims to design an autonomous mobile robot capable of cutting small scale lawn grasses in residential and commercial buildings specifically the carpet Grass. The system includes mechanical and electronic parts. The proponent is limiting the project with the following:

1. Blade vertical clearance is 1 inch fix.
2. Lawn shape Varies.
3. Manual settings for length and width.
4. Maximum area is at 50 meters length and 50 meters width.
5. Turning ON and OFF the system is done manually.
6. Manual battery charging. Battery specification is 12V/ 7.2AH, the duration of the battery charge could only take 2 hours and the charging time takes 5 hours maximum.
7. Humidity sensor, Bumper Switches and the PIR sensor are used for navigation.
8. The PIC16F887 microcontroller is used to control the actions of the sensors and actuators of the robot.

During grass cutting there are some areas of the workplace that cannot be reached by the blade especially grasses that are grown besides the rocks, trees, and center islands living it untrimmed. Technically, the type of ground texture should be compressed, plain, and free from stones or small objects. Furthermore, the project is designed to be autonomous during its operation and it is recommended that the site should be dry. It cannot be used during rainy days since the majority of the parts of the project are sensitive to any unwanted conductors.

CHAPTER TWO

2.0 LITERATURE REVIEW

Conventional lawn mowers are manually driven or pushed, where a driver or pusher is required to maneuver the direction of the mower on the desired course. For weeding and cutting activities, the path travelled by the mower is mostly fixed in a certain pattern predetermined by the driver or operator. Therefore, the criteria to develop an autonomous lawn mower has the primary requirement that the mower be guided to travel on a desired path with minimal or no human intervention. With the development of technology, many scientists and researchers have studied, designed, or invented various autonomous vehicles which can self-propelled and guided automatically while human only have to monitor or control through some remote means.

For most of the researches, many type of guidance systems and obstacle detection system are developed and applied to the vehicle, such as GPS, vision capture by camera, infrared or sonar wave sensor, and all these devices collect the data and input information and send for analysis and calculation by computer which then convert it into command for controlling the actuator and motor. When the actuator and motor are activated, it will control the wheel steer with certain angle or direction and the sensor attached to the wheels and actuator will give feedback information to the main computer to analyze and give a command or response for the next step. This cycle will repeat until the job is finished. This was supposed to be a good solution to autonomous vehicle but since the cost of the installation is and investment is higher, so it cannot be a popular commercial product, and the cost of maintenance will be high as well. Usually, operators who control such system will also need professional and technical skill training, and it becomes expenditure which requires more time and money.

From the U.S. Patent by ***Pansire, (1980)***, an invention of self-propelled and self-guiding lawn mower was invented. A fully automatic lawn mower which is self-propelled and guiding based on the principle of magnet following a passive ribbon or wire of ferromagnetic material. The concept of providing guidance for a machine utilizing the principal of a magnet located on the machine predetermined path defined by a passive wire of ferromagnetic material or permanent magnet that impregnated material laid on or in ground. The drive wheels are coupled to a continuously rotating drive shaft by individual solenoid actuator, the drive shaft is turned by a battery powered electric motor and the guidance system generating steering command through activating and deactivating the actuators. This invention is limited with the magnetic force is enough or not to attract and maintain the lawn mower stable and the travel path is limited by the predetermined path.

Reid, et al, (2000) from North America had carried out some research on an agricultural automatic guidance. This was then the recent research in agricultural vehicle guidance automation in North America and in autonomous lawn mowers. The conceptual framework of an agricultural vehicle guidance automation system as shown in Fig. 1 In the research, they had studied the various types of electronic device and steering controller. For the steering controller, the actuator which converts the control signal from a feedback controller to an appropriate mechanical adjustment in steer angle. Hydraulic steering system was developed around 1980, after that, the electro-hydraulic steering system was developed for agricultural vehicles. In 1998, Proportional Integral Derivative (PID) steering controller for agricultural tractor guided by a Geomagnetic Direction Sensor (GDS) was further developed to achieve suitable steering performance. The wheel position sensor calculates the angle that the wheels are turned. The machine vision" video camera scans the immediate surroundings and watches for obstacles. The global positioning system determines the tractor's precise location on the field. The inertia sensor senses the movement of the tractor in the field and calculates its path. The computer guidance control uses 'sensor fusion' to combine all of the information coming from the different sensors. The electro-hydraulic steering valve receives orders from the computer and controls the steering to cater the precise need.

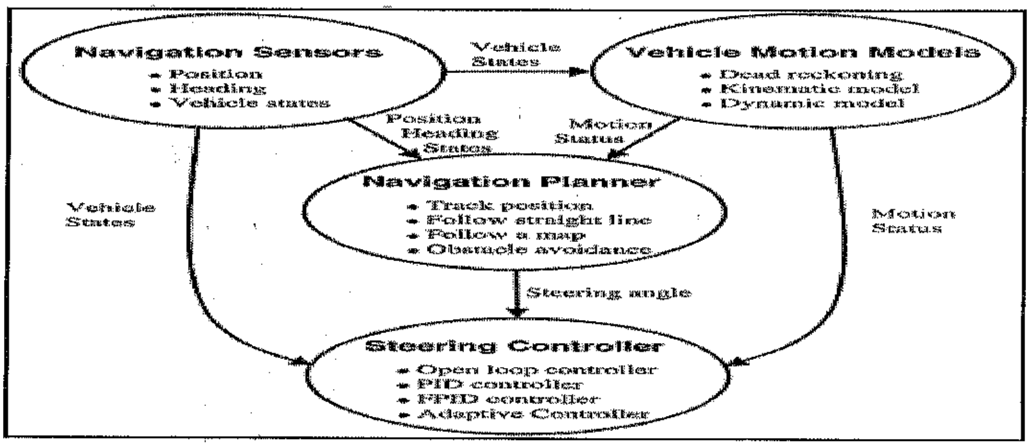


Fig. 2.1. Basic elements of agricultural vehicle automation system and autonomous lawn mower (Reid et al, 2000)

In 2002, Batavia et al., was carried out a research on autonomous coverage operation in semi-structured outdoor environment. This study focused on the comprehensive navigation system capable of extended coverage operations in semi-structured environments. The system is able to track specified paths with high accuracy, detect small obstacles reliably, and plan coverage patterns to completely cover a specified area, where, the user interface can be displayed directly on vehicle or remotely. Human intervention was occasionally necessary due to persistent obstacle detection false positives and hardware failures. Future work will concentrate on improving localization to reduce the dependence on high accuracy (and high cost) GPS, and additional testing.

Nelson, (1997) obtained the U.S. Patent for an invention of automated lawn mower. A self-propelled lawn mower which utilizing a rotating directional loop antenna to determine its positioning within the cutting area by measuring the angle between transmitters placed in the cutting area. The orientation is determined by comparing present and previous positions; the stored path information is compared with the calculated position to determine the steering signal which directs the mower to move in desired path. The direct current drive motor replaced with a clutch and gear mechanism to the drive wheel directly from the engine, an actuator would select forward or reverse gears. An operator needs to monitor and control the process via the remote control and computer. A further improvement of the information transmitting is required and the safety features need to be added. A research on an agent of behavior architecture for unmanned control of a farming vehicle was done by. They presented a hybrid agent of behavior architecture to deal with the autonomous navigation of a farming vehicle. The vehicle autonomously works local piloting; follow a tentative path predefined by human operators through a set of intermediate positions. A wireless LAN is used to get a bi-directional communication between the vehicle and human supervisor. Sensor-fusion algorithms are proposed to overcome the lack of GPS signals so as to obtain continuous and precise positioning. The autonomous tractor focused on the steering wheel and on the brake and clutch pedals, maintaining the manual driving mode. Different solenoids/electro -valves and actuators were integrated for the steering control system. In the experiment, gradual action was achieved by pulse width modulation (PWM) control of the three-way-valve that commands the steering hydraulic circuit and its schematic is shown in Fig. 2. A closed-loop control system is required to reach and keep the steer angle reference.

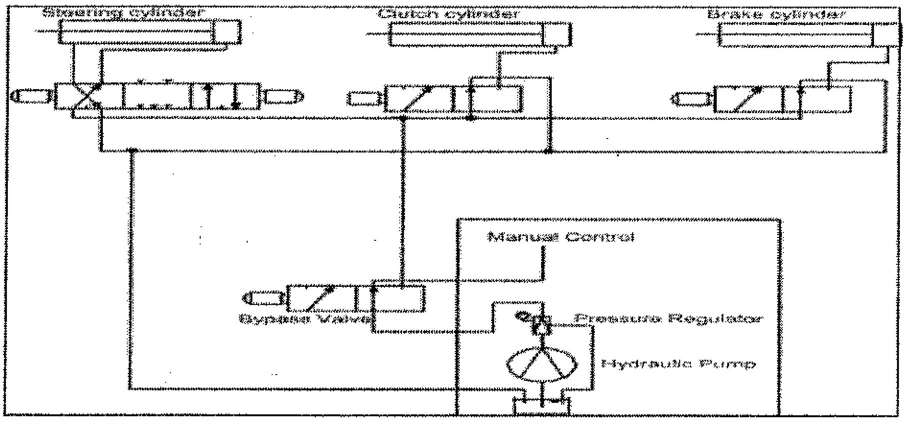


Fig. 2.2. Schematic of the hydraulic system mower (Garcia-Perez, L., et al, 2007).

A model recognition and validation for an off-road vehicle electro hydraulic steering controller was done by ***Zhang, Q. (2002)***. Automated steering control is essential for autonomous off-road vehicles which use an electro hydraulic (E/H) actuator to implement the steering control as can be seen in Fig. 3. The design and validation of an E/H steering controller through a combination of system identification, model simulation and field test was presented. A kinematic model of the steering linkage geometry provided the gain between the hydraulic actuator and the front wheel. The system model was used to close the steering control loop based on the feedback signal from the hydraulic steering actuator rather than from the front wheels. The simulation and vehicle test result indicated that, the developed steering controller was capable of efficiently handling the non-linearity and dynamic asymmetry of the E/H steering control system. It was also found to be capable of achieving prompt and accurate steering control on an off-road vehicle regardless of the nonlinear nature and the changing ground conditions.

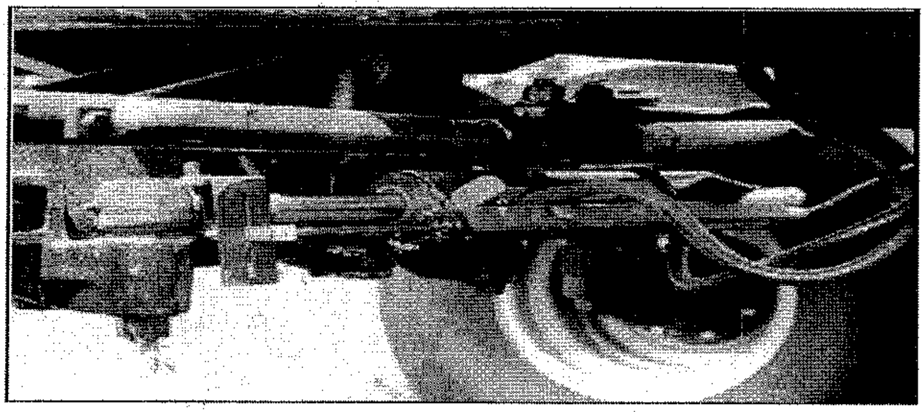


Fig. 2.3. Hydraulic steering actuating system on the test vehicle (Zhang et al, 2001).

Recently in 2008, Cohen et al. tried the simulation of moving lawn area which is continuous planer area by a mobile robot. The robot is given as input a bitmap of a known geometric area and derives an optimal covering path by implementing and improving the well-known on-line Full Scan Spanning Tree Covering (STC) algorithm. Their algorithm is shown in Fig. 4.

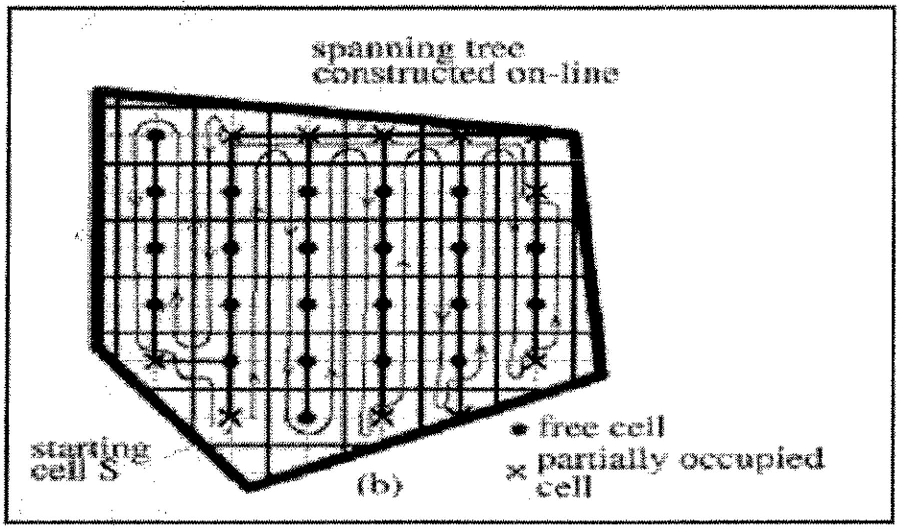


Fig. 2.4. Grid approximation of a given work area and the spanning tree (Cohen et al, 2008).

An efficient area coverage algorithm should meet several performance measurements.

1. Run-time should be fast and efficient – which is accomplished by the robot being able to calculate its movement on-line. For very large areas if run-time is slower than linear, the robot will not be useable.
2. The over-cover measurement is the relative size of the area that is covered more than once by the robot. This measurement should be as low as possible. As the over-cover measurement grows, the overall time to cover the entire area rises, which increases the cost of using the robot (money, energy, time and resources).
3. Turns are the number of turns made by the robot as it moves. The number of turns should also be as low as possible for the same cost reasons as mentioned above. Similarly ***Wong et al (2003)*** studied the topological coverage algorithm for mobile robots. It uses natural landmarks in the environment to construct a planar graph representing a decomposition of reachable surface into simple sub regions that can be covered by a zigzag pattern. The grid based methods generally used for navigation in coverage applications can require considerable memory and computation and is susceptible to odometry error. On the other hand, the topological map used in this paper is proven

to be robust against sensor and actuator noise. It is also compact as its resolution corresponds to the complexity of the environment.

The earliest walk-behind style lawnmower was the reel type with both motive and cutting power being supplied by the operator. Modern rotary mowers began appearing in the 1930s, when light and powerful enough engines became available to spin a blade at high enough speeds. Powered versions and riding mowers have become ubiquitous but the technology has not fundamentally changed. That is, until very recently when modern electronics has made it possible to completely automate the machine.

In 1995, Husqvarna released the first version of its Auto-mower. Since then, they have sold over 100,000 robots around the world. It would seem that they have pretty much figured out how to build autonomous lawnmowers, but how well do they perform? One of the key features of a freshly cut lawn is the regular pattern or parallel lines left behind on the grass. The Auto-mower zigzags randomly around the lawn, which will probably eventually cut all the grass but is far from efficient about it and doesn't leave behind a high quality of cut or visually pleasing pattern. The boundary of the lawn must be defined by a guide wire buried in the ground, which can be cumbersome to install and restricts future changes to the landscape. This is also the only way for it to mow up next to obstacles such as the house or flowerbeds. The last resort for an unexpected obstacle in the mower's path must be dealt with by physical bump sensors. If the obstacle is a tree or rock, this is a satisfactory solution. It bumps it, backs up and finds its way around it. If the 'obstacle' happens to be a small child or pet, this is a much less acceptable solution. We also reviewed some related studies that may provide understandings in the design and development of Digital Compass-aided Autonomous Lawn Mowing Robot.

2.1 Autonomous Lawn Mower:

This lawnmower requires boundary wire to be installed around the perimeter of the lawn area. Additionally, this mower used a random path which requires more time to mow and also they do not leave the typical clean mowing lines that people have come to expect in a well-manicured lawn. This project begins the design for a lawnmower that can not only mow a lawn autonomously, but also navigate in straight parallel paths. Placing the shaft encoder in a more protected location would be a good improvement over the current design which leaves it exposed and prone to damage. The project technical system aided the researcher in designing its control system. Furthermore, the project is operated by a gasoline engine instead of electric source in which giving advantage for the researcher since this particular project will be made of electric powered system in which it will lessen the cost for power consumption.

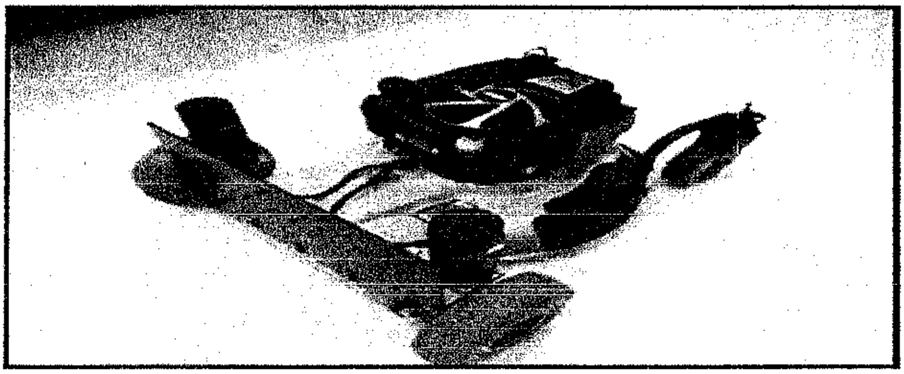


Fig. 2.5. Autonomous Lawnmower (Indiana University).

2.2 Vision-Based Obstacle Detection Lawnmower:

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. Furthermore, it is stated that RGB color values and hue values at corresponding saturation values have been found to be insensitive to shadows and changing lighting conditions. Based on this study, ION (Institute of Navigation) competition obstacles such as fencing are either black or white, they are heavily saturated making it possible to create a robust obstacle identification system that relies on hue values alone and yields few false positives during real-time operation. The CWRU grass cutting robot design gives an idea to the researcher based on the system design and its execution in said task. The system help the proponent's way on designing 10 its own system especially the architectural design, the technology used takes great cost and impractical to use for such simple task and it seems not user friendly for average user.

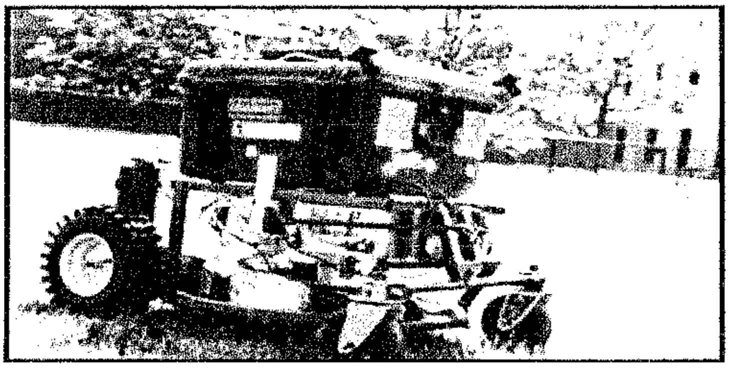


Fig. 2.6. CWRU Cutter (Cleveland Ohio)

2.3 GPS-Aided Autonomous Lawnmower

The design of the Miami Red blade III is subdivided into five main systems: the sensing system, the control system, the monitoring and testing system, the safety system, and the base mower mechanical chassis system. Figure 3 shows a flow diagram presenting the relationships between these five bus-systems. Figure 4 displays a picture of the final physical implementation of the lawnmower. The current implementation employs the same mechanical chassis system and safety system of the Miami Red blade II. However, the current of this lawnmower has been upgraded with a modified DGPS system, new wheel encoders, and a more advanced control system. In addition to this, acoustic sensors and a laser ranging system have been added in order to supply obstacle detection capabilities. Figure 5 shows the random path of the design.

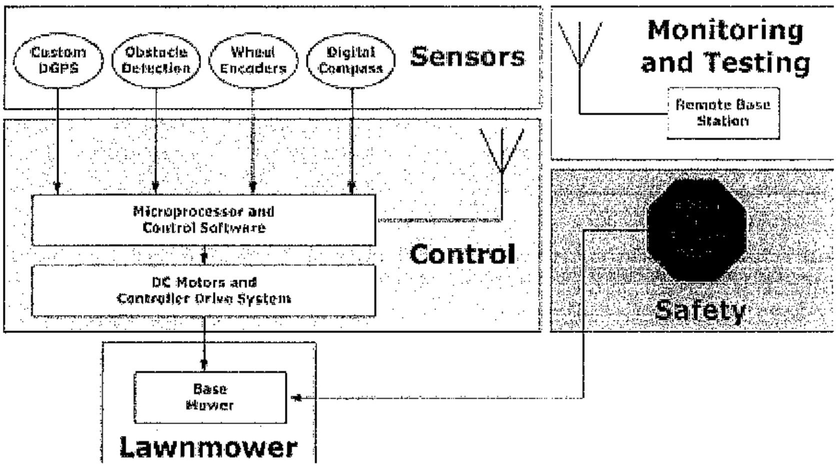


Fig. 2.7. System Block Diagram of GPS-aided Lawnmower

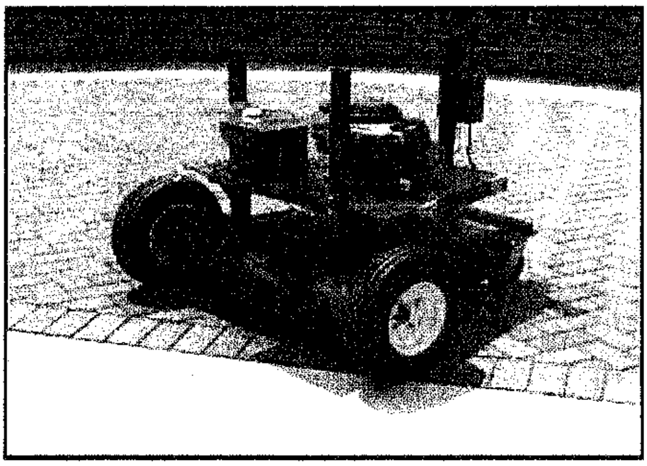


Fig. 2.8. Red blade III (Y. Morton)

The overall cost of the project is in great value and yet increases its capability. The system requires two way power source; electricity and gasoline for its rotational blades. The researcher aims to optimize the consumption of this energy in order to meet its objectives. This project will use a digital compass for navigation instead of using GPS. Using digital compass is relatively the same with the function of using GPS, but for such application GPS will give complexity and over powering its ability for such task.

The figure below shows its result on actual simulation. Considering the performance of Red Blade III, the researcher will design a practical way compared to the existing system. In addition, it takes more time to complete task in random approach rather than following a predefined path.

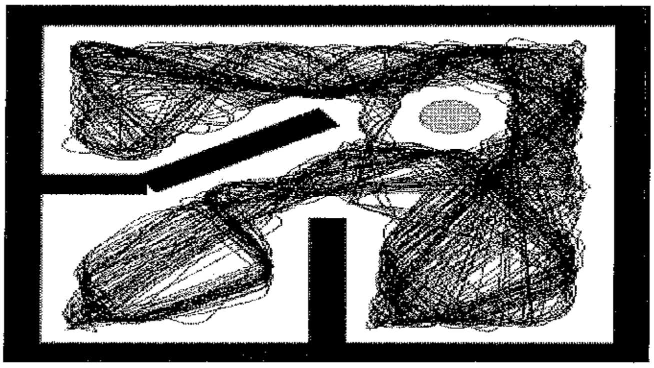


Fig. 2.9. Pattern Result (Y. Morton)

2.4 Brief History of Autonomous Robots

Autonomous mobile robot concept is a relatively-new topic when whole robotics is considered. The term **"robota"** was first used in a play by a Czech author Karel Capek in 1921. Etymologically, the word **"robota"** means **"servant"** in Czech language. The word "robot" was first introduced in English by Rossum's Universal Robots. They conceived a future of fully-automated workers. Considering the historical examples of autonomous mobile robots, it is necessary to mention ***Grey Walter's mobile robot, "Tortoise"***. Grey Walter (University of Bristol, UK) was building three-wheeled mobile robots in 1950. Tortoise uses two basic sensors like a light and a touch sensor.

Hilare Mobile Robots created a breakthrough in mobile robotics. The Hilare family was developed in LAAS in years 1977 to 1992. First Hilare robot, Hilare-I was developed in 1977. Two driving wheels and a caster wheel are used in actuation. Multibus is used as the bus in that robot with four Intel 802286 processors. In communication, a 9600 baud serial radio modem is used. The robot had odometer, 16 US sensors, and a laser range finder as the sensor equipment.

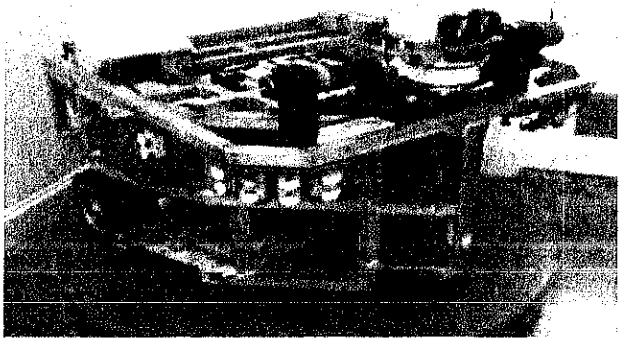


Figure 2.10. Hilare 1 Mobile Robot

2.4.1 Lawn Mower, the History

The first tool ever used to cut grass to a more desirable length was the scythe. The scythe has a simplistic design, containing a long wooden handle with a curved blade attached perpendicularly to the end. Until the 19th century, the scythe was the only option for cutting grass, which proved to be a long tedious process. The first actual mower was invented in 1830 by Edwin Beard Budding. Budding was an engineer from England who first discovered the idea of a mower from a cylindrical machine used for cutting in a mill. The mower that he developed was composed of a large roller which provided power to the cutting cylinder using gears. The cutting cylinder contained several blades connected in series around the cylinder. His innovation opened the door for numerous advancements in lawn cutting.

In the 1920s and 1930s the electric powered mower, along with rotary cutting, were created but did not become popular until considerably later. Throughout the 1940s the only innovations were developing smaller, lighter weight designs along with more powerful engines. In the 1960s, the designs were now being produced in plastic materials to further reduce the weight and cost. When using metals for our robot there will be a need for welding (manual welding and robotic welding). ***Adekunle A.A et al (2012)*** agree that manual welding is cost effective compared to the robotic welding. Cost of maintenance of robots is so exorbitant to the extent that ordinary person cannot afford it.

Three main types of mowers now came to the picture, *the walk-behind, the riding and the tow-behind mowers.*

1. ***Walk-behind mowers*** were the first invented and by far the simplest. The main problem of a walk-behind mower is that the amount of lawn mowed is extremely small compared to

that of the other two types of mowers. Not to mention one must literally walk behind it for the duration of the lawn mowing, which could be hours or even days. Walk-behind mowers can be completely mechanical, like the first lawn mowers, gasoline powered or even electrically powered.

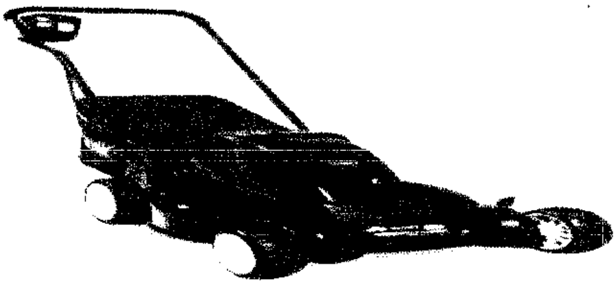


Figure 2.11. Walk Behind Mowers

2. ***Riding mowers*** are much more complex. An operator is riding on the actual mower, which is ran by a much larger engine than in the walk-behinds. They can be much larger than walk-behinds and can move faster and for a longer period of time, considering an operator would need a break after a little time using a walk-behind. For a visual concept of a riding mower, the Dixie Chopper.

Figure 2.12. Riding Mower

3. ***Tow-behind mowers*** are used for much larger areas, like massive fields, and are used much more in agriculture and road sides. Tractors or powerful vehicles must tow these devices. Most are mechanical, much like some of the first lawn mowers ever invented. They use the rotation and energy from being pulled over ground to rotate and cut grass, sod or whatever needs to be cut.

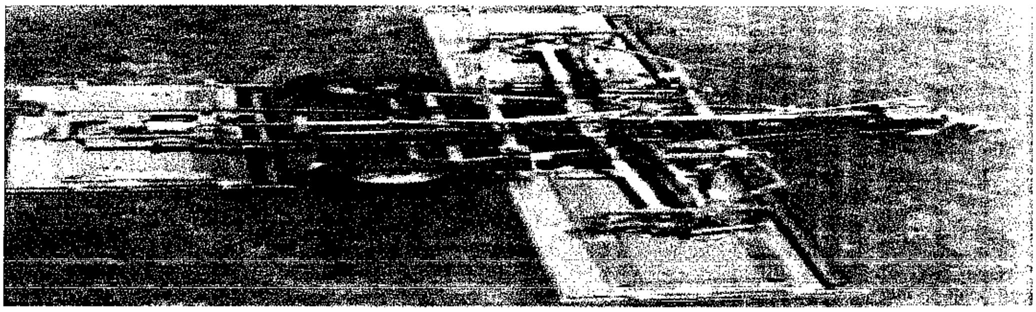


Figure 2.13. Tow Behind Mower

2.5 Cutting Patterns

Lawn mowers can have two types of cutting styles: spiral and random.

The spiral cutting pattern is achieved when both wheels turn at two very different speeds with the outmost wheel moving the fastest. This can be done by applying two different PWM signals.

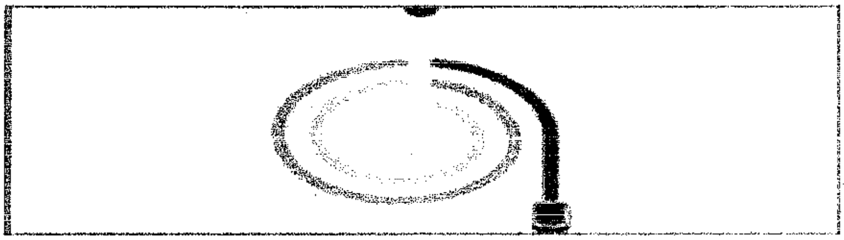


Figure 2.14. Spiral Cutting

The random cutting pattern only occurs once the humidity sensor tells the microcontroller that it is on concrete, then the robot will change cutting pattern and will randomly cut the grass. Essentially, the robot will cut linearly until it is interrupted by the humidity sensor or the ultrasonic sensor. If it is interrupted by the ultrasonic sensor then that means there is an object in its path and will back up and turn right. In the case that the humidity sensor measures low humidity (on concrete) it will also stop and back up and turn right. Theoretically if the robot has enough power it can cut the entire lawn.

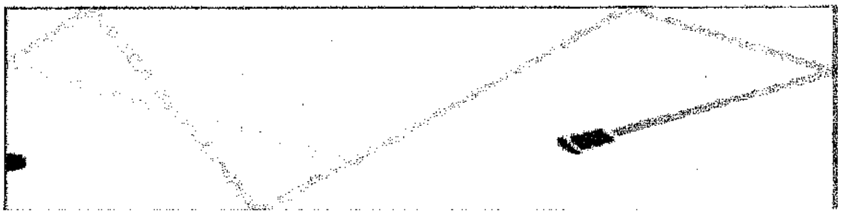


Figure 2.15. Random Cutting

CHAPTER THREE

3.0 METHODOLOGY

The lawn mower body was first designed with Autodesk Inventor to give an idea of how the robot will look like. The electronic parts were later taken into consideration. First, we thought of how to power the lawn mower and we came up with the idea of charging its battery from the sun even while it is at work and we can also charge it directly from the electrical power source. Either ways, the battery required to power the whole system must be charged. So we used the proteuse software (The ISIS and ARES software) to design the power circuit and the control circuit.

3.1 The Target of Study

Grass is the target of study. It must be able to Cut grass, and must follow all the laws of a robot. The laws of robotics are:

- A robot must not harm human being or by inaction bring harm to human
- A Robot must obey human being unless it is in conflict with a higher order law
- A Robot must protect itself from harm unless it is in conflict with a higher order law
- A Robot must not harm humanity or by inaction bring harm to humanity.

This design contains a microcontroller, some sensors, DC motors and a charging system.

Adding these elements together, we get our robotic lawn mower. The sensors are the eyes of our robot. The goal was to let our robot see the difference between grass and concrete while monitoring its surroundings continuously. Our robot needs to detect if it is on grass versus on concrete and we decided to use a humidity sensor. Since concrete/dirt and grass are distinctively different in density and moisture levels, the humidity was a good factor to distinguish both materials. In addition to sensing humidity, we wanted object detection; both humans and objects. An ultrasonic sensor is used to detect if the robot was heading into an object. Safety is the main concern when designing a robot with blades. We don't want our robot to start operating if it was being held in the air by the user. To power the system there are many options. With recharging batteries, there are various chemistries but we decided to go with the Lead acid battery. The Lead acid battery is found to be the best because charging and monitoring a lead-acid battery is very simple, we just need to monitor the battery voltage having a microcontroller on-hand.

Sizing the battery will depend on what we are powering, specifically the motors. We went with two 7.2AH DC motors with integrated gear heads. The needed torque did not need to be a lot because we were going to have a small prototype. The block diagram of our design is shown in figure 3.1.

3.2 Block Diagram of the Proposed System

The figure below represents the block diagram of the proposed system. The brain part of the system is the micro-controller (PIC16F877A), there is an array of sensors arranged for safety of the robot and the environment. Ultrasonic sensor is used to detect the obstacle in the path of the robotic mower. In the device Lithium polymer battery is used because its gives a higher power for the motor. For the movement of the system stepper motor with 200 rpm rating are used. And for the cutting blade, it chooses BLDC motor with 1200KV rating which gives 19980 rpm at 11.V supply. Solar panels used is 12v 2300ma rated one.

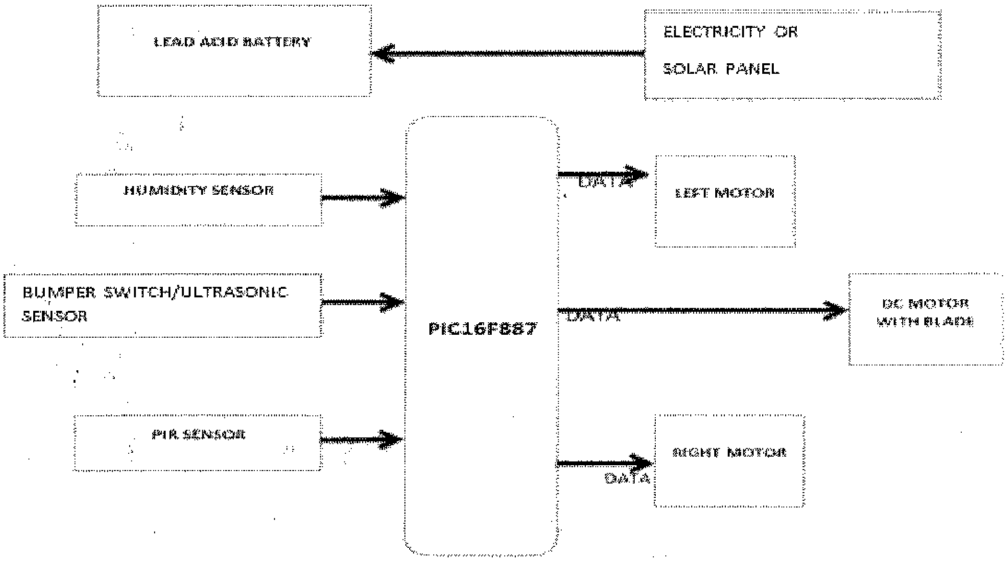


Figure 3.1. System Block Diagram

Determining where to place our sensors is crucial to the overall effectiveness of our design. Initially, we knew to place the humidity sensor facing down into the ground. The solar panels were to be placed horizontal on the robot because to achieve maximum sun exposure. The microprocessor must be in the robot to protect it from the natural elements. Our ultrasonic sensor will be mounted directly in front of the robot for maximum detection. The only sensor that will be angled is the PIR because it needs to detect humans and since the robot is at ground level it must be facing up to effectively detect humans.

3.3 System Overview:

The researcher takes several steps to meet the objectives of the project design. This levels are the following; System Requirements, Hardware Selection and Designing, Hardware and Software assembly. These steps are illustrated by Figure 3.2.

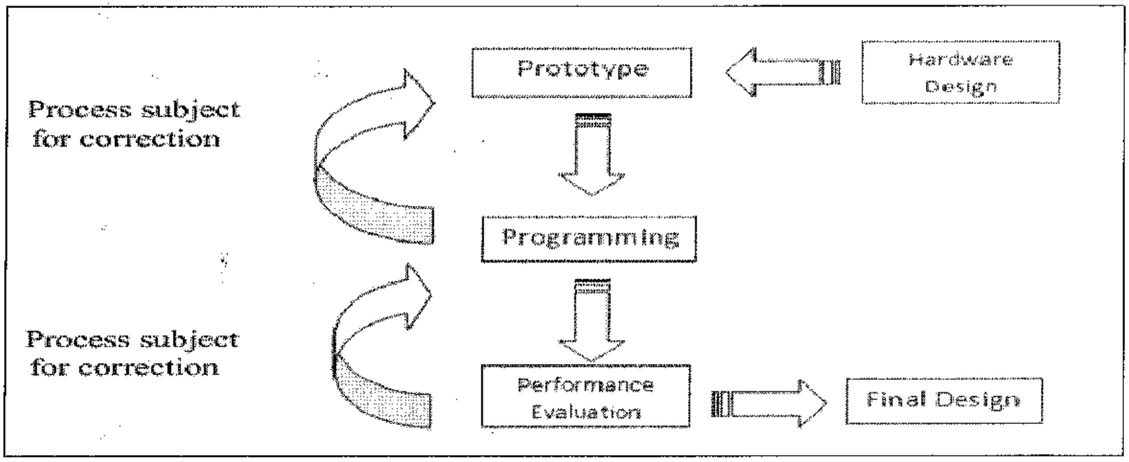


Fig. 3.2. The Project Evaluation Flow Chart

3.4 Microcontroller System Requirements:

The type of computer must meet the requirements for the development environment use in this project. The **PICKit 3 programmer** is used to program the microcontroller

Table 1 shows the recommended host computer requirements. We used a **MikroC PRO Compiler** for Windows XP.

Table 1. Computer Requirements

Computer System Specification	
Operating System	Windows XP SP2 /Windows 7/ Linux /Mac
System Memory (RAM)	512MB/ 1GB or higher
CPU(Central Processing Unit)	Pentium 4, 2.0 Ghz processor or Higher
Hard Drive	40GB or greater
USB Port / Communication Port	Supported by 2.0 version

3.4.1 The PIC16F887 Microcontroller:

Microcontroller is single chip device containing the processor along with memory and interface devices on the same integrated circuit chip. It is developed for use in control appliances, automotive, entertainment and telecommunications industries.

3.4.2 Interfacing with the Microcontroller

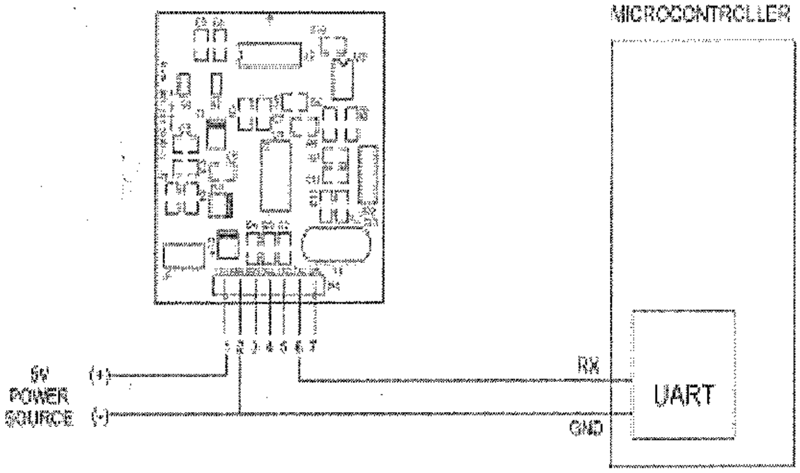


Figure 3.3. Interfacing with Microcontroller.

The figure above shows the wiring diagram between the two modules. Pin 6 in digital compass module was the transmitter and on the other side was the receiver of the microcontroller which was pin 0. Heading values are serially transmitted to the microcontroller module and it was then saved to a buffer.

The following detailed values are:

- DPDT(Double Pole Double Throw)
- 12V DC SPDT (Single Pole Double Throw)
- 12V DC 2N2222, 0.8 A NPN transistor
- TIP 29, 3A NPN transistors
- Resistors (1Kilohm)
- LED(light emitting diode) indicators
- 1000µF, 25V
- Inductor

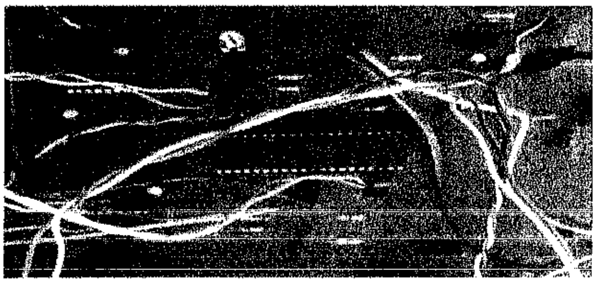


Figure 3.4. Motor Control System

3.4.3 Characteristics of microcontroller:

- Compact and low cost
- RAM from 1k to 100k of bytes
- Clock speed is in tens of MHz
- Uses internal bus to communicate with memory and other devices on the chip
- Processor - used to execute program instructions. Called the Central Processing Unit (CPU). Processor contains
  - Control Unit – Determines timing and sequence operation
  - Arithmetic Unit – performs logical evaluations and data manipulation
  - Registers – memory locations inside the CPU that holds internal data while instructions are being executed.

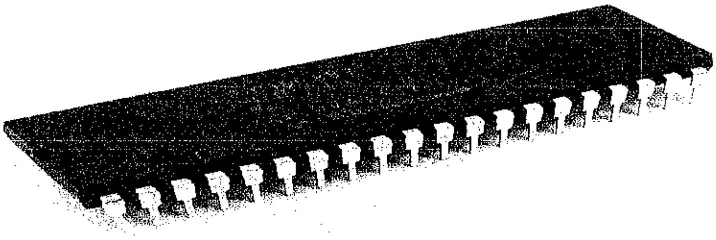


Figure 3.5. PIC16F887 Microcontroller

3.5 Lead Acid 12v 7.2AH Battery

The researcher used lead-acid 12V, 6AH maintenance free rechargeable battery as the main power source of the robot. This type of battery was chosen because of its non-spillable, long life span and can sustain average power for the system. Lead acid batteries are most economical for larger power applications where weight was little concern.

Figure 3.6. Panasonic Maintenance Free Battery

The following are the specifications of the battery used [12]:

- Open-circuit (quiescent) at full charge: 12.6 V (2.1V per cell)
- Open-circuit at full discharge: 11.7 V
- Loaded at full discharge: 10.5 V.
- Continuous-preservation (float) charging: 13.4 V for gelled electrolyte; 13.5 V for AGM (absorbed glass mat) and 13.9 V for flooded cells
- All voltages are at 20 °C (68 °F), and must be adjusted −0.0235V/°C for temperature changes.
- Typical (daily) charging: 14.2 V to 14.4 V (depending on temperature and manufacturer's recommendation)
- Equalization charging (for flooded lead acids): 15 V for no more than 2.205 hours. Battery temperature must be absolutely monitored.

3.6 Brush Motor:

The brushed DC electric motor generates torque directly from DC power supplied to the motor by using internal commutation, stationary magnets (permanent or electromagnets), and rotating electrical magnets. Like all electric motors or generators, torque was produced by the principle of Lorentz force. Advantages of a brushed DC motor include low initial cost, high reliability, and simple control of motor speed.

Fig 3.7. DC Motor Brush Dc Motors RS-775W-A09 12V Lawn Mower Motor

We used improvised tachometer using limit switch attached beside the blade. The outer part of the blade was attached with a small ramp causing the switch to turn on and off. This procedure was done for measuring the RPM (revolution per minute) for this type of motor. Technically the batteries were fully charge and directly connected to the motor. The measured RPM for this motor was approximately equal to 5789 rpm, while the existing battery operated lawnmower has a 6600 rpm. The result reading was taken at the serial monitor using gizduino microcontroller and was programmed to count pulses per minute. Based on the values it seems different but nearer to the based value.

3.7 Hardware and Software Assembly

Figure 3.8. Shows the microcontroller network where source code is made and compiled using **MikroC PRO** compiler. This data is then uploaded to the on board microchip of the microcontroller using a **PICKit 3 programmer**, in which this data will perform several instruction sets enabling the system work in sequence.

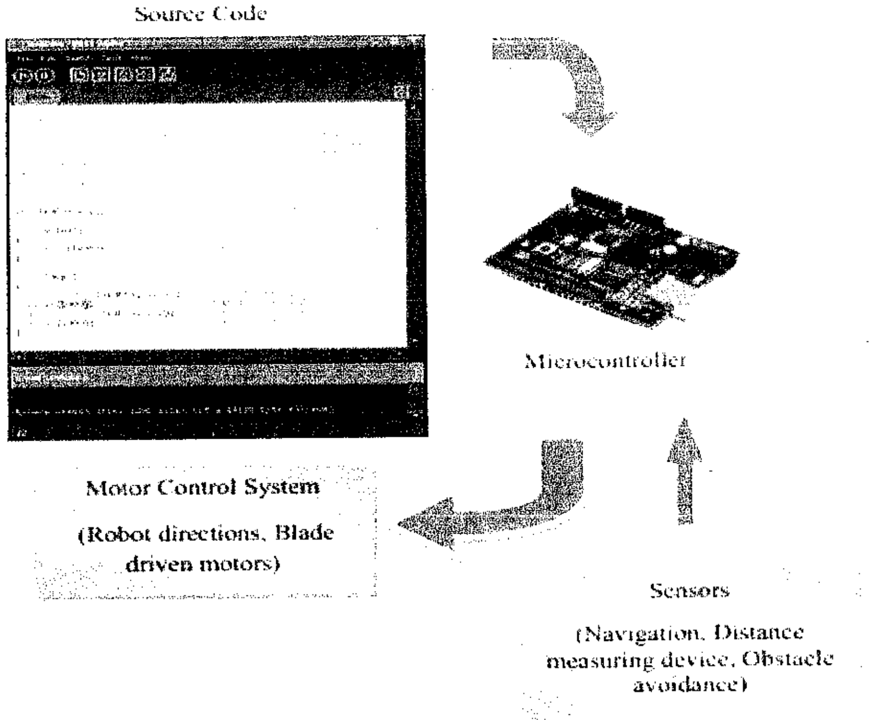


Figure 3.8. System Interconnection Diagram

The source code or the textual programming was compiled using **MikroC PRO Compiler**, basically used C++ programming language. After compilation, it was then uploaded to the controller board PIC16F887 microcontroller through Prolific USB to UART interface. The program sequence executes series of equivalent task with respect to the main function and purpose of the project. As shown in the Table 2, sensors or switches as well as the digital compass are treated as inputs. It was then computed and converted to equivalent action. The motor control and indicators were treated as outputs, able to respond sets of instructions for maneuvering the robot's destination.

3.8 Mechanical System

The Power Transmission often includes a Gear Ratio or Mechanical Advantage. A Gear Ratio can increase the output torque or output speed of a mechanism. The Gear Ratio is defined as the input speed relative to the output speed. Gearing is employed in the transmission, which contains a number of different sets of gears that can be changed to allow a less speeds but greater torque at the wheel. The gear ratios inside the gearbox are important because different gear ratios will change the characteristics of robot's performance.

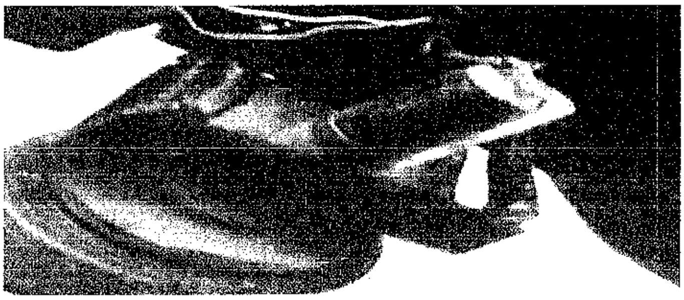


Figure 3.9. Motor Gear Reduction

3.9 Components Used

1. **THE PIR SENSOR:** The **RB-Plx-75** from **Parallax** is a PIR sensor was chosen base on short range abilities. If the robot detects a human close up then it will stop whatever it is doing until the human leaves the area. This specific PIR sensor will output a pulse of 5V if it detects humans and will output 0V during idle. The advantage of this sensor is that it will reset itself if when it detects nothing. But if it detects something multiple times then the output will stay logic high (5V) until the human leaves the area. This feature was used in our design to let our robot know the difference between someone who is just passing by and someone else who is staying too long in the area, which is a dangerous situation. This chip has three pins: Vcc (5V), ground, and 'alarm' data pin.

Figure 3.10. PIR Sensor

2. **THE HUMIDITY SENSOR:** The microcontroller sends a signal to the humidity sensor for 40ms to activate the sensor. The sensor now responds to the mic for like 70ms, then the sensors checks for 40bit signal. The first 8bits checks for humidity, the next 8bit checks for the fractional side of it which is usually 0. It then checks for the temperature which is a whole number. The fourth checks for the fractional level of temperature which is zero. The fifth bit checks if all the information required is complete, it is usually called the check sum. The collector is connected to 5v pin 33 of a microcontroller. When PIR sensor goes high, it activates the base of the transistor. When pin 33 goes low, the motor should stop for 3seconds+.

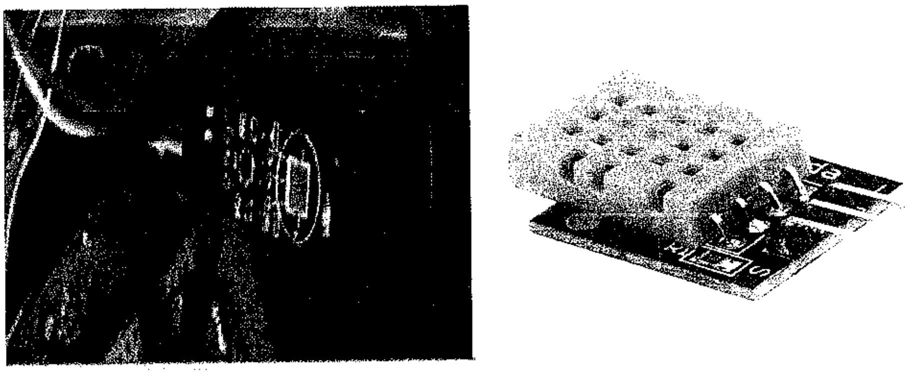


Figure 3.11. Humidity Sensor

3. **Bumper Switch:** The **bumper switch** is a pushbutton that when pressed can cause the robot to respond as programmed. It does this by maintaining a HIGH signal on its sensor port, which means the **bumper switch** is turned off when not pressed. The **bumper**

switch is a pushbutton that when pressed can cause the robot to respond as programmed. It does this by maintaining a HIGH signal on its sensor port, which means the **bumper switch** is turned off when not pressed.

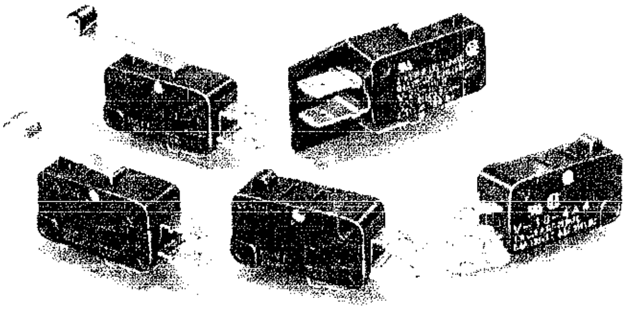


Figure 3.12. Bumper Switch

4. **LEAD ACID BATTERY:** A lead acid battery gives much longer life if it is never drained more than 75% of its capacity. Assuming we need a minimum 1 hour run time, then to leave a 75% reserve would need a 1.5AH/0.25 = 6AH battery, 7AH being the nearest size. The size of such a battery would mean it will not be possible to protect it under the waterproof lid, so it would need to sit on top of the lid. This makes the mower higher and the locomotion motors need to carry the weighty battery, so may have difficulty on an incline.
5. **CUTTING MOTOR:** The mower blade needs to turn very quickly and have reasonable although not excessive torque. Too much torque could prove dangerous in case it hits a foot, will use a lot of current and should be unnecessary for a 'maintenance cut'.

Figure 3.13. The Cutting motor

6. **DRIVING MOTORS:** The driving motors are located at the left and right side of the wheel. They are used to drive the mower and also used for turning into directions. To turn to the left, the left wheel motor will be stopped while the right wheel motor keeps rotating till the robot makes a successful angle turning.

Figure 3.14. The driving motor

7. **MICROCONTROLLER:** The PIC16F887 microcontrollers were programmed and used to direct the function of the robot. It is one of the latest products from microchips. It features all the components which modern microcontrollers normally have. It was used due to its low price, wide range of application, high quality and easy availability. It is an ideal solution in applications such as; the control of different processes in industry, machine control devices, measurement of different values etc.

3.10 Software Used

We made use of:

- Autodesk Inventor
- Proteuse
- Mickro C PRO for PIC

3.10.1 The Autodesk Inventor design

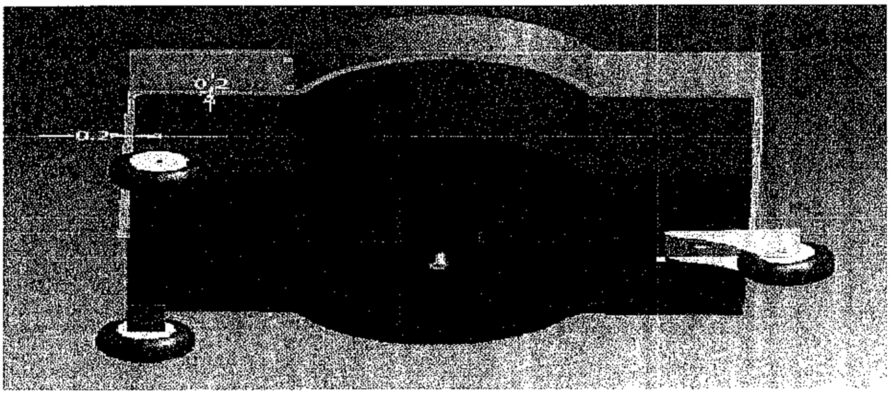


Figure 3.15. Bottom view of the 3D modelling

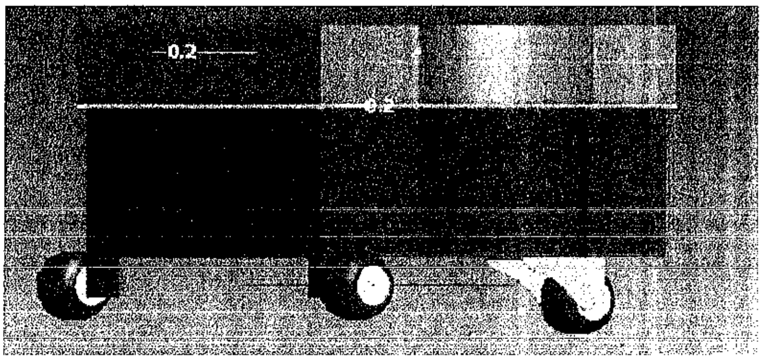


Figure 3.16. Side view of the 3D modelling

The mechanical body consists of

- The wheels (3): 2 driving wheels and a Castor

Although a four wheel design may be more stable, a two-wheel + castor design is easier to control and manufacture so I set about designing such a chassis.

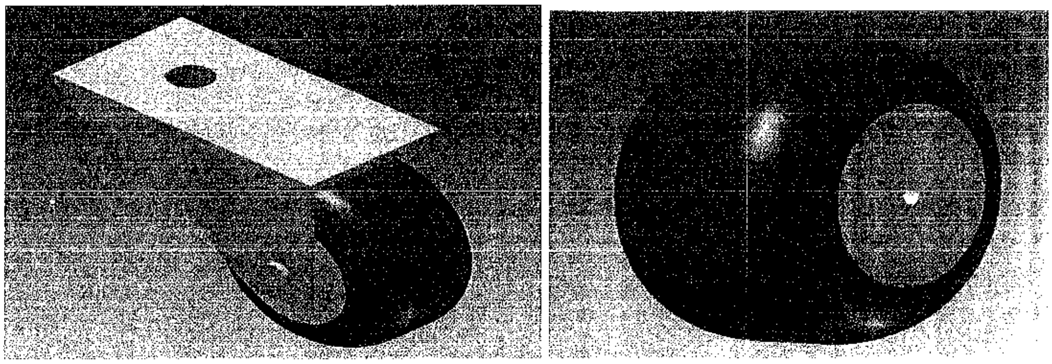


Figure 3.17. The 3D modelling of the wheels (castor and 2 pairs of wheel)

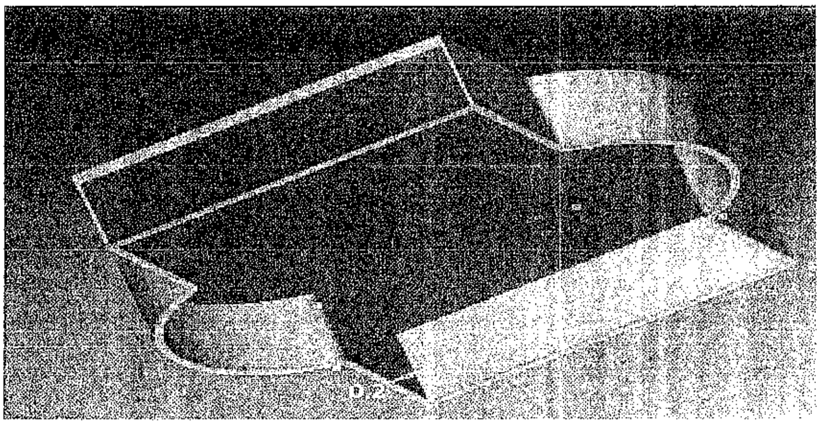


Figure 3.18. The 3D modelling of the cover

- The body

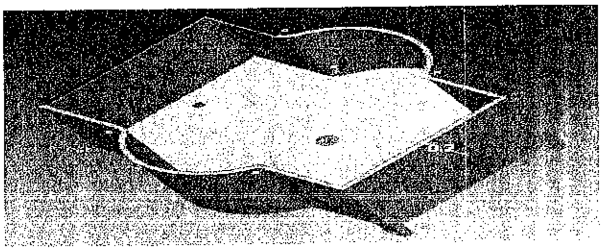


Figure 3.19. The 3D modelling of the Body

- The blade

The blades are a problem, they need to be sharp but not so sharp they cause major injury if the mower rolls over your foot. Put a picture of wind turbine or mower blade.

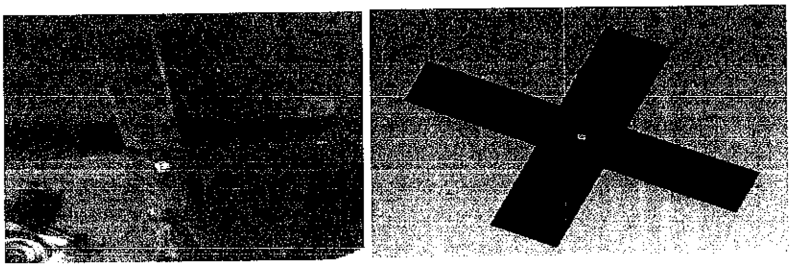


Figure 3.20. The cutting blade

3.10.2 The Electronic Circuits Generated by the Use of Proteuse

THE 12V POWER CIRCUIT

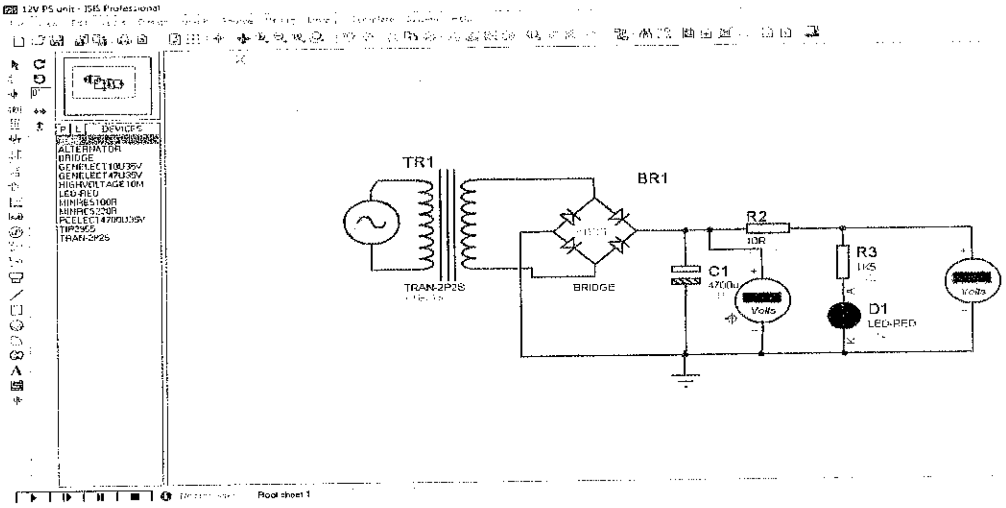


Figure 3.21. The Electrical Power Source

3.11 DESIGN CALCULATIONS

Formula

Gear Reduction, Note that the wheel diameter is 9cm.

Number of teeth that mesh = $nrev_{in}\ 2\ \pi\ r_{in}\ /\ Pd$

$\tau_{OUT}\ /\ \tau_{IN} = \rho_{OUT}\ /\ \rho_{IN}$ (torque relationship in terms of radiuses)

Gear Ratio = $\omega_{IN} : \omega_{OUT}$

Where:

$nrev_{in}$ - number of revolution of input gear
$2\ \pi\ r_{in}$ - circumference area of input gear
Pd - Pitch diameter
τ - Torque
ω - Angular velocity in radian per seconds

Output Torque = Input Torque x Ratio of Gear Increaser
Output Speed = Input Speed / Ratio of Gear Increaser

Area Computation

$A_{left} = A_{input\ area} - A_{mowed}$
$A_{mowed} = A_{width} + A_{length}$
$A_{width} = \sum \{2\ [0.127(W) - (w+1)]\}$
$A_{legth} = \sum \{2\ [0.127(L) - (\ell+1)]\}$

Where: w & ℓ - are the updated width and length as it tends to the center or at the origin wherein length and width are equal to zero.
5 inches = 0.127 meters

Wheel Encoder

1pulse = 4 inches = 0.33ft
1m ≈ 9 pulses

3.12 THE CONTROLLER CIRCUIT

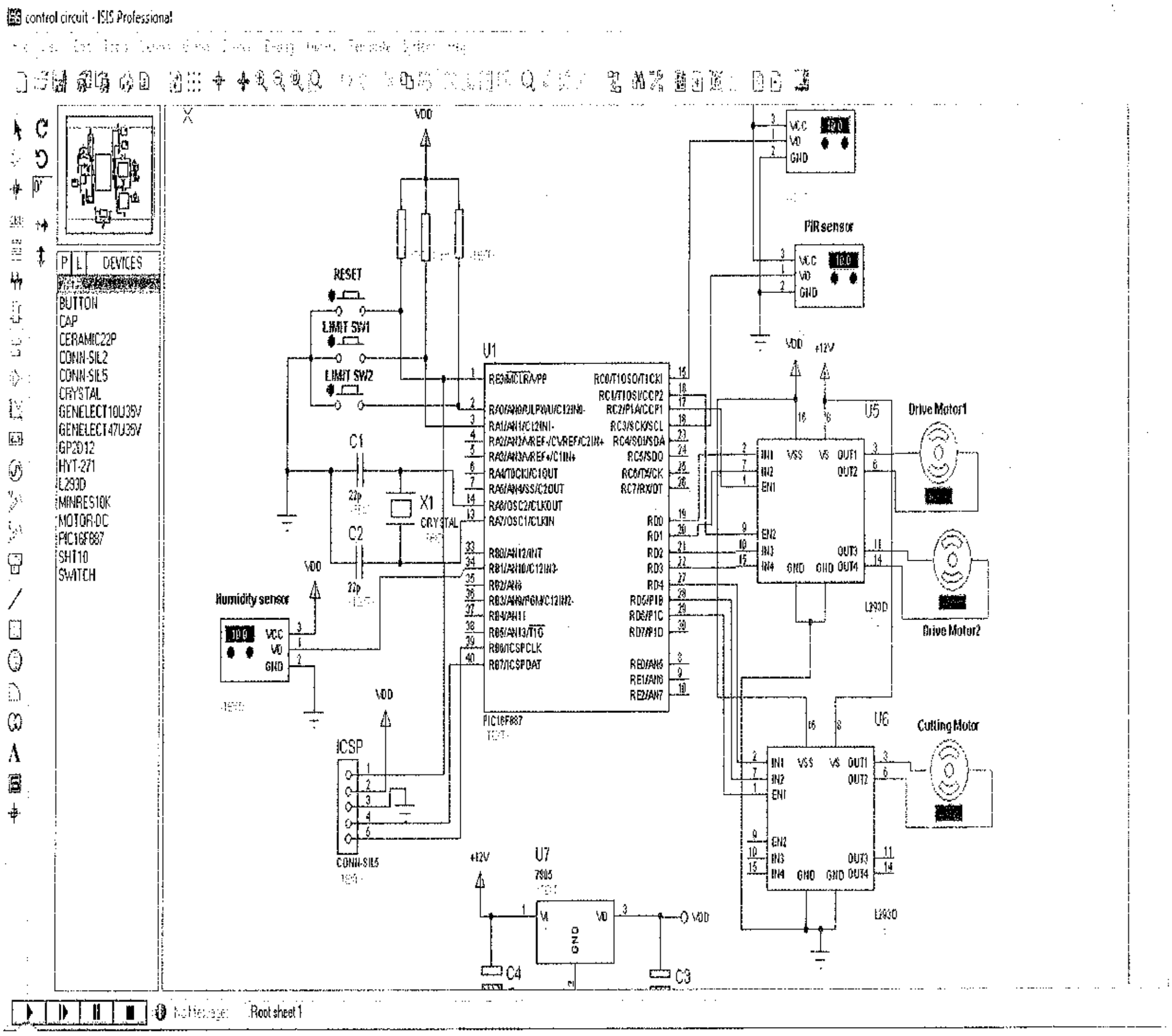


Figure 3.22. The Controller Circuit

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The objectives of this project are to design an autonomous automated lawn mower and test its effectiveness. The main part of the system is the motor control, navigation system due to obstacles, and cutting deck. This chapter covers the results of the design, development and testing of the overall system.

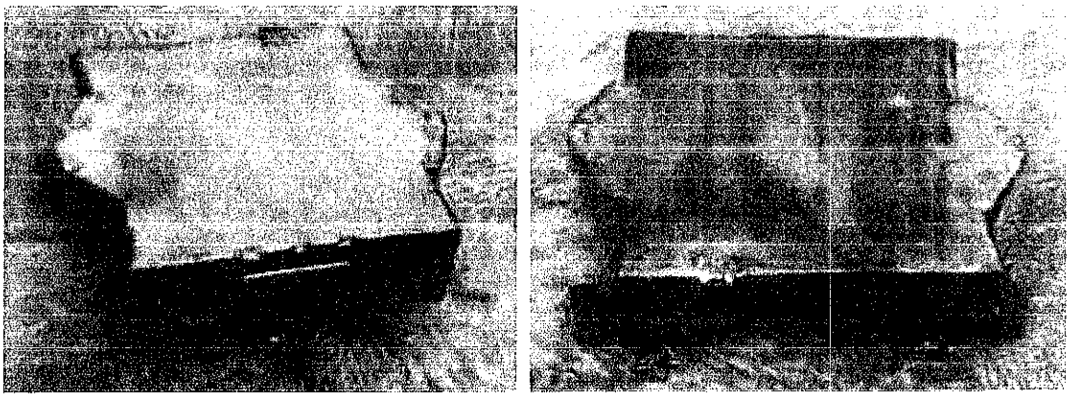


Figure 4.1. The final design of the Autonomous lawn mower

4.1 Motor Control Test

The motor control must be responsive making it sure that the system works properly. The system comprise of two different set of drivers (1 for the driving motors and the other for the cutting motor), Pic 16F887 microcontroller, 5V voltage regulator, sensors (PIR sensor, humidity sensor and bumper). The following figures below shows the step by step testing process.

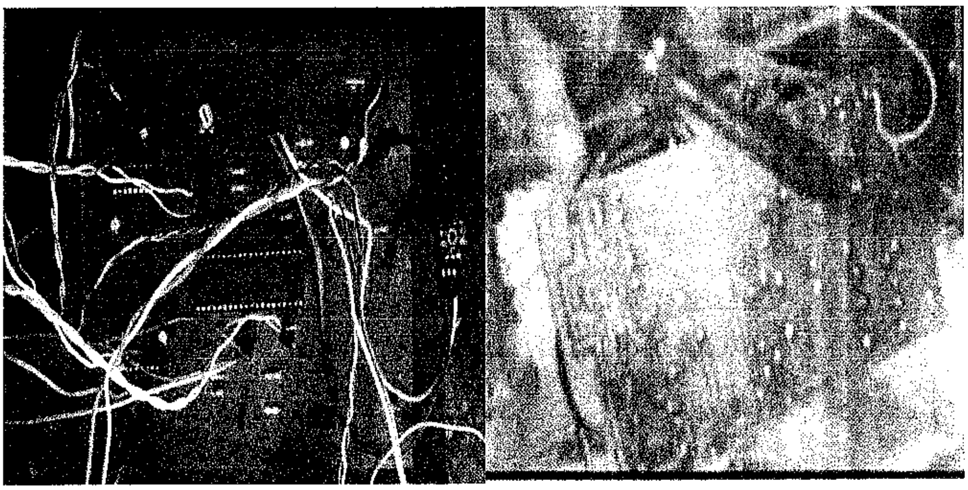


Figure 4.2. Connecting Wires and Power Supply to the controller circuit

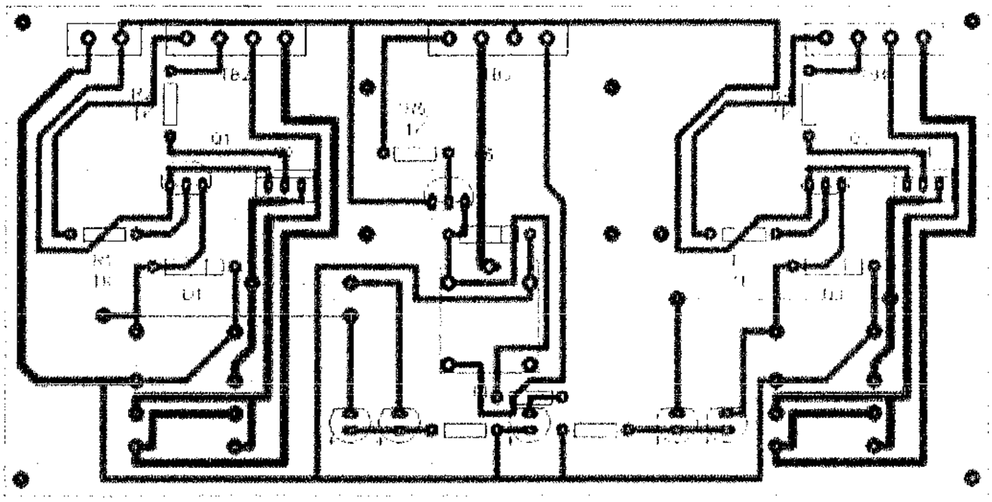


Figure 4.3. H-Bridge PCB Foil Layout

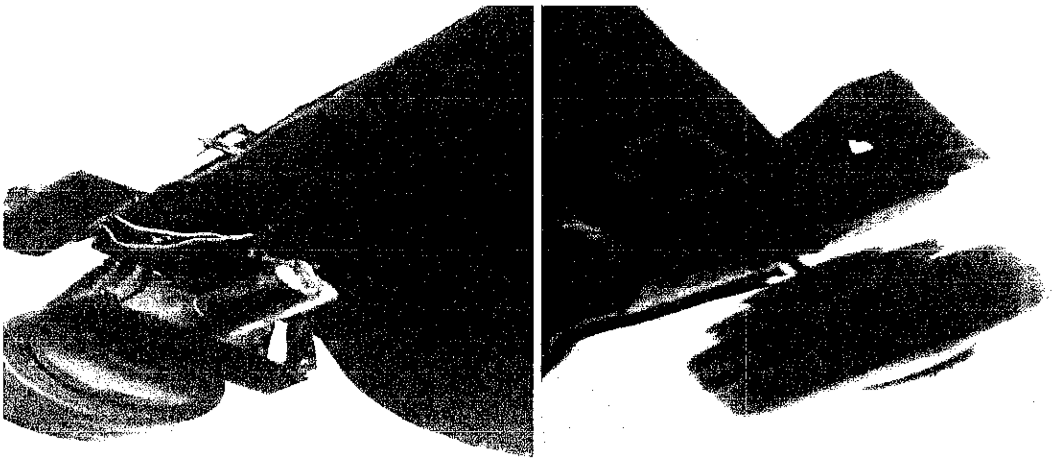


Figure 4.4. Motor Left and Right Test Run

4.2 Motor Truth Table

The process of testing was done using the truth table wherein, equivalent commands took place.

Table 2. H-Bridge Truth Table

A	B	RESULT/ACTION
0	0	Stop
0	1	Clockwise Direction
1	0	Anticlockwise Direction
1	1	Move forward
1	1	Move Backward

Truth table was defined by a mathematical table used in logic circuits specifically in connection with Boolean algebra, Boolean functions, and propositional calculus to compute the functional values of logical expressions on each of their functional arguments, each combination of values taken by their logical variables.

4.3 Navigation System

The Figure 4.5 and 4.6 shows the actual module of the navigation of the various movement of the robot with respect to the following factors.

1. The presence of grass using the humidity sensor located at the bottom part of the robot. The robot tends to move continuously in search of a lawn without its blade rotating until the humidity sensor senses the presence of grass.
2. The presence of human being or animals using the PIR sensor located at the middle front of the robot. The robot makes use of the PIR sensor in sensing and avoiding human being. The ability of the robot to make decisions in turning left or right is essential in ensuring safety.
3. The presence of obstacles (stones, walls, material) are sensed by the two bumper switches attached to the left and right corners at the front of the robot.

NOTE: the robot makes use of two different sensors in avoiding collision with obstacles and human beings. This is because human being is given more preference of protection compared to every other type of obstacles.

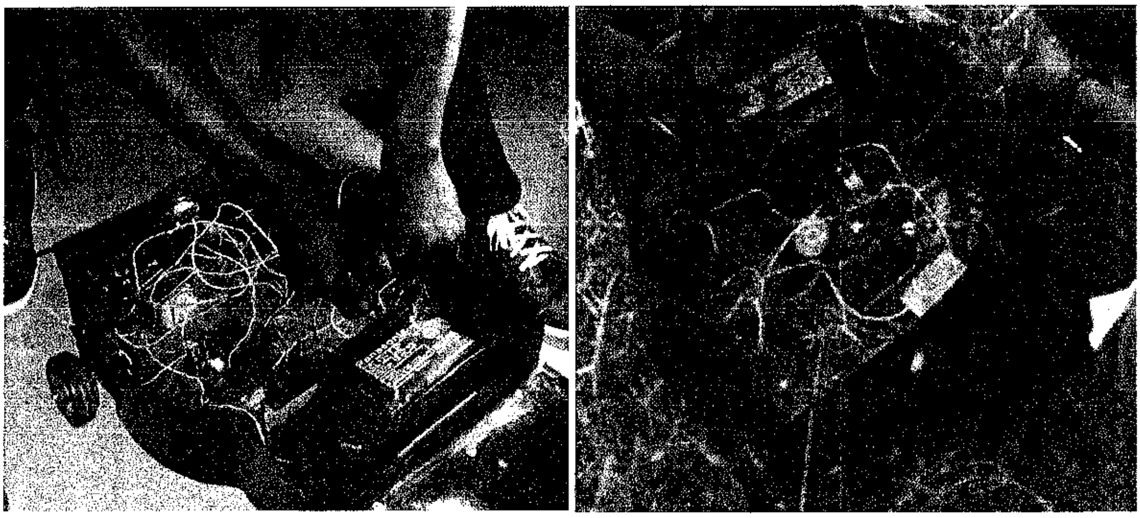


Figure 4.5. Micro controller Navigation Interface Test

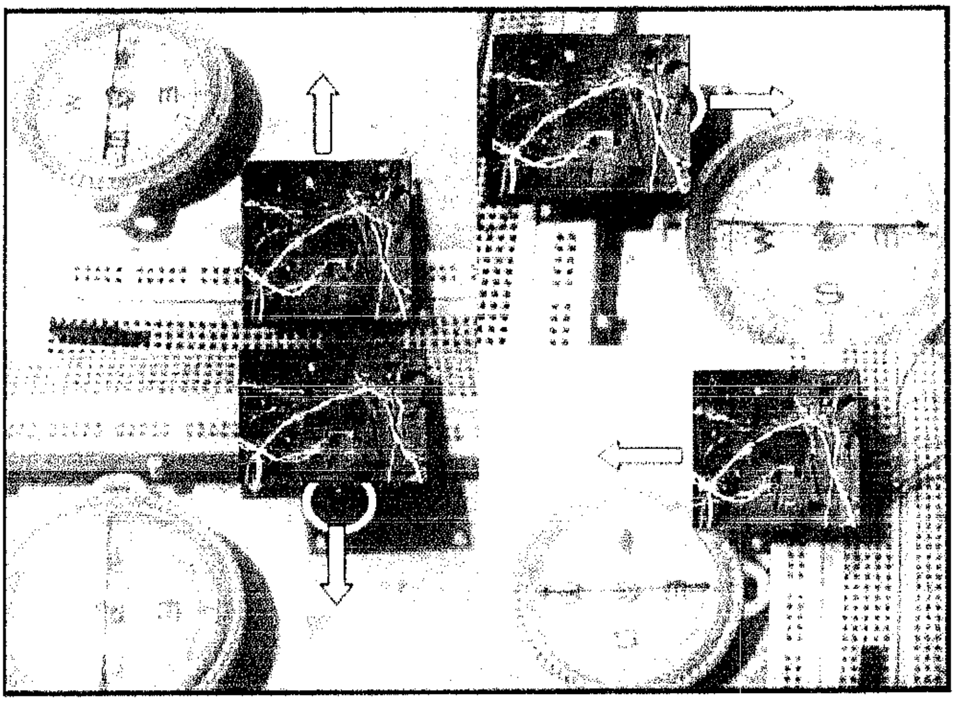


Figure 4.6. Bearing Orientation of both wheels

4.3.1 Movement Stability

The following factors were taken into consideration in order to achieve the movement stability;

- The type of ground
- Ground elevations
- Terrain texture
- The type of grass grown on the lawn
- The soil structure
- The dryness of the lawn
- The height of the grass
- The number of obstacles present on the lawn site.

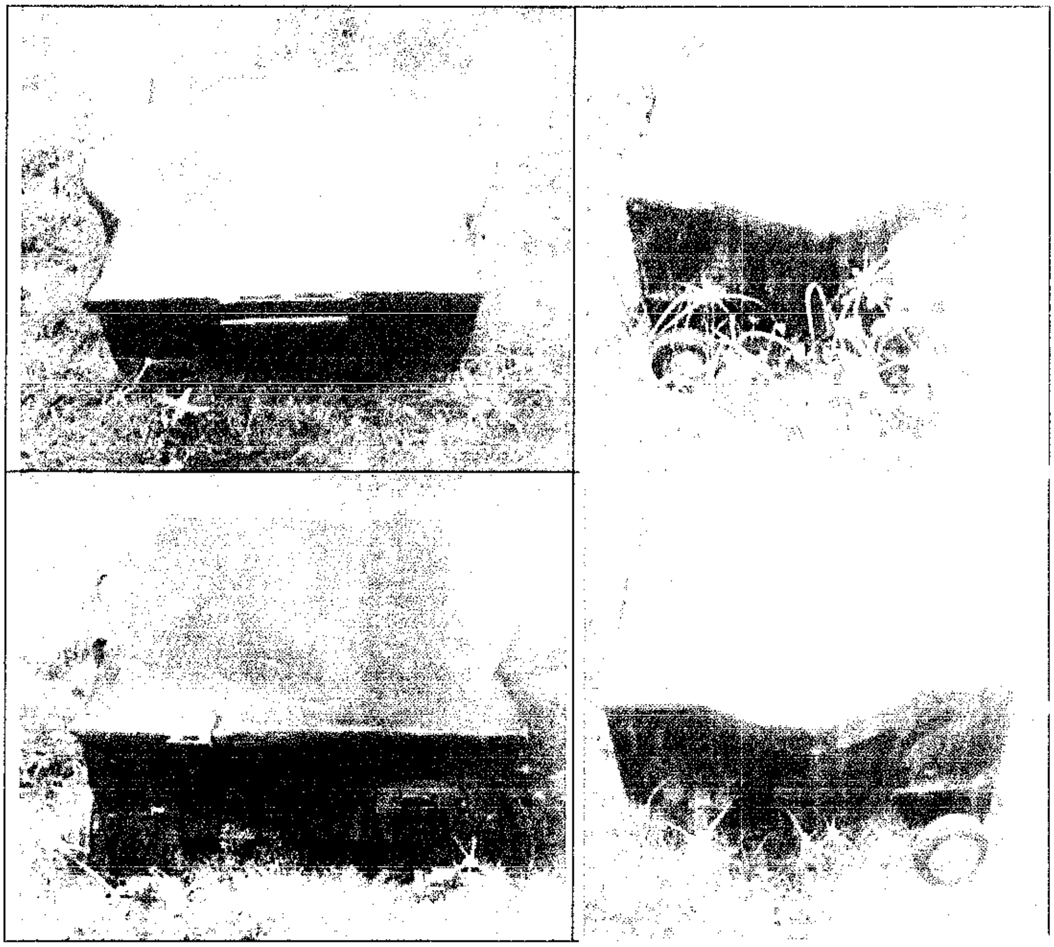


Figure 4.7. Robot's Track Using Sensors

4.4 Power Supply and Charging Test

We designed the battery charger circuit into the robot wherein the red light from the LED denotes charging while the green light from the LED signifies that the battery is fully charged.

Figure 4.8. Robot's Charging Phase

The battery charging time takes 4 hours to reach 14.2V and the working time is at 2.5 hours. Manual monitoring of voltage stored in the battery is advised when charging because the battery will power the controller favorably at the range of 12.9V – 13.5V. The battery is fully charged at 14.2V, but the minimum voltage required by the controller circuit is 12V.

A bridge rectifier is used to convert the AC voltage to DC voltage but it will still have AC ripple. The capacitor is used to filter the ripple.

The 555 Timer is used to set the low voltage threshold and the high voltage threshold to 11.2V and 14.2V respectively. The output of the comparator triggers a relay to disconnect charging operation and the green LED comes ON to indicate battery FULL.

When the battery is discharging during operation, the green LED remains ON while the comparator compares discharging voltage to the low threshold. By the time it reaches low threshold, the comparator triggers the relay and connects back to the charging operation, the red LED comes ON.

Variable Resistor is used to set the threshold values.

Note: The diode is used to protect the transistor due to the back E.M.F of the motor

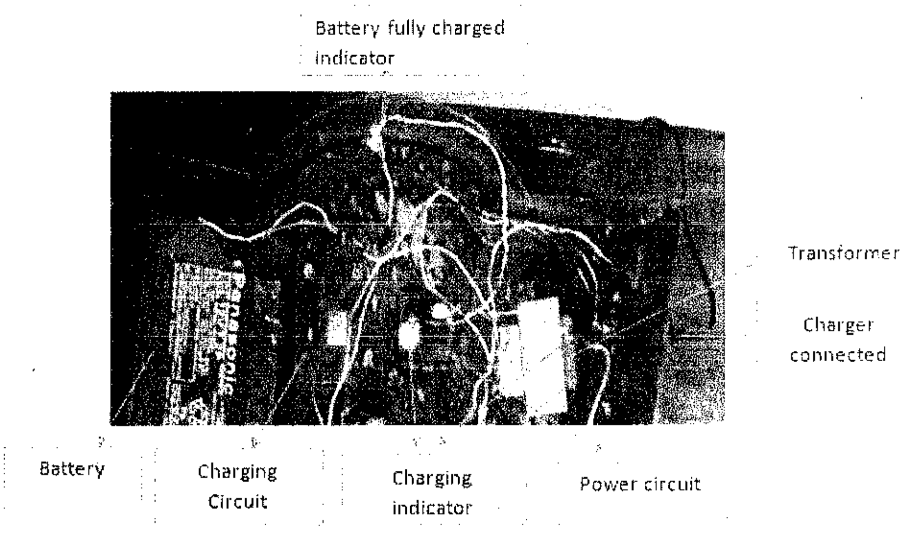


Figure 4.9. Robot's Charging Labelled Parts

Figure 4.10 shows technically the current through the battery. Initially it reads 0.980 amperes, after 2 hours it reads 0.623 amperes. The current and voltage of the battery can be checked manually by making use of a multimeter.

Figure 4.10. Manual checking of the Battery's Charge

Figure 4.11 shows how the voltage of the battery can be checked by making use of the charger circuit built into the robot. The wires of the battery should be connected to the charger circuit to determine if the battery is charged, low or fully charged.

NOTE:

- The red light of the LED on the charger circuit flashes when the battery is low.
- The red light of the LED on the charger circuit turns ON when the battery is charged. The
- The green light of the LED on the charger circuit turns ON when the battery is fully charged

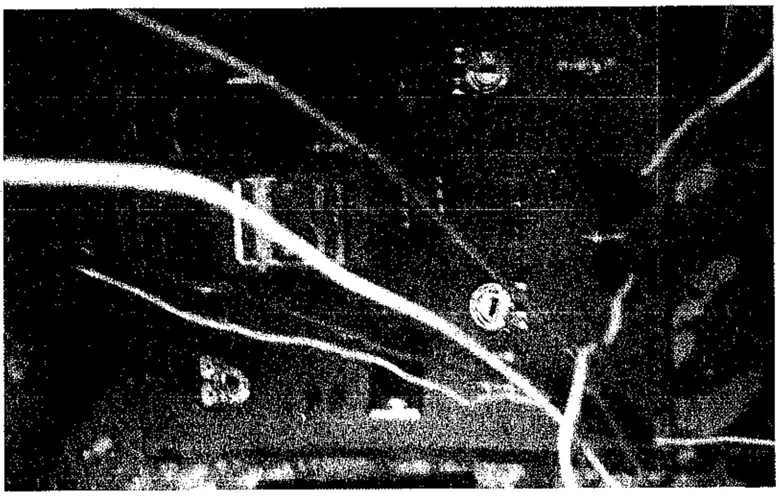


Figure 4.11. Charger circuit

We made use of a 24V transformer because the voltage that must charge the 12V battery must be above that of the battery. This is also the reason why we couldn't make use of a 12V voltage regulator because it won't charge the battery.

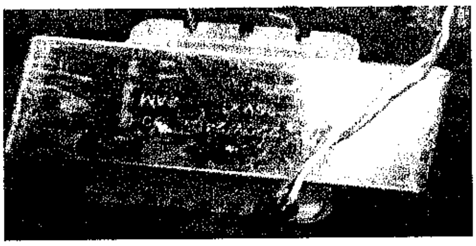


Figure 4.12. 24V Transformer

4.5 Cutting Deck

The bottom part of the mower was the cutting deck. The design was actually replicated the original blade of gasoline type grass cutter. The blade is fastened to the mounted at the inside centre of the robot. The centre motor is very powerful compared to the two driving wheel motors.

Figure 4.13. Cutting Deck Motor

The blades are firmly fastened to prevent user from any injuries. During the evaluation of the design the proponent test the trimming rate of the blade. The blade design trimmed **2.25 seconds per square feet.**

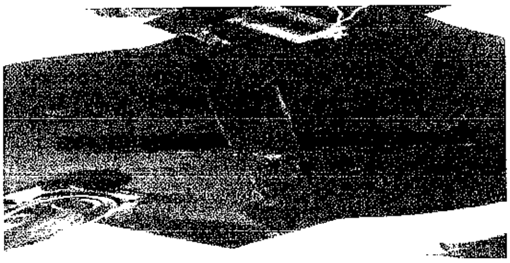


Figure 4.14. Cutting Deck Blades

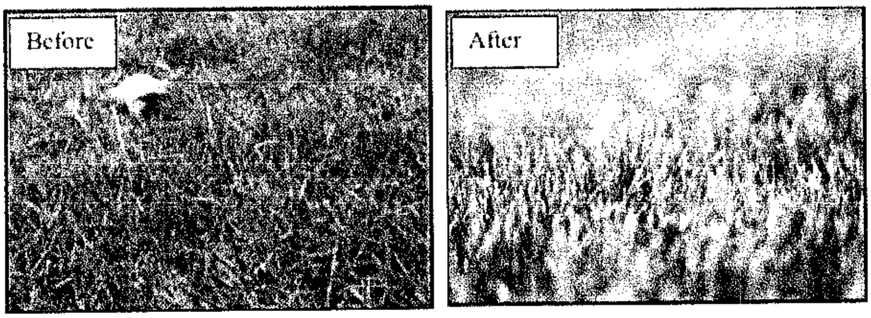


Figure 4.15. The grass result after trimming using the autonomous lawn mower

The picture shown in Figure 4.16 was a small scale lawn area and was taken at the ***administrative Block of the Faculty of Agriculture opposite ICT in Ikole campus, Federal University Oye-Ekiti.*** Lawn area is at 6 meters length and 1 meter width.

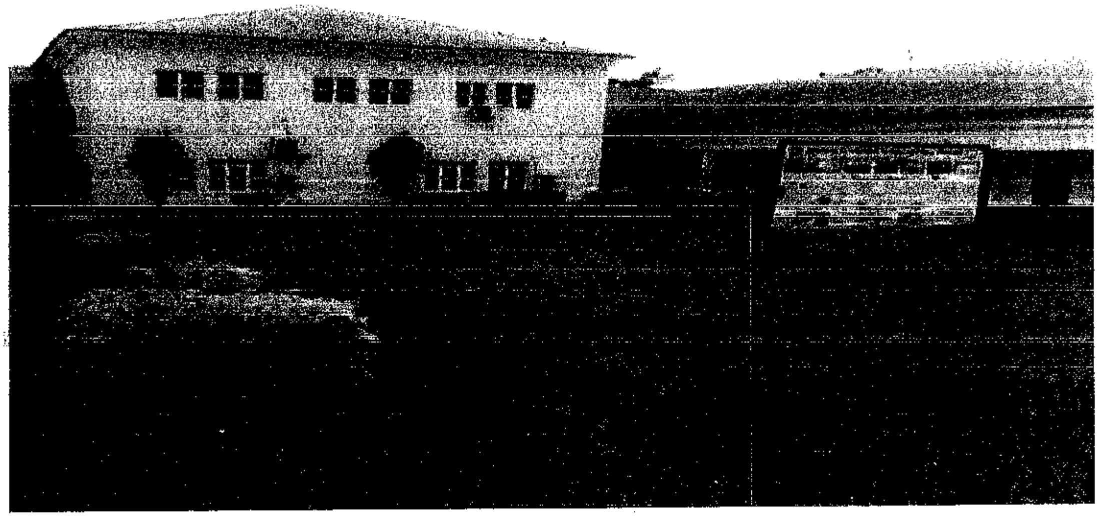


Figure 4.16. The Faculty of Agriculture lawn used for the result computation and analysis

4.6 Efficiency

Information was gathered based on the given dimension of blade diameter at 5 inches, assuming that the mowed portion of the lawn is equal to the blade diameter. The result of the mowed area was the summation of the mowed area given the constant width of 5 inches multiplied by the given length and width value in a particular Before After area. This calculation was done based on the Figure 4.17. Figure 4.17 was served as reference for ideal scenario and illustration of computation process to come up formulation in getting the total area mowed. Table 4 and 5 was the tabulated results for the actual scenario in which Table 5 shows the significance of the machine design based on the ideal machine.

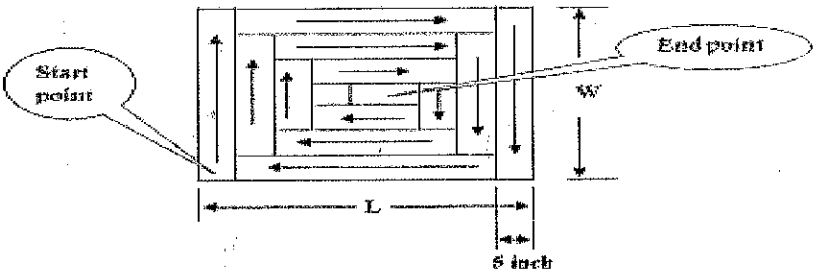


Figure 4.17. Mowed Area Approximation

Table 3. Results and Covered Area Computation on Different Grasses

DIMENSION (L×W)	CARPET GRASS		SPEAR GRASS		TRIDAX		STUBBORN GRASS	
	Mowed Area (%)	Mowed Area (sq.m)	Mowed Area (%)	Mowed Area (sq.m)	Mowed Area (%)	Mowed Area (sq.m)	Mowed Area (%)	Mowed Area (sq.m)
L=W (5×5=25sq.m) equal parameter values for a lawn with few or no obstacles								
Trial 1	80.0	20.00	85.0	21.25	90.0	22.50	65.0	16.25
Trial 2	82.0	20.50	84.0	21.00	87.0	21.75	68.0	17.00
Trial 3	83.0	20.75	86.0	21.50	93.0	23.25	60.0	15.00
Trial 4	81.0	20.25	85.0	21.25	92.0	23.00	70.0	17.50
Trial 5	80.0	20.00	87.0	21.75	89.0	22.25	67.0	16.75
AVERAGE VALUE	**80.0**	**20.00**	**85.4**	**21.35**	**90.2**	**22.55**	**66.0**	**16.50**
L=W (5×5=25sq.m) equal parameter values for a lawn with many or scattered obstacles								
Trial 1	70.0	17.50	75.0	18.75	84.0	21.00	50.0	12.50
Trial 2	69.0	17.25	71.0	17.75	81.0	20.25	58.0	14.50
Trial 3	72.0	18.00	69.0	17.25	78.0	19.50	52.0	13.00
Trial 4	73.0	18.25	81.0	20.25	84.0	21.00	60.0	15.00
Trial 5	71.0	17.75	79.0	19.75	80.0	20.00	58.0	14.50
AVERAGE VALUE	**71.0**	**17.75**	**75.0**	**18.75**	**81.4**	**20.35**	**55.6**	**13.90**

The table above shows the result of the experiment carried out on different grasses using the autonomous lawn mower. The gathered data was divided into four categories of different species of common grasses (carpet grass, Spear Grass, Tridax and Stubborn grass) that are found in Ikole-Ekiti lawn with few or no obstacles, and the other with scattered or many obstacles present in the lawn for different lawn grasses. After making use of our autonomous lawnmower in trimming and cutting the lawn, the following data and result was obtained.

It was observed that the robot is more ***effective when working on a lawn with few or no obstacles***. This allows the robot the freedom to reach and cover almost every part of the field at equal area parameters. The equal area parameters for the lawn with few or no obstacles were greater than the equal area parameters with many or scattered obstacles, meaning the percentage of area mowed for the first condition was greater compared to the other one.

The analysis from the table above proves that the ***stubborn grass with a coverage of 66.6% and 16.5sq.m*** are the most difficult type of grass that can be trimmed in a lawn using the autonomous robot. This is because of its strong root and scattered bunch of branches.

It is evident that ***carpet grass with a coverage of 80% and 20sq.m are the most preferred and suitable grass*** of all the varieties listed that are intended for a lawn or a field. This is because they don't grow broad leafs and they can be easily maintained at shorter height while covering every intended space with no ordinary grounds. Though the robot ***produce greater efficiency*** when used on a field covered with ***tridax and spear grass*** but tridax are not considered to be a ***part of the grass family*** while the ***tall height of spear grass*** makes it difficult for the robot to workable.

Table 4. T-Test Results Obtained from the Faculty of Agric. Lawn, Opposite ICT

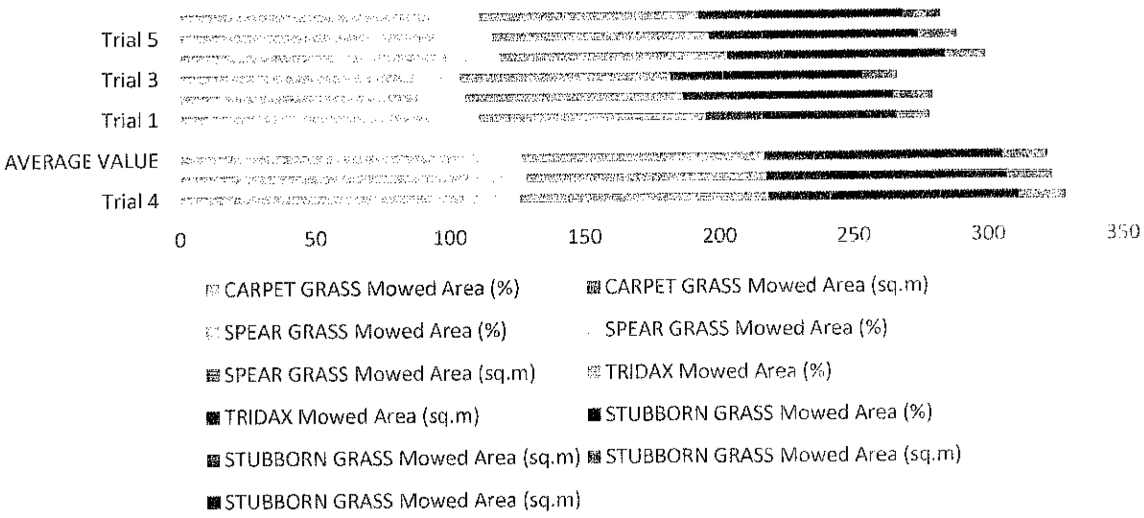
TRIALS	ACTUAL AREA (sq.m)	MOWED AREA WITH FEW OR NO OBSTACLES (%)	MOWED AREA WITH MANY OR SCATTERED OBSTACLES (%)	T-TEST VALUE
First	**L × W = AREA** **23 × 16 = 368**	95.0	83.5	**0.894**
Second		95.4	83.4	
Third		95.1	83.6	
Fourth		95.2	83.7	
Fifth		95.3	83.8	
TOTAL		**95.2%=350.34sq.m**	**83.6%=307.65sq.m**	

Table 5 shows the statistical results of the two categories, the first column was the control values or the ideal value of the area of the lawn at the Agric. Faculty, opposite ICT measured by the user. On the other hand, second and third column was the gathered experimented values based on the actual execution of the robot at various trials of operation with few or no obstacles and with many or scattered obstacles. The last column shows the average or the mean value for the five trials.

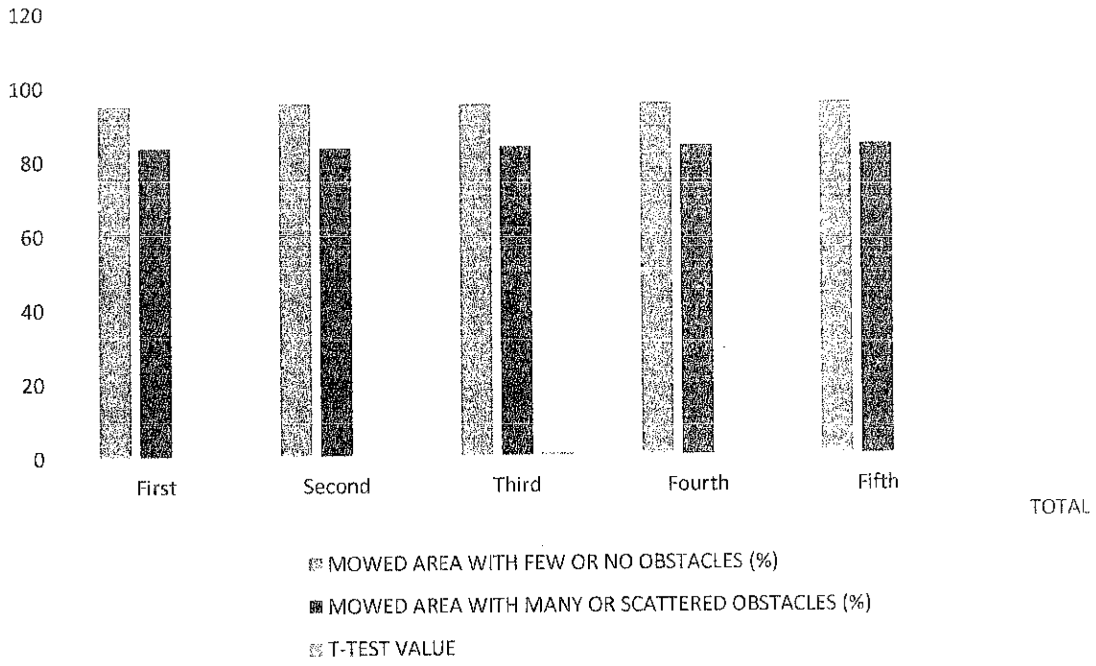
These statistical results are taken with the use of **T-Test**. It has a reference alpha of 10% wherein, equal dimensions has a value of **0.894**. For validating these results, the T-Test value should be greater than the alpha so that it can be consider for having a significant difference between the two, in which considering the result taken is truly greater than alpha.

Considering the average output value for equal area parameter lawn with few or no obstacles of a 25.0 meter square, the average coverage that is not mowed is about 4.8% or with 95.2% area coverage mowed. While the average output value for equal parameter lawn with many or scattered of a 25.0 meter square, the average coverage that is not mowed is about 16.4% or with 83.6% area coverage mowed. ***The average gives us the result of our T-Test which is 0.894.***

LAWN MOWED AREA CHART FOR VARIOUS TYPES OF GRASSES



T-TEST CHART FOR MOWED AREA WITH FEW AND MANY OBSTACLES



CHAPTER FIVE

5.0 CONCLUSION

The system requirements for the robotic lawn mowing system are met. The possibility of cutting and trimming grasses autonomously without the use of fuel to power its engines accompanied with the robots high performance made us recommend this robot as a laudable project that will benefit the economy globally and most importantly Nigeria.

The complete designing of the materials and the sensing navigating paths are done, and testing that lead to a total system performance that is excellent. Based on the results it would be better if the lawn area has approximate equal dimensions to have a better mowed coverage. The robot can mow better if the type of lawn grass is a **Carpet Grass and Short Spear Grass**.

Compared to the other autonomous lawnmower this robot would be much cheaper with a relative high performance. It is able to trim lawn grass automatically which no longer requires human intervention to manually operate during the mowing process making it more convenient. Trimming lawn grass through the automated autonomous machine may not be faster than the manual grass cutter but it is cleaner, safer, and has more energy saved than the manual and also they differ on the technology used which is a great factor in evaluating their capabilities.

The design of the system relies on its sensors (PIR sensor, humidity sensor and bumper switches) for its navigation. An ease on modification and troubleshooting procedure has helped us in acquiring good results. Finally, we were able to achieve the following objectives:

1. Determination of the materials and the electronic components that will be needed in the design.
2. Fabrication of an autonomous lawn mower from locally sourced materials.
3. Usage of electricity in recharging a battery as a power source of the system.
4. Development of an autonomous automated system that cuts down lawn grass safely and its environment friendly.

5.1 Recommendations

Limitations

1. In cases where the floor is wet, the humidity sensor is unable to differentiate between the humidity of grass and the floor.
2. The PIR's range of sensing is really high, the mower might not work with any living thing on the lawn.
3. We were unable to get an Ultrasonic sensor we ordered online, so we used bumpers instead.
4. The mower can fall down on sloppy ground, even when not in operation.
5. The noise from the cutting blade can be disturbing.
6. Since the body is made of metal, it gets on while working for long in the sun.
7. The movement of the autonomous robotic lawn mower is random, it cuts grass randomly and so cannot be used for beautification purposes.
8. The weight of the body is really heavy, it affects the movement of the wheels.

The design of the Autonomous Lawn Mowing Robot has further development that can still be carried out. After reviewing the results, the following recommendations are presented for the improvement of the project.

1. Compensate the power supply to the battery by making use of an on-board solar panel that will provide the robot with constant and steady power required for the robot to be used irrespective of the availability of electricity. Adding a solar panel to the design would add value to the autonomous lawn mower.
2. Ultrasonic sensors should be used instead of the bumper switches to allow the robot to detect and avoid obstacles
3. Improve the number of blades on the cutting deck making it more time efficient.
4. Use lightweight metal as the medium for the chassis.
5. Increase the wheel diameter of the system.
6. Use greater amount of battery charge and with lighter weight.

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APPENDICE A

User's Manual;

The preparation for using the device has the following steps to be followed to ensure the correct operation and to come up with the right output with respect to its main objective.

1. Place the robot to the lawn

2. Press the Start button. (Note: After pressing the button move away from the area, blades are very sharp it may cause injury.)

3. After the pushing of the start button, the robot will wait 10 seconds before it start moving and cutting. (Note: during this 10 seconds, ensure the path of the robot is clear of human presence as this might prevent the movement of the robot because of the PIR sensor.)

4. When charging the battery:

a. Plug the charger to the respective polarity located at the left front side of the robot.

b. The red indicator light of the LED on the **power circuit** will come ON the very instant the charger is plugged.

b. Charging hour is 5 hours.

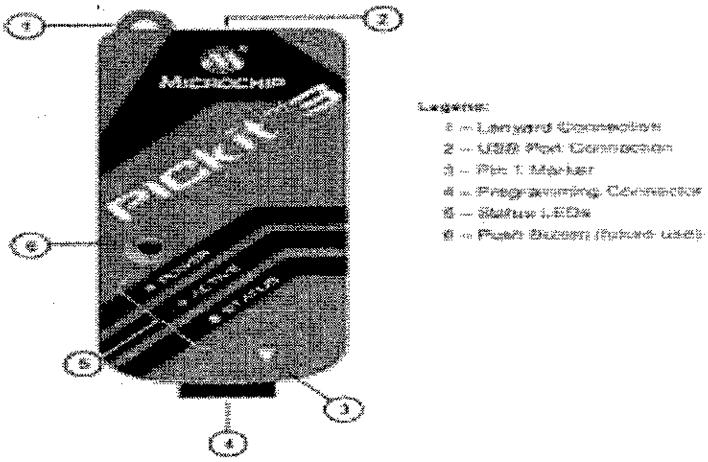
c. Check regularly using a multimeter the voltage of the battery. The required voltage needed by the controller is 12V. It is best to keep the battery charged at 12.9V - 13.6V.

5. Determining the status of the battery. FULLY CHARGED/ CHARGED/ BATTERY LOW

a. If the green indicator light of the LED on the **charging circuit** comes ON, then the battery is fully charged at 14.2V.

b. If the red indicator light of the LED on the **charging circuit** comes on, it's either the battery is charging or the battery is charged i.e. its voltage is between 11.2V – 14.2V. (Note: a minimum of 12V is the required voltage needed by the **controller circuit.**)

6. When user wanted to change or erase the existing program written on the microcontroller, press and hold the Reset button. **A PICKit 3 programmer** is used to program the microcontroller



7. The microcontroller controls the action of all the input sensors (PIR sensors, humidity sensor and bumper switches). Note: the action of all the input sensors are performed by the use of a 5V.

8. The microcontroller controls the action of all the output transducers (the cutting blade motor and the two left and right back wheels for movement and direction). Note: the action of all the output transducers are performed by the use of a 12V.

9. The Pic MCU allows comparison between two or different input signals.

APPENDIX B

Definition of Terms:

Area. It is a measure of the size of a surface region, usually expressed in units that are the square of linear units.

Autonomous Robots. Robot that can perform desired tasks in unstructured environments without continuous human guidance.

Brushed DC Motor. An internally commutated electric motor designed to be run from a DC power source.

Chain Wheel. A toothed wheel that meshes with a roller chain to transmit motion.

Collision. An event in which two or more bodies or particles come together with a resulting change of direction.

Commutator. A rotary electrical switch in certain types of electric motors or electrical generators that periodically reverses the current direction between the rotor and the external circuit.

EEPROM (Electrically Erasable Programmable Read Only Memory). Type of memory whose values are kept when the system is turned off just like a tiny hard drive placed inside a chip.

Gearbox. Provides speed and torque conversions from a rotating power source to another device using gear ratios.

GPS (Global Positioning System). A navigational system involving satellites and computers that can determine the latitude and longitude of a receiver on Earth by computing the time difference for signals from different satellites to reach the receiver.

H-Bridge. An electronic circuit which enables a voltage to be applied across a load in either direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards and backwards.

Image Processing. Any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image.

Lawn. An area of aesthetic and recreational land planted with grasses or other low durable plants, which usually maintained at a lower and consistent height.

Lawnmower. A machine with a rotating blade for cutting grass.

PIR Sensor: is an electronic sensor that measures infrared (IR) light radiating from objects in its field of view.

APPENDIX C

The Code

```
_move_forward:
;LAWNMOWER SIMULATION.c,13 ::                void move_forward()
;LAWNMOWER SIMULATION.c,15 ::                PORTD.F0 = 1;
     BSF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,16 ::                PORTD.F2 = 1;
     BSF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,17 ::                }
     RETURN
; end of _move_forward

_stop_move_forward:
;LAWNMOWER SIMULATION.c,19 ::                void stop_move_forward()
;LAWNMOWER SIMULATION.c,21 ::                PORTD.F0 = 0;
     BCF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,22 ::                PORTD.F2 = 0;
     BCF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,23 ::                }
     RETURN
; end of _stop_move_forward

_reverse:
;LAWNMOWER SIMULATION.c,25 ::                void reverse()
;LAWNMOWER SIMULATION.c,27 ::                PORTD.F1 = 1;
     BSF          PORTD+0, 1
;LAWNMOWER SIMULATION.c,28 ::                PORTD.F3 = 1;
     BSF          PORTD+0, 3
;LAWNMOWER SIMULATION.c,29 ::                }
     RETURN
; end of _reverse

_stop_reverse:
;LAWNMOWER SIMULATION.c,31 ::                void stop_reverse()
;LAWNMOWER SIMULATION.c,33 ::                PORTD.F1 = 0;
     BCF          PORTD+0, 1
;LAWNMOWER SIMULATION.c,34 ::                PORTD.F3 = 0;
     BCF          PORTD+0, 3
;LAWNMOWER SIMULATION.c,35 ::                }
     RETURN
; end of _stop_reverse

_turn_right:
;LAWNMOWER SIMULATION.c,37 ::                void turn_right()
;LAWNMOWER SIMULATION.c,39 ::                PORTD.F0 = 1;
     BSF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,40 ::                PORTD.F2 = 0;
     BCF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,41 ::                }
     RETURN
; end of _turn_right

_stop_turn_right:
;LAWNMOWER SIMULATION.c,43 ::                void stop_turn_right()
```

```
;LAWNMOWER SIMULATION.c,45 ::                PORTD.F0 = 0;
      BCF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,46 ::                PORTD.F2 = 0;
      BCF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,47 ::                }
      RETURN
; end of _stop_turn_right

_turn_left:
;LAWNMOWER SIMULATION.c,49 ::                void turn_left()
;LAWNMOWER SIMULATION.c,51 ::                PORTD.F0 = 0;
      BCF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,52 ::                PORTD.F2 = 1;
      BSF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,53 ::                }
      RETURN
; end of _turn_left

_stop_turn_left:
;LAWNMOWER SIMULATION.c,55 ::                void stop_turn_left()
;LAWNMOWER SIMULATION.c,57 ::                PORTD.F0 = 0;
      BCF          PORTD+0, 0
;LAWNMOWER SIMULATION.c,58 ::                PORTD.F2 = 0;
      BCF          PORTD+0, 2
;LAWNMOWER SIMULATION.c,59 ::                }
      RETURN
; end of _stop_turn_left

_cutting_motor:
;LAWNMOWER SIMULATION.c,61 ::                void cutting_motor()
;LAWNMOWER SIMULATION.c,63 ::                PORTD.F4 = 1;
      BSF          PORTD+0, 4
;LAWNMOWER SIMULATION.c,64 ::                PORTD.F5 = 0;
      BCF          PORTD+0, 5
;LAWNMOWER SIMULATION.c,65 ::                }
      RETURN
; end of _cutting_motor

_stop_cutting_motor:
;LAWNMOWER SIMULATION.c,67 ::                void stop_cutting_motor()
;LAWNMOWER SIMULATION.c,69 ::                PORTD.F4 = 0;
      BCF          PORTD+0, 4
;LAWNMOWER SIMULATION.c,70 ::                PORTD.F5 = 0;
      BCF          PORTD+0, 5
;LAWNMOWER SIMULATION.c,71 ::                }
      RETURN
; end of _stop_cutting_motor

_interrupt:
      MOVWF        R15+0
      SWAPF        STATUS+0, 0
      CLRF         STATUS+0
      MOVWF        ___saveSTATUS+0
      MOVF         PCLATH+0, 0
      MOVWF        ___savePCLATH+0
      CLRF         PCLATH+0
;LAWNMOWER SIMULATION.c,73 ::                void interrupt()
;LAWNMOWER SIMULATION.c,75 ::                TMR0=10;
```

```
        MOVLW        10
        MOVWF        TMR0+0
;LAWNMOWER SIMULATION.c,76 ::                  count++;
        INCF         _count+0, 1
;LAWNMOWER SIMULATION.c,77 ::                  if(count==16)
        MOVF         _count+0, 0
        XORLW        16
        BTFSS        STATUS+0, 2
        GOTO         L_interrupt0
;LAWNMOWER SIMULATION.c,79 ::                  if (Button(&Switch1_Port,
Switch1_Pin, Debounce_Time, 0))
        MOVLW        PORTB+0
        MOVWF        FARG_Button_port+0
        MOVLW        1
        MOVWF        FARG_Button_pin+0
        MOVLW        20
        MOVWF        FARG_Button_time_ms+0
        CLRF         FARG_Button_active_state+0
        CALL         _Button+0
        MOVF         R0+0, 0
        BTFSC        STATUS+0, 2
        GOTO         L_interrupt1
;LAWNMOWER SIMULATION.c,81 ::                  if(PORTB.RB1==0)
        BTFSC        PORTB+0, 1
        GOTO         L_interrupt2
;LAWNMOWER SIMULATION.c,83 ::                  stop_move_forward();
        CALL         _stop_move_forward+0
;LAWNMOWER SIMULATION.c,84 ::                  delay_ms(1000);
        MOVLW        6
        MOVWF        R11+0
        MOVLW        19
        MOVWF        R12+0
        MOVLW        173
        MOVWF        R13+0
L_interrupt3:
        DECFSZ       R13+0, 1
        GOTO         L_interrupt3
        DECFSZ       R12+0, 1
        GOTO         L_interrupt3
        DECFSZ       R11+0, 1
        GOTO         L_interrupt3
        NOP
        NOP
;LAWNMOWER SIMULATION.c,85 ::                  turn_right();
        CALL         _turn_right+0
;LAWNMOWER SIMULATION.c,86 ::                  delay_ms(1000);
        MOVLW        6
        MOVWF        R11+0
        MOVLW        19
        MOVWF        R12+0
        MOVLW        173
        MOVWF        R13+0
L_interrupt4:
        DECFSZ       R13+0, 1
        GOTO         L_interrupt4
        DECFSZ       R12+0, 1
        GOTO         L_interrupt4
        DECFSZ       R11+0, 1
```

```
      GOTO        L_interrupt4
      NOP
      NOP
;LAWNMOWER SIMULATION.c,87 ::                 move_forward();
      CALL        _move_forward+0
;LAWNMOWER SIMULATION.c,88 ::                 delay_ms(3000);
      MOVLW       16
      MOVWF       R11+0
      MOVLW       57
      MOVWF       R12+0
      MOVLW       13
      MOVWF       R13+0
L_interrupt5:
      DECFSZ      R13+0, 1
      GOTO        L_interrupt5
      DECFSZ      R12+0, 1
      GOTO        L_interrupt5
      DECFSZ      R11+0, 1
      GOTO        L_interrupt5
      NOP
      NOP
;LAWNMOWER SIMULATION.c,89 ::                 turn_left();
      CALL        _turn_left+0
;LAWNMOWER SIMULATION.c,90 ::                 delay_ms(1000);
      MOVLW       6
      MOVWF       R11+0
      MOVLW       19
      MOVWF       R12+0
      MOVLW       173
      MOVWF       R13+0
L_interrupt6:
      DECFSZ      R13+0, 1
      GOTO        L_interrupt6
      DECFSZ      R12+0, 1
      GOTO        L_interrupt6
      DECFSZ      R11+0, 1
      GOTO        L_interrupt6
      NOP
      NOP
;LAWNMOWER SIMULATION.c,91 ::                 }
L_interrupt2:
;LAWNMOWER SIMULATION.c,92 ::                 }
L_interrupt1:
;LAWNMOWER SIMULATION.c,93 ::                 if (Button(&Switch_Port,
Switch_Pin, Debounce_Time, 0))
      MOVLW       PORTC+0
      MOVWF       FARG_Button_port+0
      MOVLW       4
      MOVWF       FARG_Button_pin+0
      MOVLW       20
      MOVWF       FARG_Button_time_ms+0
      CLRF        FARG_Button_active_state+0
      CALL        _Button+0
      MOVF        R0+0, 0
      BTFSC       STATUS+0, 2
      GOTO        L_interrupt7
;LAWNMOWER SIMULATION.c,95 ::                 if(PORTC.RC4==0)
      BTFSC       PORTC+0, 4
```

```
	GOTO		L_interrupt8
;LAWNMOWER SIMULATION.c,97 ::		stop_move_forward();
	CALL		_stop_move_forward+0
;LAWNMOWER SIMULATION.c,98 ::		stop_cutting_motor();
	CALL		_stop_cutting_motor+0
;LAWNMOWER SIMULATION.c,99 ::		delay_ms(2000);
	MOVLW		11
	MOVWF		R11+0
	MOVLW		38
	MOVWF		R12+0
	MOVLW		93
	MOVWF		R13+0
L_interrupt9:
	DECFSZ		R13+0, 1
	GOTO		L_interrupt9
	DECFSZ		R12+0, 1
	GOTO		L_interrupt9
	DECFSZ		R11+0, 1
	GOTO		L_interrupt9
	NOP
	NOP
;LAWNMOWER SIMULATION.c,100 ::		reverse();
	CALL		_reverse+0
;LAWNMOWER SIMULATION.c,101 ::		delay_ms(3000);
	MOVLW		16
	MOVWF		R11+0
	MOVLW		57
	MOVWF		R12+0
	MOVLW		13
	MOVWF		R13+0
L_interrupt10:
	DECFSZ		R13+0, 1
	GOTO		L_interrupt10
	DECFSZ		R12+0, 1
	GOTO		L_interrupt10
	DECFSZ		R11+0, 1
	GOTO		L_interrupt10
	NOP
	NOP
;LAWNMOWER SIMULATION.c,102 ::		stop_reverse();
	CALL		_stop_reverse+0
;LAWNMOWER SIMULATION.c,103 ::		delay_ms(1000);
	MOVLW		6
	MOVWF		R11+0
	MOVLW		19
	MOVWF		R12+0
	MOVLW		173
	MOVWF		R13+0
L_interrupt11:
	DECFSZ		R13+0, 1
	GOTO		L_interrupt11
	DECFSZ		R12+0, 1
	GOTO		L_interrupt11
	DECFSZ		R11+0, 1
	GOTO		L_interrupt11
	NOP
	NOP
;LAWNMOWER SIMULATION.c,104 ::		turn_left();
```

```
      CALL        _turn_left+0
;LAWNMOWER SIMULATION.c,105 ::          delay_ms(2000);
      MOVLW       11
      MOVWF       R11+0
      MOVLW       38
      MOVWF       R12+0
      MOVLW       93
      MOVWF       R13+0
L_interrupt12:
      DECFSZ      R13+0, 1
      GOTO        L_interrupt12
      DECFSZ      R12+0, 1
      GOTO        L_interrupt12
      DECFSZ      R11+0, 1
      GOTO        L_interrupt12
      NOP
      NOP
;LAWNMOWER SIMULATION.c,107 ::          }
L_interrupt8:
;LAWNMOWER SIMULATION.c,108 ::          }
      GOTO        L_interrupt13
L_interrupt7:
;LAWNMOWER SIMULATION.c,112 ::          move_forward();
      CALL        _move_forward+0
;LAWNMOWER SIMULATION.c,113 ::          cutting_motor();
      CALL        _cutting_motor+0
;LAWNMOWER SIMULATION.c,114 ::          }
L_interrupt13:
;LAWNMOWER SIMULATION.c,115 ::          count=0;
      CLRF        _count+0
;LAWNMOWER SIMULATION.c,116 ::          }
L_interrupt0:
;LAWNMOWER SIMULATION.c,117 ::          INTCON.T0IF=0;
      BCF         INTCON+0, 2
;LAWNMOWER SIMULATION.c,118 ::          if(PORTB.RB0==0)
      BTFSC       PORTB+0, 0
      GOTO        L_interrupt14
;LAWNMOWER SIMULATION.c,120 ::          stop_move_forward();
      CALL        _stop_move_forward+0
;LAWNMOWER SIMULATION.c,121 ::          stop_cutting_motor();
      CALL        _stop_cutting_motor+0
;LAWNMOWER SIMULATION.c,122 ::          delay_ms(2000);
      MOVLW       11
      MOVWF       R11+0
      MOVLW       38
      MOVWF       R12+0
      MOVLW       93
      MOVWF       R13+0
L_interrupt15:
      DECFSZ      R13+0, 1
      GOTO        L_interrupt15
      DECFSZ      R12+0, 1
      GOTO        L_interrupt15
      DECFSZ      R11+0, 1
      GOTO        L_interrupt15
      NOP
      NOP
;LAWNMOWER SIMULATION.c,123 ::          }
```

```
        GOTO        L_interrupt16
L_interrupt14:
;LAWNMOWER SIMULATION.c,126 ::            move_forward();
        CALL        _move_forward+0
;LAWNMOWER SIMULATION.c,127 ::            cutting_motor();
        CALL        _cutting_motor+0
;LAWNMOWER SIMULATION.c,128 ::            }
L_interrupt16:
;LAWNMOWER SIMULATION.c,129 ::            }
L__interrupt20:
        MOVF        ___savePCLATH+0, 0
        MOVWF       PCLATH+0
        SWAPF       ___saveSTATUS+0, 0
        MOVWF       STATUS+0
        SWAPF       R15+0, 1
        SWAPF       R15+0, 0
        RETFIE
; end of _interrupt

_main:
;LAWNMOWER SIMULATION.c,131 ::            void main()
;LAWNMOWER SIMULATION.c,135 ::            TRISB.RB1=1;
        BSF         TRISB+0, 1
;LAWNMOWER SIMULATION.c,136 ::            TRISC.RC4=1;
        BSF         TRISC+0, 4
;LAWNMOWER SIMULATION.c,137 ::            PORTB.RB1=0;
        BCF         PORTB+0, 1
;LAWNMOWER SIMULATION.c,138 ::            PORTC.RC4=0;
        BCF         PORTC+0, 4
;LAWNMOWER SIMULATION.c,140 ::            TRISB.RB0=1;
        BSF         TRISB+0, 0
;LAWNMOWER SIMULATION.c,141 ::            ADCON1=1;
        MOVLW       1
        MOVWF       ADCON1+0
;LAWNMOWER SIMULATION.c,142 ::            PORTD=0b00000000;
        CLRF        PORTD+0
;LAWNMOWER SIMULATION.c,144 ::            TRISD.RD0=0;
        BCF         TRISD+0, 0
;LAWNMOWER SIMULATION.c,145 ::            TRISD.RD1=0;
        BCF         TRISD+0, 1
;LAWNMOWER SIMULATION.c,146 ::            TRISD.RD2=0;
        BCF         TRISD+0, 2
;LAWNMOWER SIMULATION.c,147 ::            TRISD.RD3=0;
        BCF         TRISD+0, 3
;LAWNMOWER SIMULATION.c,148 ::            TRISD.RD4=0;
        BCF         TRISD+0, 4
;LAWNMOWER SIMULATION.c,149 ::            TRISD.RD5=0;
        BCF         TRISD+0, 5
;LAWNMOWER SIMULATION.c,151 ::            INTCON.GIE=1;
        BSF         INTCON+0, 7
;LAWNMOWER SIMULATION.c,152 ::            INTCON.PEIE=1;
        BSF         INTCON+0, 6
;LAWNMOWER SIMULATION.c,153 ::            INTCON.T0IE=1;
        BSF         INTCON+0, 5
;LAWNMOWER SIMULATION.c,154 ::            OPTION_REG.T0CS=0;
        BCF         OPTION_REG+0, 5
;LAWNMOWER SIMULATION.c,155 ::            OPTION_REG.PSA=0;
        BCF         OPTION_REG+0, 3
```

```
;LAWNMOWER SIMULATION.c,156 ::                OPTION_REG.PS2=1;
      BSF          OPTION_REG+0, 2
;LAWNMOWER SIMULATION.c,157 ::                OPTION_REG.PS1=1;
      BSF          OPTION_REG+0, 1
;LAWNMOWER SIMULATION.c,158 ::                OPTION_REG.PS0=1;
      BSF          OPTION_REG+0, 0
;LAWNMOWER SIMULATION.c,159 ::                INTCON.RBIE=1;
      BSF          INTCON+0, 3
;LAWNMOWER SIMULATION.c,160 ::                INTCON.INTE=1;
      BSF          INTCON+0, 4
;LAWNMOWER SIMULATION.c,161 ::                OPTION_REG.INTEDG=0;
      BCF          OPTION_REG+0, 6
;LAWNMOWER SIMULATION.c,163 ::                while (1)
L_main17:
;LAWNMOWER SIMULATION.c,165 ::                cutting_motor();
      CALL          _cutting_motor+0
;LAWNMOWER SIMULATION.c,166 ::                delay_ms(2000);
      MOVLW        11
      MOVWF        R11+0
      MOVLW        38
      MOVWF        R12+0
      MOVLW        93
      MOVWF        R13+0
L_main19:
      DECFSZ       R13+0, 1
      GOTO         L_main19
      DECFSZ       R12+0, 1
      GOTO         L_main19
      DECFSZ       R11+0, 1
      GOTO         L_main19
      NOP
      NOP
;LAWNMOWER SIMULATION.c,167 ::                move_forward();
      CALL          _move_forward+0
;LAWNMOWER SIMULATION.c,168 ::                }
      GOTO         L_main17
;LAWNMOWER SIMULATION.c,169 ::                }
      GOTO         $+0
; end of _main
```

APPENDIX D

Bill of Materials

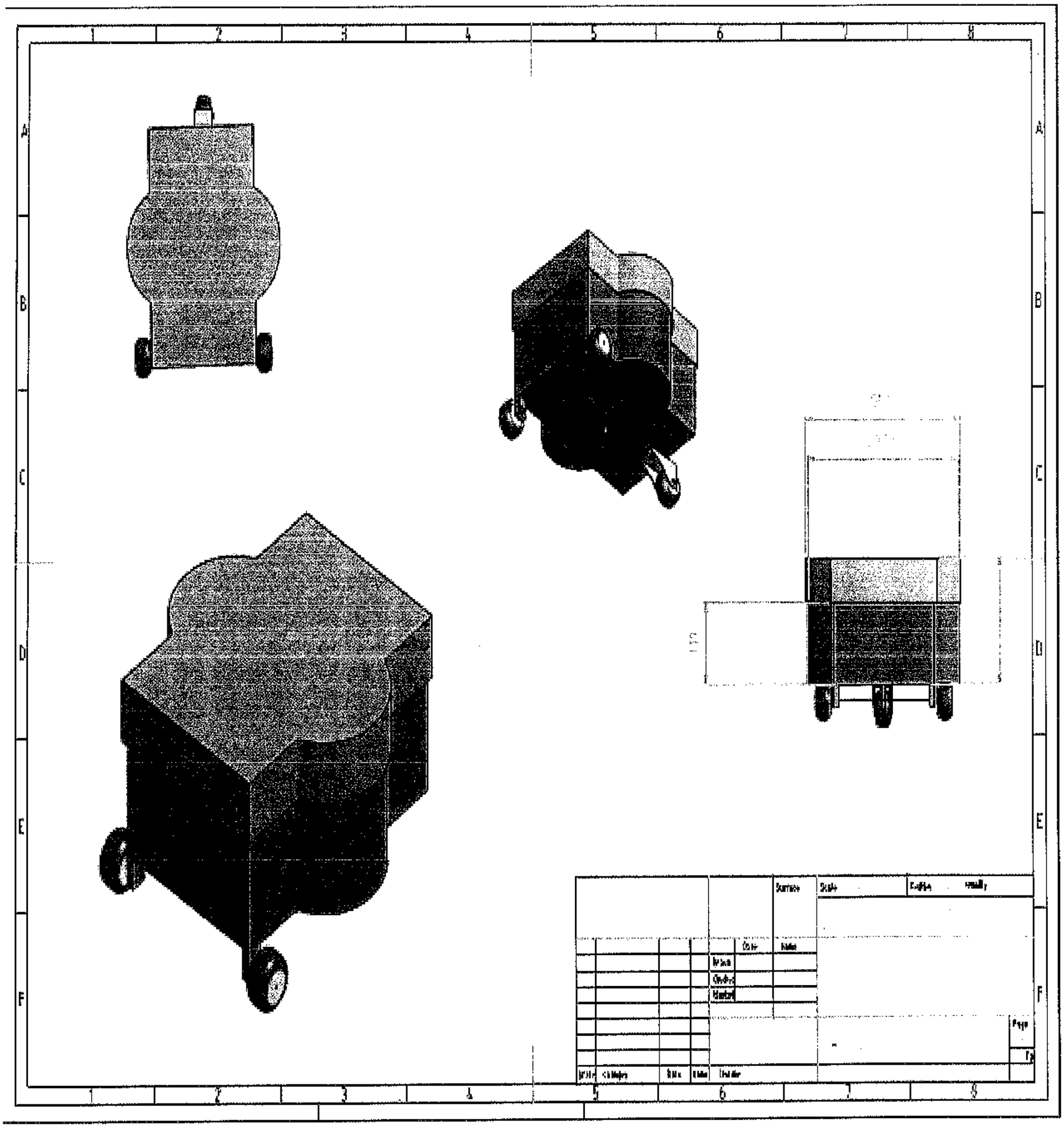
Table 5. Bill of Materials

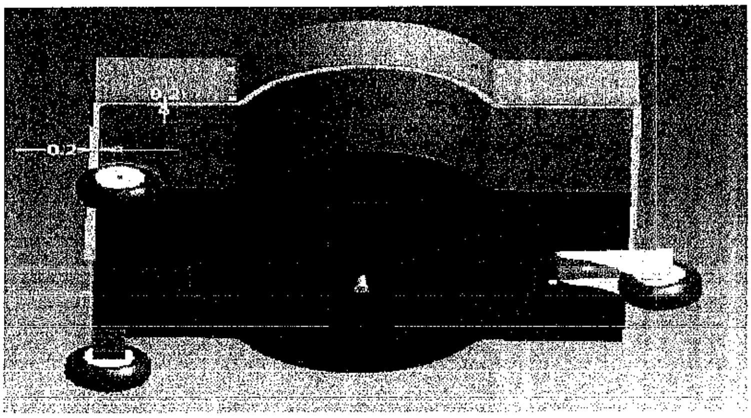
S/N	Component name	Specification	Model	Quantity	Unit Price (₦)	Price (₦)
1	Drive motor (DC geared Motor)	12V, 300rpm, 0.6A	B0080DL25Q	2	1,910.61	3821.22
2	Cutting motor (DC geared Motor)	12V, 1000rpm, 0.3A, 0.5W	HGA25-310	1	1,233.38	2466.75
3	Bumper Switches	5V		2	250.00	500.00
4	Lead battery	2.1Ah, 12V, 0.82kg	NP21-12	1	2,000.00	2000.00
5	Transformer	12V, 3A		1	500.00	500.00
6	Bridge rectifier			2	100.00	200.00
7	Filtering cap			1	60.00	60.00
8	Voltage regulator	12V		1	100.00	100.00
		5V		1	100.00	100.00
9		10M		4	20.00	80.00
		100K		4	20.00	80.00

	resistors	10k		4	20.00	80.00
		4.7K		4	20.00	80.00
		390Ω		4	20.00	80.00
		2.2K		4	20.00	80.00
		6.8K		4	20.00	80.00
11	transistors		TIP2559	2	50.00	100.00
				2	50.00	100.00
12	Limit switches			4	95.68	382.72
13	Humidity sensor			2	316.94	633.88
14	PIR sensor			2	290.03	580.06
15	capacitors	100uF		2	20.00	40.00
		100nF		2	20.00	40.00
		470nF		2	20.00	40.00
		22nF		2	20.00	40.00
		1nF		2	20.00	40.00
16	Crystal oscillator				200.00	200.00
17	Push button			2	20.00	40.00
18	wheels			4	750.00	3,000.00
19	Wheel hub (plastic gears)			2	100.00	200.00
20	Connecting wires			2	300.00	600.00
21	LED			3	50.00	150.00
22	Microcontroller			1	2,500	2,500.00
23	Body fabrication				9,000	9,000.00
24	Miscellaneous				22,000	22,000.00
					TOTAL	**49.994.63**

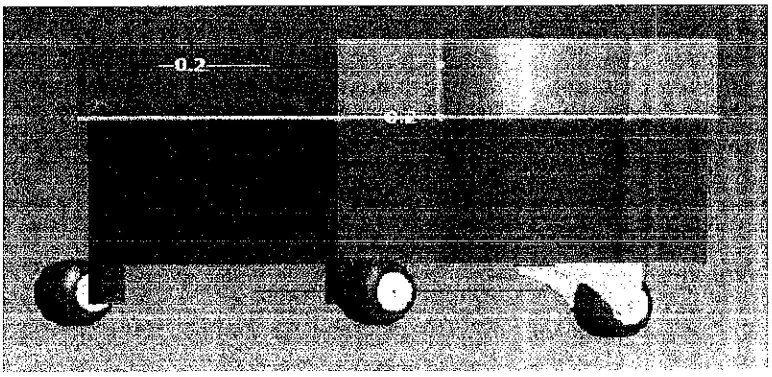
APPENDIX E

3D MODELLING OF THE AUTONOMOUS LAWN MOWER

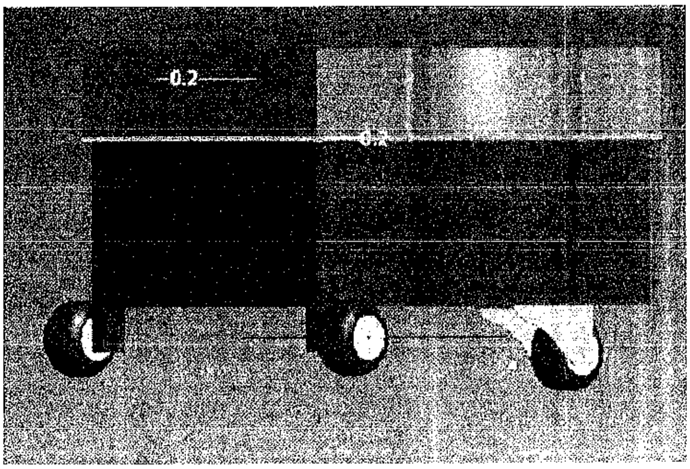




Bottom view of the lawn mower



Side view of the lawn mower



Side view of the lawn mower