DESIGN, FABRICATION AND EVALUATION OF AN AUTOMATED LINE FOLLOWER ROBOT WITH A UNIT LOAD CARRIER

BY

ESAN OLORUNFEMI JAMES

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A project report submitted to the Department of Mechatronics Engineering, Federal University Oye Ekiti in partial fulfillment of the requirements for the award of the B. Eng. (Hons) in Mechatronics Engineering.

Department of Mechatronics Engineering

Faculty of Engineering

2019

CERTIFICATION

This project with the title

DESIGN, FABRICATION AND EVALUATION OF AN AUTOMATED LINE FOLLOWER ROBOT WITH A UNIT LOAD CARRIER

Submitted by

ESAN OLORUNFEMI JAMES

Has satisfied the regulations governing the award of degree of

BACHELOR OF ENGINEERING (B.Eng) IN MECHATRONICS ENGINEERING

Federal University Oye-Ekiti, Ekiti State.

SUPERVISOR

NAME: Engr. O. D. Martins

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DATE: 27/3/2019

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SIGNATURE: ....

DATE: ....

EXTERNAL EXAMINER

NAME: ....

SIGNATURE: ....

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DECLARATION

I Esan Olorunfemi James declares that, this project work was carried out as a result of my personal effort under the supervision of Engr. Martins of the department of Mechatronics Engineering, Federal University Oye-Ekiti, Ekiti State, as part of the requirement for the award of Bachelor of Engineering Degree in Mechatronics Engineering, and has not been submitted elsewhere for this purpose. All sources of information are explicitly acknowledged by means of reference.

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I would like to use this opportunity to express my profound gratitude and appreciation to Engr. O.O. Martins for his guidance, relentless help and continuous supervision towards the success of this project. It will be a crime to forget the head of department of Mechatronics Engineering in person of Dr. Arowolo for his encouragement and kind gestures. I would also like to recognize the ideas and suggestions proffered by the staffs of the department of Mechatronics Engineering during the course of the project. Special thanks to the department technologists for their prompt assistance in the fabrication process. I am grateful to my parent (Mr. and Mrs. Esan) and my sister for their willingness and readiness to help me at all time.

DEDICATION

I dedicate this project to God Almighty for his sustaining Grace and Love. I also dedicate this project to my parents (Mr and Mrs Esan) for their endless and selfless support towards the success of this work.

ABSTRACT

This project focuses on the techniques involved in the design, fabrication and evaluation of an improved material handling system for a typical industrial application. Generally, a successful attempt has been made in this present work to build an automated line follower robot with a unit load carrying capability. This system is equipped with three wheels mechanical drive ability with a steerable standard wheel at the front, an Arduino UNO as the main microcontroller to react towards the data received from the push-button and infrared sensors to give fast, smooth, accurate and safe movement in structured environment. The mobile robot follows a black path over a white surface and detects turns and curves on its path which then modifies the motors appropriately. The automated line follower robot is designed with a unit load carrier over head to transport items placed on the carrier automatically when at the loading point.

Consequently, the automated line follower robot was tested and allowed to run repeatedly as it was designed to operate and a mathematical model was used to describe the operation of the robot from a loading point to a specific destination. Thus, the robot cycle time is 2.05min/delivery from the loading point down to the offloading point after which it makes a U-turn at the reset point.

CHAPTER ONE

1.1 INTRODUCTION

Automation basically refers to the technology by which processes or procedures are executed or performed without human assistance (Groover & Mikell, 2014). Automation has become the core of modern manufacturing so much that, no company is able to survive in a competitive market without automating its operations. In the field of automation, robots can be used as a master or a slave in doing the repeated tasks. A robot is a reprogrammable, multifunctional device designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks (George , 1979).

One of the key components of automation in a manufacturing process is the Material Handling System (Ravazzi & Villia, 2009). A Material Handling system is responsible for loading, unloading, moving or generally transporting any type of materials (raw material, work in process, and finished good) within and out of manufacturing cells such as warehouses, machines and assembly lines. Moreover, Material Handling System (MHS) consists of different components (conveyors, automated guided vehicles (AGV), automated storage and retrieval system) which AGV is considered as the most flexible equipment of MHS.

An Automated guided vehicle system (AGVS) is a material handling system that uses independently operated, self-propelled vehicles guided along defined pathways (Tiptur, 2015). Furthermore, a typical Automated Guided Vehicle is a 'Line Follower Robot' which follows a path. The path can be visible like a black line on a white surface (or vice-versa) or it can be invisible like a magnetic field designed to be flexible and obstructive.

Hence, this project contains a robotics based approach to automating material handling system using a line follower robot which moves autonomously without human intervention.

1.2 Historical Background

Automated guided vehicles have played a role in moving material and product for decades. The first system was built and introduced in 1953. It was a modified towing tractor that was used to pull a trailer and follow an overhead wire in a grocery warehouse (Mhia, 2009).

The first big development for the AGV industry was the introduction of a unit load robot in the mid-1970s. This unit load AGVs gained widespread acceptance in the material handling marketplace because of their ability to serve several functions: a work platform, a transportation device, and a link in the control and information system for the factory (Olmi & Roberto, 2011). Since then, AGVs have evolved into complex material handling transport vehicles ranging from mail handling AGVs to highly automated automatic trailer loading AGVs using laser and natural target navigation technologies.

1.3 Scope of Study

The line follower robot involves the design, fabrication and evaluation of the robot movement on a black path over a white surface from a loading point to an unloading point automatically. It involves cost analysis, modifications and the selection of suitable materials which fulfill the design requirements for the fabrication. It also covers the design description, analysis and calculations as well as the history of automated guided robots and applications.

Hence, the automated line follower robot can safely transport a unit load without human intervention within production logistic, warehouse and distribution environments from a loading point to an unloading point automatically. It is also programmed to follow a dark line on a white background and detect turns or deviations which then, modify the motors appropriately.

1.4 Problem Statement

Nowadays, manufacturers seek to implement methods of automation appropriate for increasing productivity and shorter throughput times. Material handling systems using carts and trucks with human drivers has caused unreliability and inefficiency in the part of assembly line forming the weakest link. As a result of this, Automating material handling processes using intelligent technology to maximize productivity and reduce operating cost, has proven to be the solution to unreliability and inefficiencies caused by human errors and labor, during repetitive and burdensome materials transportation.

1.5 Objectives

The objectives of this project are to;

i. Develop an automated line follower robot that moves over a black line on a white surface using feedback mechanisms as a means of control.

ii. Design a line follower robot that can take decisions independently without human intervention

iii. Design a line follower robot with a unit load carrier that can transport materials over a long distance from the loading point.

1.6 Contribution to Knowledge

The contributions made to this project as a result of innovative and extensive research are highlighted below. They are;

- Ability for the robot to transport or convey a unit load with the help of an overhead carrier.
- U-turns capabilities enabled after delivering the load at the required destination
- A status LED to indicate when the robot is moving, stationary and at the loading point.

CHAPTER TWO

2.1 LITERATURE REVIEW

This chapter provides a condensed summary of literature reviews on key topics related to an automated guided line follower robot. Hence, this chapter would review the previous studies of mobile guided robots that have been developed, provide knowledge and technical background on the technology available and methodologies used by other research counterparts around the world on the topic.

Mobile robots have played a vital role in moving material and product for more than 50 years. The first automated guided robot system was built and introduced in 1953 by Barrett Electronics of Northbrook (Hammond, 1986). It was a modified towing tractor that was used to pull a trailer and follow an overhead wire in a grocery warehouse. By the late 1950's and early 1960's, towing automated guided robots were in operation in many types of factories and warehouses.

Out of this technology came a new type of guided robot, which follows invisible UV markers on the floor instead of being towed by a chain (Wilkins, 2014). This system was deployed at the Willis Tower (formerly Sears Tower) in Chicago, Illinois to deliver mail throughout its offices. As a result of this, the introduction of a unit load robot in the mid-1970s fascinated inline transportation because of their ability to serve several functions.

Since then, guided robots such as line follower, have evolved into complex material handling transport vehicles ranging from mail handling robots to highly automated automatic trailer, loading automated guided vehicles using laser and natural target navigation technologies. (Egemin, 2008).

Ramshetty, (2014) designed an android based autonomous coloured line follower robot that can differentiate among various colours and choose a desired one to find its target. From the android mobile, instructions are given to the robot that senses a line and adjusts itself accordingly towards the desired target by correcting the wrong moves using a simple feedback mechanism. The robot is capable of following different colours with congested curves as it receives the continuous data from the infrared sensors. This robot avoids collision and moreover, in cases where ambient light interferes with the sensors thereby disturbing the transition of data at that time, RFID (Radio Frequency Identification) readers detect the desired target by detecting RFID tag placed at the destination

Therefore, the concept of the android based colour line follower robot was practically implemented based on PIC Microcontroller, RFID reader and infrared sensors. The block diagram of the overall system is shown below.

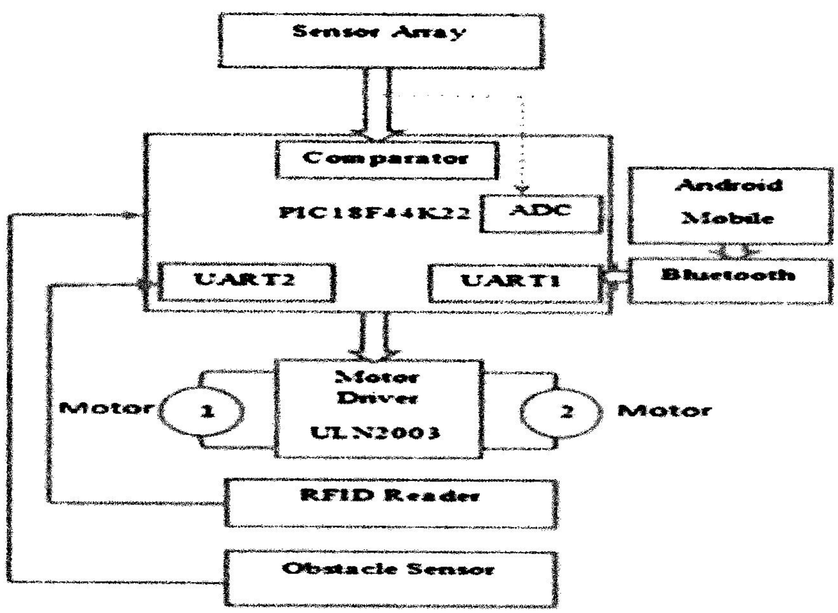


Figure 2.1: Block diagram of A Coloured Line Follower Robot.

Source: (Ramshetty, 2014)

Wira, *et al.*, (2017) introduced a line follower mobile robot for surveillance camera monitoring system to assist in solving the limited coverage problem faced by the conventional surveillance camera which is usually installed at a fixed position. Line follower was chosen to provide a mobile movement of the surveillance monitoring system. The line follower system in this mobile system was guided by using four pairs of an infrared transceiver that projected to the ground in order to follow the track line. The development of the robot also involves the use of an Arduino UNO integrated with a monitoring system LabView,

However, this work has some limitations pertaining to the flexibility of the robot on its path. It was observed that, the line sensor missed sensing the line at some designed sharp corners and obstacles detected on its paths cannot be avoided thus making it not effective in unstructured environments and highly intelligent applications.

Pintu & Dubey, (2013) demonstrated the ability of two line follower robot to interact with each other thereby, assisting in task sharing role in any sophisticated system. The operation is analogous to a relay race of human being. The system was designed majorly using the microcontroller P89V51RD2 which has distinguished addresses. Thus, when one robot identifies and validates the ID, it starts to detect the address and perform the task accordingly. Moreover, the desired operation of the task sharing by the two robots was achieved but, from a security point of view, IR sensor as wireless communication media can be infringed upon by another source thereby making it not secure in delicate applications. Hence, future implementation would require the use of Zigbee module.

Zafri, et al., (2006) used a microcontroller AT90S1200 to design an autonomous intelligent line follower mini robot system. An inductive-magnetic based sensor was used to measure magnetic field which shows the orientation and position of the pathway of the mobile robot to get real-time navigation information. Moreover, this work describes the performance as relating to the movements of the robot during its pathway by way of getting information in real time from different magnetic sensors implemented in the system, and based on a V2X(2-axis magnetometer) digital compass, microcontroller and odometric measurements.

Hence, they developed different curve types as case studies to classify and analyze the robot behavior in its travelling operations and it was observed generally that, the robot transition was not smooth as a result of the inductive magnetic based sensor adopted.

Faradia, et al., (2011) developed a line follower algorithm for a Two Wheels Balancing Robot. They used an ATMEGA32 as the brain board controller to react towards the data received from the Balance Processor Chip to monitor the changes of the environment through two infra-red distance sensor to solve the inclination angle problem. Consequently, the system will immediately restore to the set point (balance position) through the implementation of internal PID algorithms at the balance board. Moreover, the line following mode can be established based on the algorithm programmed in the Brain Board once the robot achieved balance state.

Hence, they were able to develop a dynamically stabilized balancing robot with line follower functions as a result of the combination of a line follower program with an internal self-balancing algorithm.

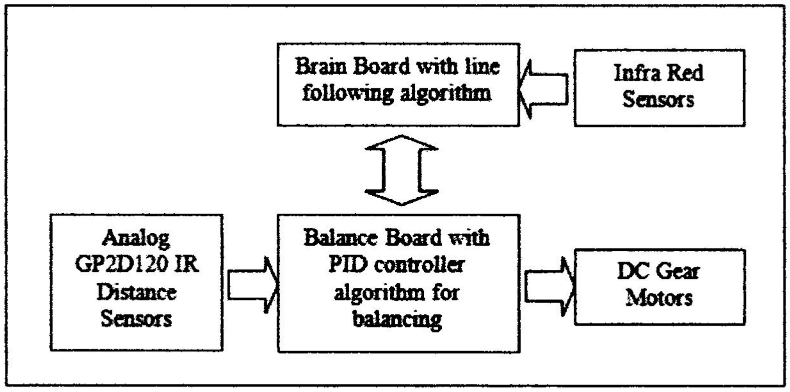


Figure 2.2: Balbot General System Block Diagram

Source: (Faradia, et al., 2011)

Nakib, Deloara, & Mamunur, (2017) introduced an approach which improved the ability of a line follower robot to autonomously follow a path that has straight lines, curve, 90 degree bends, T-junctions and intersections using minimum number of sensors. This paper discusses about some experimental result on sensor positioning and controlling strategy of a line follower robot and the development of an algorithm through which a line follower robot can detect T-junction, intersection and 90 degree turns accurately with minimum number of sensors. The robots hardware consists of an Arduino Uno as the main circuit board and two reflective sensors positioned side by side for detecting the line.

Moreover, experimental result revealed that the robot was able to follow the sample test path smoothly and easily as designed. However the limitation of this approach is encountered whenever the robot attempts to pass through 90 degree bends and junctions at high speeds. This implies that, the best performance of the robot can only be achieved when the robot is on a low speed.

Deepak *et al.*, (2013) proposed a line following robot capable of transporting medicine to the patient whenever they need it. Generally, the line is specified as a predefined path that can be either visible like a black line on a white surface with a high contrasted color. Light dependent resistor sensor has been attached with the robot whose resistance varies with light intensity. A switch with IR sensor has been fitted near the patient, which connection has been made by the robot too. Hence, if the patient presses the switch then a flag bit is set in the microcontroller, from which line following robot follows the line and gets to its destination near the patient thereby, providing the medicine to the patient with the help of the dc motor.

Therefore, this technology focused on the delivery of safe, timely, efficient, effective, patient-centered and equitable health care using a line following robot.

Elayaraja & Ramabalan, (2017) analyzed the trajectory tracking of an Autonomous line follower robot using the Design of Experiments (DOE) and embedded Fuzzy logic system. The experiments indicated that the time taken for 4m of trajectory path is minimal in DOE based approach as compared to DOE embedded Fuzzy logic system. It is also evident that, if wheel diameter is bigger and the distance between the caster wheel and rear is medium then, the robot takes minimum time to reach the designation. Hence, the travel time of the line follower robot against various levels of wheel diameter and the center to center distance between the caster wheel and rear wheel axis was investigated

Nugraha, Rizki, & Denny, (2015) developed a line follower robot to detect different color lines which represent different route, and restrict the operator authorization. This system uses a microcontroller with fuzzy logic implementation adopting Mamdani model inference method. To detect lines, robot is equipped with LED (Light Emitting Diode) and LDR (Light Dependent Resistance) based color sensor, and RFID (Radio frequency Identification) based identification/authorization system.

As a result of this, their result showed that the robot is capable to restrict operator authorization in pair with the stated RFID cards with 100% success result. Robot is able to move according to the predetermined guide lines from RFID card input with the maximum speed at 0.083m/s.

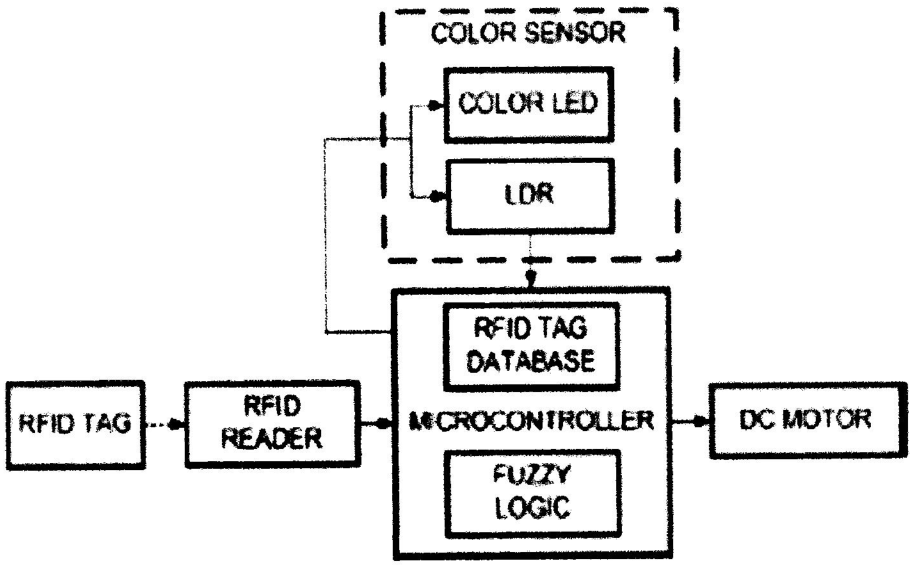


Figure 2.3: RFID Robot System Block Diagram

Source: (Nugraha, Rizki, & Denny, 2015)

Mustafa & Dilsad, (2012) worked on the development of a line follower wheeled mobile robot using an LM3S811 (ARM cortex-3 based microcontroller) as the main controller to react towards the data received from infra-red line sensors to give fast, smooth, accurate and safe movement in partially structured environment. A dynamic PID control algorithm was integrated to improve the navigation reliability of the wheeled mobile robot which uses differential drive locomotion system.

The experimental results showed that the dynamic PID algorithm can be performed under the system real-time requirements and it can be observed that dynamic PID algorithm, has better performance in every criteria compared to simple (on/off) control robot.

Sandeep, Pavan, & Prasad, (2017) designed and implemented a basic prototype line follower robot with obstacle avoiding capabilities. This prototype of the robot follows a black line, detects obstacle and take necessary actions to avoid it. They integrated an Arduino motor shield and sensors are connected to the control system powered by a 12V battery. The design includes two modules; line following and obstacle detection so that, both modules and its algorithm are implemented individually and at final, both are combined in such a way that the robot performs specified task. Hence, they concluded that the robot can be used in hospitals industries; replace conventional conveyor belts and army applications.

Akshay, Ashwini, Pradnya, & Uddhav, (2017) introduced a new approach towards a follower robot. More specifically, the approach is to design a control system which can carry luggage as well as follow the target person. In this paper, follower robotic cart is proposed by interfacing the microcontroller with ultrasonic sensor. The system is designed to provide a contactless transport along with the target person. The distance between the person and the robot is measured and the movement of the robot is decided by the inputs given to microcontroller by ultrasonic sensor.
As a result of this, the major aim of this system was to design and construct a follower robotic cart using ultrasonic sensor which can track and follow the target person in unstructured environments.

Nandini, *et al.,* (2016) worked on a robot that can be used to operate or control a restaurant to collect orders and also perform delivery operations respectively. The robot is responsible for transporting food from the kitchen to the customers seated on tables. The whole concept of the robot is built around the following components; NRF (Nordic Radio Frequency) transceiver, LCD (Liquid Crystal Display), keypad, IR sensors and Motor driver. Using IR sensors the path is traced and the readings of the sensors are used to drive the motors drivers which are installed on the robot and responsible for the robot movement.

Consequently, the result of the robot showed that upon receiving the signal from the NRF transmitter installed on the tables, the bot traced the path (using the IR sensors installed on the front end of the robot), collected the order from the particular table, brought the order back to the kitchen, and delivered the same.

Dheepak, (2014) proposed an autonomous robot which is a Pick and Place Robot using Line Tracking. Basically, this robot is used to pick and place items for some factory tasks like, sending the container from front of line to end of line or some other function that need to send item from other place to one another place. Moreover, this work eliminated some of the demerits of a behavior based navigation system (high computational power and in some cases they lead to significant cumulative errors due to the inevitable noise associated to the sensor measurements) Hence, they integrated an RFID system as a promising alternative method. The PIC (16F877A) Microcontroller was used to control the proposed autonomous mobile robot and to communicate with RFID reader. Due to the uniqueness of RFID tag, the moving control commands (such as turn right, turn left, speed up and speed down etc) can be achieved with proper actions.

Ultimately, the operation of the robot was highly dependent on the detection of the RFID tags which then enables the motor to be controlled using wireless technology thereby, producing a movement to the desired location in order to perform a pick and place operation.

Pankaj, Azeem, & Prof. Rahul, (2014) successfully designed, manufacture and tested a solar operated Line Follower Robot. The Robot follows black line path and can be automatically moved in all four directions free from the black lined path using Infrared sensors (IR). The robot is controlled by burning embedded C programming in ATMEGA 8 Microcontroller and is operated using two DC motors to drive two wheels. Photovoltaic effect is used for the rotation of the motor that enable the movement of the robot (Photovoltaic is the field of technology and research related to the devices which directly convert sunlight into electricity and solar cell is the elementary building block of the photovoltaic technology (Andris & Janez, 2009)
Thus, the most abundant and non-hazardous source of energy on our planet (solar energy) was used as a power source to operate the line follower robot.

Omer, Murat, & Dogan, (2016) investigated the use of computer controlled line follower robots in public transport. They are designed in the form of vehicles capable to move along the lines in the roads specially designed as they are taught to follow lines, thus creating a continuous flow in public transport traffic as the robots cannot go out of the roads assigned to them. The system made use of sensors placed on the autonomous robot that can send real-time environmental information successfully to the Arduino UNO. The Arduino UNO conveys the data retrieved from the sensors with the communication module to the host computer informing the operator about the current environment. Therefore, the robot transmits the instant information of temperature, moisture and speed to the host computer from the starting point. By help of the

RIFD sensor on Arduino Robot, the speed of the robot can be limited by placing RFID UHF (Ultra High Frequency) tag in the intended area as the RFID reader placed under the robot will read those tags and the robot will slow down.

The trials and tests done during the study showed that the computer interactive robots are faster to react to the environmental changes with more control over the risks than the public transport drivers.

Kazi, Abdullah, Reza, Khatun, & Basar, (2014) introduces the multiple source Multiple Destination Robot (MDR-l) having the ability to choose a desired line among multiple lines autonomously. Every line has different color as their identities. The robot can differentiate among various colours and choose a desired one to find its target. Unlike any other simple line follower robot, this robot can be considered as a true autonomous line follower robot having the ability to detect presence of obstacle on its path. A powerful close loop control system is used in the robot. The robot is capable of following very congested curves as it receives the continuous data from the sensors.

Anjumanara, Ravi, Mishra, Sinha, & Nina, (2014) proposed an autonomous robot which follows a white strip on a black surface and has the ability to drive itself. The whole concept was based on an LED-LDR sensor instead of microcontroller. The LDR (Light Dependent Resistance) acts as a sensor which senses the reflected light i.e. "transmitted light by LED". If the sensor is placed on a white surface, the D.C. motor is turned on and in black surface it will be turned off and robot will move accordingly. As a result of this, they were able to present a minimum cost robot, yet with effective and reliable capabilities

CHAPTER THREE

3.1 METHODOLOGY

This chapter is geared towards providing a detailed and comprehensive analysis on the step by step procedure, adopted in achieving the automated line follower robot with a unit load carrier and, the concept behind the project. The automated line follower robot can work autonomously on its path while loaded and unloaded.

3.1.1 Design Analysis

The Automated line follower robot was developed by an integrated design from the knowledge of mechanical, electrical & electronics, and computer engineering. Consequently, the following factors and preliminary calculations were carefully considered in the design of the robot.

3.1.1.1 Materials Selection.

Successful performance, efficiency and profitability of an engineering project depend ultimately on the choice of materials used. The materials selected were based on the following design requirement;

Chassis of the robot (Base and the Unit load Carrier)

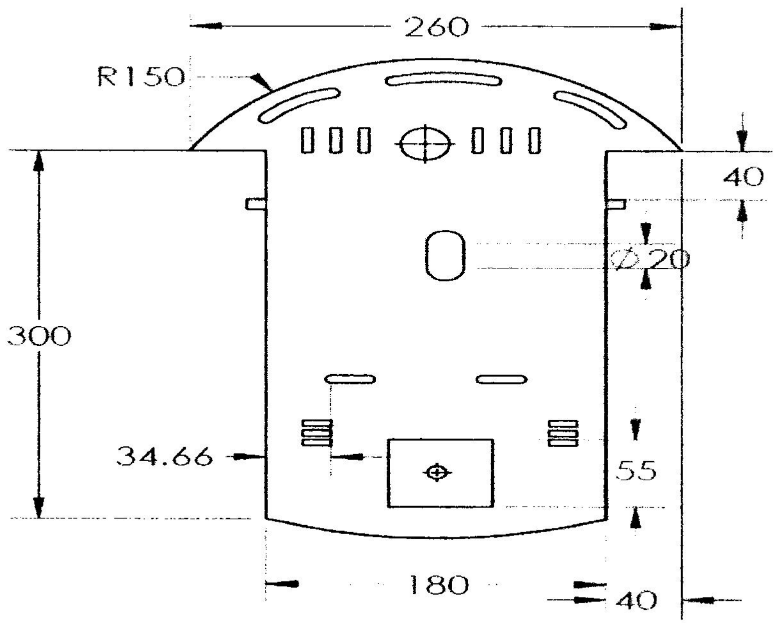
- Excellent machinability
- Rigidity
- Low cost
- Durability
- Aesthetics
- Light weight

During the screening process, the materials that did not meet the above criteria were eliminated. Thus, after ranking, the materials that best satisfy the design requirement were chosen and they include;

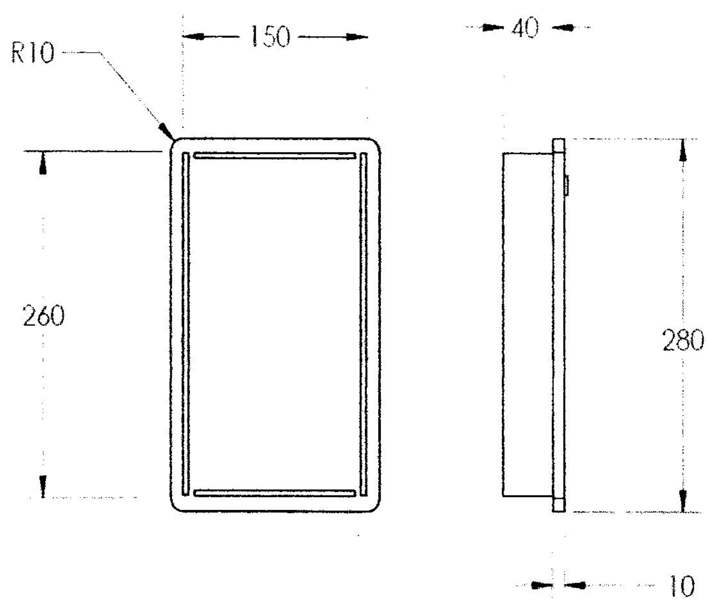
Table 3.1: Properties of the Materials used to fabricate the Robot Chassis

Material	Properties	Area used in robot design
Aluminum	Lightweight, Good corrosion resistance, malleable, excellent ductility, strength, good reflector of heat • Chemical formula: Al • Density 2.70 g/cm 3 • Melting point ~ 660.32°C • Crystal structure: face-centered cubic • Thermal conductivity 237 W/(m·K)	The base chassis of the robot
Corrugated cardboards	Stiff, strong, light weight and impact resistance • Thermal conductivity 0.1223W/(m·K) • Density 0.13 g/cm 3	Intermediate-layer of the base of the robot and the unit load carrier
Polystyrene foam	High thermal insulation, resistance to moisture, High shock absorbency, light weight and durable. • Chemical formula C_8H_8 • Density 0.96–1.04 g/cm 3 • Solubility in water; insoluble • Thermal conductivity 0.033 W/(m·K)	Surface layer to the base

Moreover, the dimensions of the robot chassis (comprising of the base and the unit load carrier) obtained from design calculations are shown below;



The base of the robot (in mm)



The carrier of the robot (in mm)

Figure 3.1: Dimensions of the Base and Carrier of the Robot

Source: Self

3.1.1.2 System Components and Description

Table 3.2: System Components of the Automated Line follower robot.

S/N	System Components	Qty	Model or Version	Description	Why Used
1.	Arduino Board	1	UNO R3	This is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), a 16Mhz crystal oscillator, an ICSP header and a reset button.	To function as the microcontroller to the robot in which programs are stored, executed and all other components can be interfaced with.
2.	Geared DC Motors with fixed standard undeformable wheels	2	TT Motors	It is a geared motor for arduino DIY (Do-it-yourself) kit wheels smart car chassis	This provides a wheeled locomotion to the robot thereby, making it mobile.
3.	Motor driver module	1	L293D driver shield	This is an L293D module for Arduino UNO MEGA2560 R3. It is a monolithic integrated high voltage, high current two channel driver.	Used to drive the motor in different directions (clockwise and anticlockwise).
4.	Infrared sensor module	3	Smart electronics IR sensor	This is a 3 pin IR infrared sensor module which consists of an opto-coupler (infrared LED and a photodiode).	This was used to guide the robot along its path by communicating with the controller as it senses the black and white

					surface respectively.
5	Steerable Standard Wheel	1	Steered wheel	Good maneuverability	Steered wheel makes the robot rotates around the wheel axle and the offset steering joint.
6.	Push Button	1	COM-00097 micro switch	It is a momentary pushbutton switch	Enables the load placed on the carrier to be detected when pressed.
7.	LED	1	Green LED	This a green Light emitting Diode	To indicate the status of the robot when moving and stationary.
8.	DC- DC step up power converter module	1	DC-DC step MT 3608	It is an adjustable voltage regulator that helps to step up to the required voltage	This was used to maintain the output voltage to 5V by adjusting the potentiometer screw.
9.	Micro USB Li-ion battery charger module	1	Micro USB 5V TP4056	It features a battery overcurrent protection capability with a micro USB input terminal to recharge the li-ion battery and still retain the input voltage	Used to recharge the li-ion battery after long hours of operation.

10.	Male to female jumper wires	36	Jumpers	It's a male to female jumper wire set with clips at both ends	This provides interconnectivity features between different components used.
11.	Resistor	1	1kΩ (Ohms)	It is a four band colour code resistor (brown, black, red, gold)	This was used as a pull-up resistor to the push-button
12.	Motor bracket T-headset	2	TT geared	This is an acrylic plastic machined for fastening	It was used to fasten the DC motor to the base of the robot and make it fixed.
13.	DC source 3600mAh	1	Li-ion	It is a rechargeable two terminal lithium ion battery	This is the robot source of power

3.1.1.3 Component Overview

1. **Infrared Sensor Module**

This is an electronic device which detects IR radiation falling on it. It basically consists of two IR LEDs. The IR emitter LED emits infrared radiation and IR detector LED receives it after the radiation is reflected from a surface. Furthermore, they are placed in a reflective way i.e. side – by – side so that whenever they come in to proximity of a reflective surface, the light emitted by IR LED will be detected by Photo diode. In case of black surface, which has a low reflectance, the light gets completely absorbed by the black surface and doesn't reach the photodiode. The IR sensor module basically consists of three components:

- IR LED
- Photodiode
- Comparator

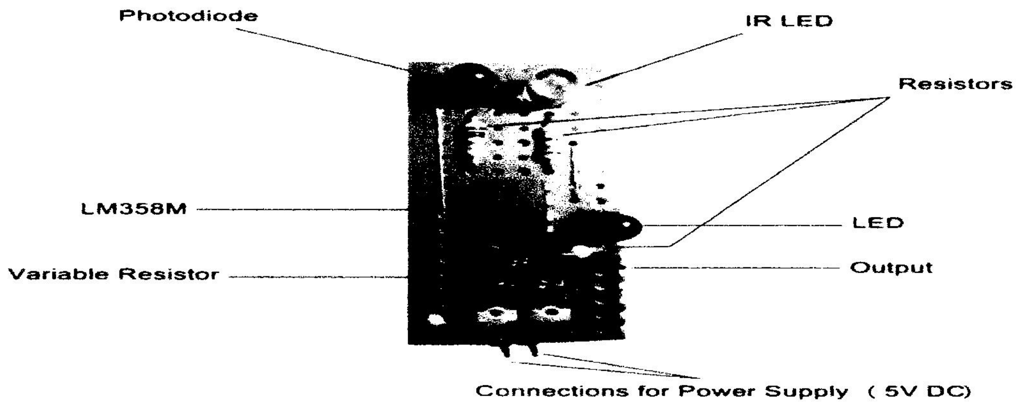


Figure 3.2: Infrared Sensor Module

Source: (Jayant, 2015)

a. IR LED:

IR LED is a light emitting diode which emits the IR radiations. The basic function of the emitter is to convert electricity into light. It works on the principle of recombination of the electron-hole pair. As in the conduction band of a diode, electrons are the majority carrier and in the valence band, holes are majority carrier. So when an electron from a conduction band recombines with a hole of valance band, some amount of energy is released and this energy is in the form of light. The amount of energy released is dependent upon the forbidden energy gap.

b. Photo Diode:

The photodiode is a p-n junction diode which is connected in reverse bias direction. The basic function of the detector is to convert light into electricity. As its name implies that it works effectively only when the certain number of photon or certain amount of light falls on it. When there is no fall of light on the photodiode it has an infinite resistance and act as an open switch but as the light starts falling on the photodiode, the resistance becomes low and when the full intensity of light fall on the photodiode then its resistance becomes zero and it starts act like a closed switch.

c. **LM358 Op-Amp**:

Op-Amp stands for operational amplifier. It is a DC-coupled high gain amplifier with differential inputs and single output. Typically the output of the op-amp is controlled by either negative feedback or positive feedback. When voltage at non-inverting input (+) is higher than the voltage at inverting input (-), then the output of the comparator (PIN 1) is High and if the voltage of inverting input (-) is higher than non-inverting end (+), then output is LOW

Technical Specification of the IR module used

- Input Power: 3.3V or 5VDC.
- Three pin interface which are OUT, GND and VCC:
- Will output logic LOW when black surface is detected
- VCC is the positive power supply, compatible with +3.3V or +5V.
- Two LED indicators, one (Red) as power indicator, another (green) as object detection indicator.
- Obstacle detection range: 2cm to 10cm
- Adjustable sensitivity with on board potentiometer, this translates to adjustable detection range.
- Detection angle: 35 degree
- Dimension: 3.1cm x 1.5cm
- Weight 0.02kg

2. Arduino

Arduino Uno R3 is a microcontroller board, based on the ATmega328P (datasheet). Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on a computer, used to write and upload computer code to the physical board. Unlike most previous programmable circuit boards, the Arduino does not need a separate piece of hardware (called a programmer) in order to load new code onto the board – you can simply use a USB cable. Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. Finally, Arduino provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

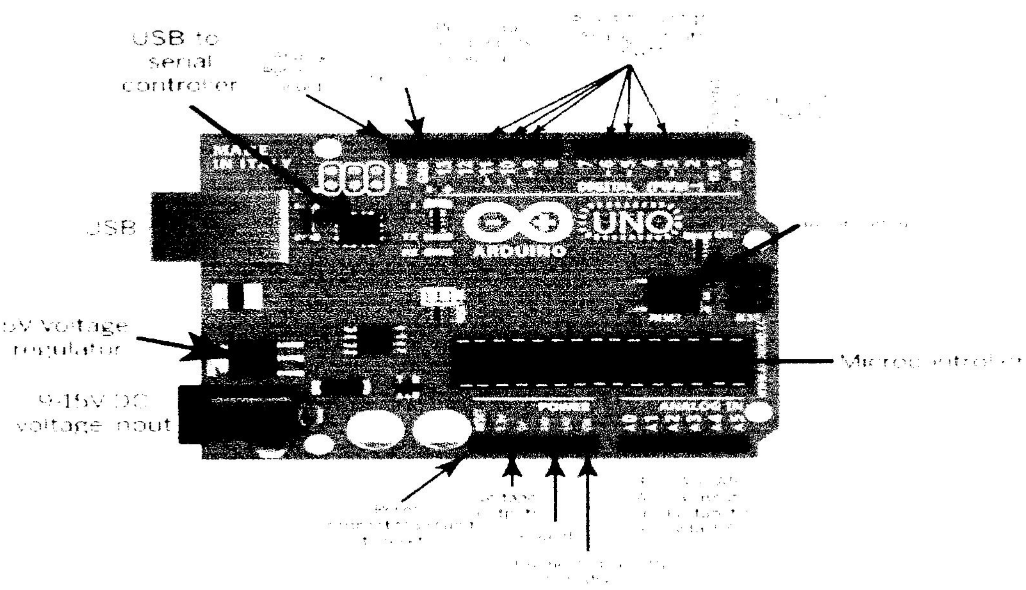


Figure 3.3: Arduino UNO R3

Source: (Smellar, 2017)

3. L293D Driver module

L293D driver module is an integrated circuit chip which is usually used to control motors in autonomous robots. Motor driver act as an interface between Arduino and the motors. It works based on the concept of H-bridge. H-bridge is a circuit which allows the voltage to be flown in either direction. As the voltage needs to change its direction for being able to rotate the motor in clockwise or anticlockwise direction hence, H-bridge IC are ideal for driving a DC motor. The L293D is a 16 pin IC, with eight pins, on each side, dedicated to the controlling of a motor. There are 2 INPUT pins, 2 OUTPUT pins and 1 ENABLE pin for each motor. L293D consist of two H-bridges.

- **Why Four (4) grounds in the IC?**

The motor driver IC deals with heavy currents. Due to so much current flow the IC gets heated. So, we need a heat sink to reduce the heating. Therefore, there are 4 ground pins. When we solder the pins on PCB, we get a huge metallic area between the grounds where the heat can be released.

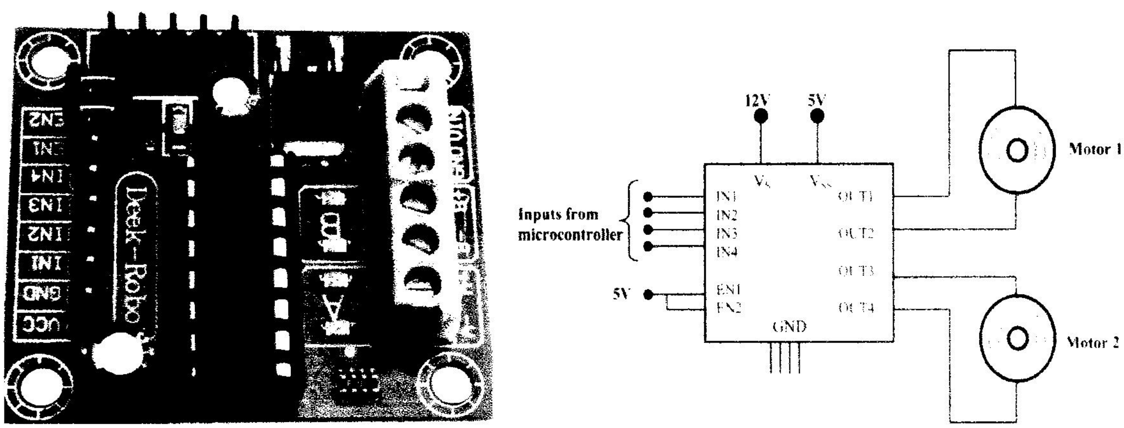


Figure 3.4: L293d Driver Shield Module

Source: Alliexpress.com

- **Why Capacitors in the driver module?**

The DC motor is an inductive load. So, it develops a back EMF when supplied by a voltage. There can be fluctuations of voltage while using the motor say when suddenly we take a reverse while the motor was moving in some direction. At this point the fluctuation in voltage is quite high and this can damage the IC. Thus, we use four capacitors that help to dampen the extreme variation in current.

Technical Specification of the L293D driver module used

- Chip operating voltage 4.5V to 6V
- Maximum output current to motor 600mA
- Weight = 20.0g

3.1.1.4 Circuit Diagram and Analysis

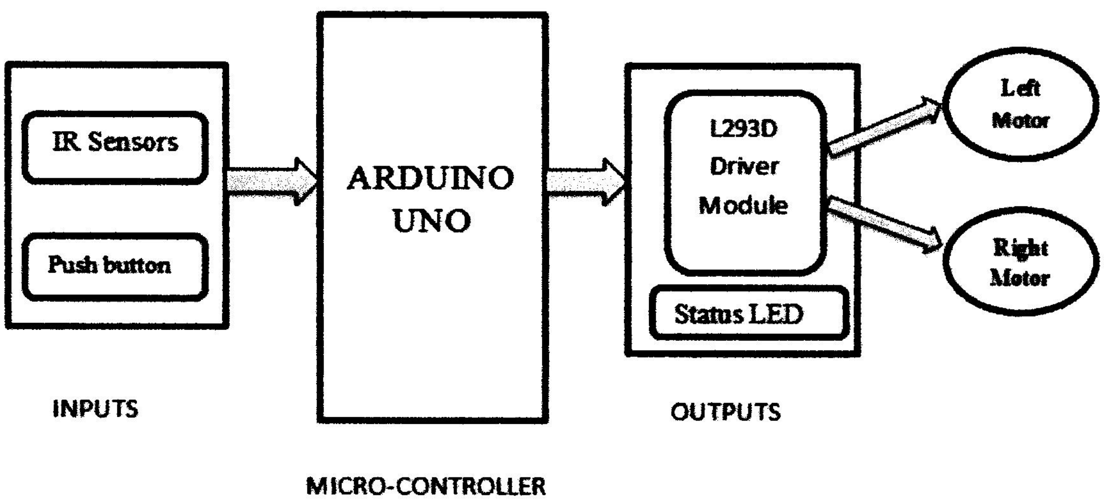


Figure 3.5: Block diagram of the Robot

Source: Self

3.1.1.4.1 Circuit Diagram

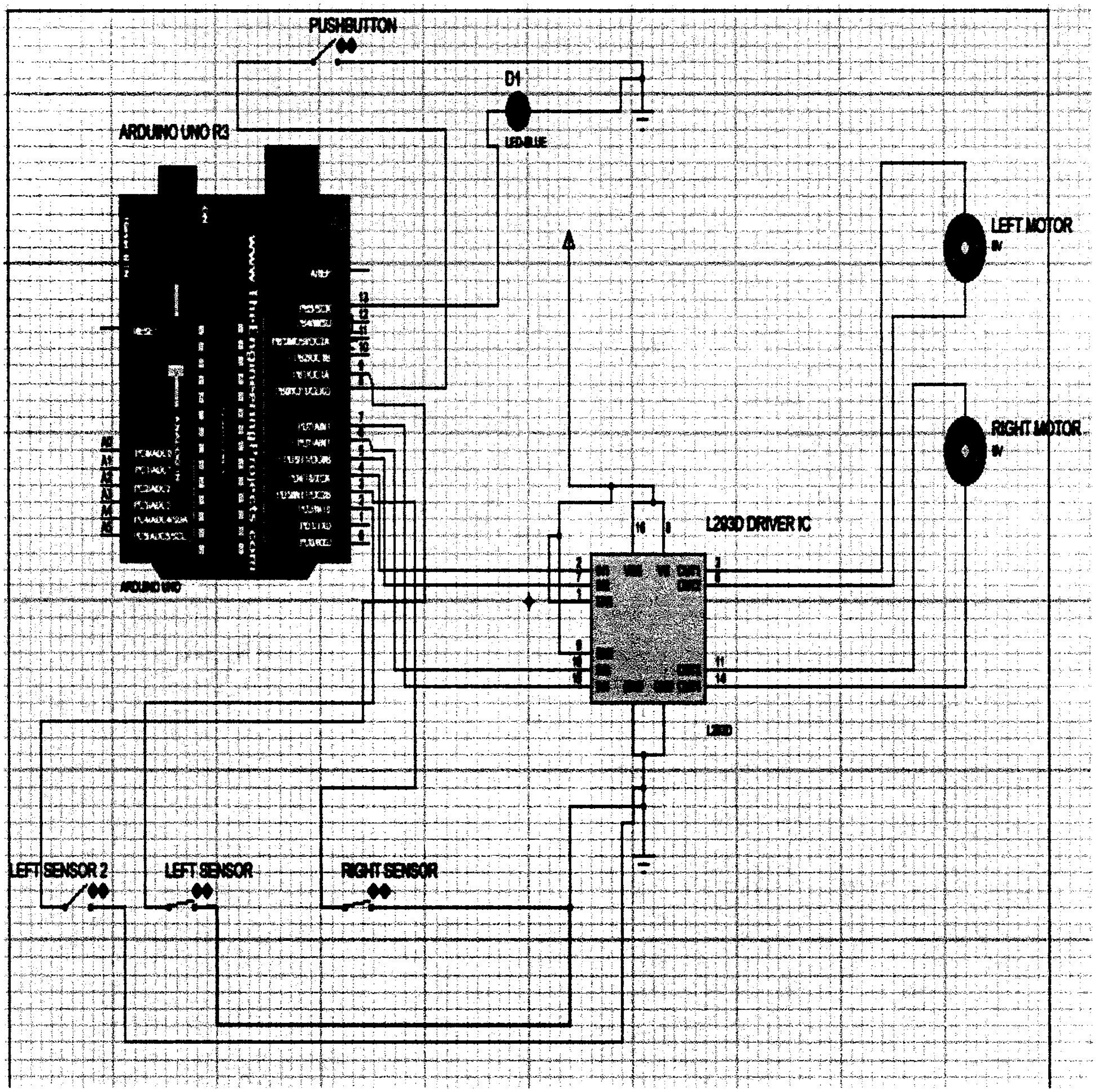


Figure 3.6: Circuit Simulation of the Robot

Source: Self

3.1.1.4.2 Circuit Explanation

The right IR sensor and left IR sensor was connected to the digital pin 2 and 3 of the arduino respectively. Moreover, the left IR sensor 2 as shown above was connected to the digital pin 9 of the arduino to detect the loading point located along the line. The L293D driver features two enable pins (1&2) which were connected to Vcc to make it high. Furthermore, the IN1, 1N2 and IN3, IN4 pins of the driver IC were connected as output to the arduino to control the DC motors as per the instruction specified by the program. The circuit has the pushbutton and status LED attached to digital pin 8 and 13 respectively and all grounds were connected to the GND terminal.

Consequently, when the unit load is placed to the carrier of the robot, the pushbutton detects the load and sends an HIGH input signal to the controller. If the robot is in its loading point, this would be detected by the left sensor 2 and then activates the robot to move when the load is placed momentarily. Then, the two IR sensors at the front shown above (left IR & Right IR) control the movement of the robot and adjust the motors operation accordingly.

3.1.1.4.3 Coding

The coding of the Arduino UNO R3 was written with the help of the Arduino IDE software, using the high level programming language 'C'. The compiled sketch was verified and uploaded to the arduino using a USB peripheral cable. Moreover, since the major mode of operation of the robot is to operate autonomously thereby, performing material handling task flawlessly, then the possible set of finite states to define the robot movement and operation at every point in time, has been defined and specified with the help of the program code. Hence, the code comprises of several variables depending on the input received and different outputs also ensue based on the combination of the inputs. The sketch of the code with detailed explanation can be found in the appendices

3.1.2 CALCULATIONS: FORMULAS, EQUATIONS AND APPLICATIONS

3.1.2.1 Power Consumption of the Robot

The successful operation of a robot over a long time highly depends on the power supplied and power consumed by the robot. As a result of this, the robot is designed to work for long hours by considering each components power consumption and then, obtaining the net power consumption experienced by the robots. Thus, the DC source required to achieve the required specification can be determined.

Table 3.3: Components specifications

S/N	Components	Specification
1.	L293D motor driver	Current: 500mA Operating voltage: 4.5 – 6V
2.	Arduino	Current: 45mA Operating voltage: 3.3V, 5V, 9V
3.	IR Sensors (3)	Current: (0.5mA × 3) = 1.5mA Voltage: 5V
4.	Green LED	10mA at 5V

Output voltage required = 5V

Hence, total current required to flow through the circuit will be

$$I_T = (0.5 + 0.045 + 0.015 + 0.010) = 0.57 = 570mA$$

$$I_T = 570mA$$

So, the power consumption of the robot will be

$$P = IV$$

$$P = 0.57 \times 5 = 2.85W$$

But, the battery's capacity is 3,600mAh. This implies that the power rating of the battery at 5V is

$$P_{batt} = 3.6A \times 5V = 18Wh$$

Hence, this means that the battery can deliver 18W load for one hour. Thus, for longer operation of the robot, the battery can sustain the robot to work for;

$$\frac{\mathbf{18Wh}}{\mathbf{2.85W}} = \mathbf{6.3\ hours} \approx \mathbf{5\ hours}\ (considering\ losses)\ before\ been\ recharged.$$

Consequently, using a Li-ion Battery of capacity 3,600mAh would enable the robot to work for 5 hours thereby satisfying part of the aims and objectives of building the robot.

3.1.2.2 Robot Movement Mechanism

The movement mechanism is an important part of a robot. Its objective is focused on how to move the robot from one point to another one. The automated line follower robot features a three wheel mechanical model chassis with a differential steering method. This involves two DC motors at the rear fixed with standard undeformable wheel and a steerable standard wheel at the front.

Consequently, the selection of the DC motor used by the robot was based on;

1. **The torque required:** High torque is needed to drive the wheel and robot when the carrier is loaded. This is achieved by a gear train system integrated to the shaft of the DC motors. Using the below formula, the output speed and torque can be derived from the gear train:

<u>The specification of the DC motor</u>

Operating voltage: 3V to 12V DC (recommended of about 6 to 8V)

No- load current 190mA

Load current 70mA (250mA max)

Weight: 400g

No load speed: 4320 rpm depending on operating voltage **(needs to be reduced)**

Torque: 1.63mNm **(which needs to be increased)**

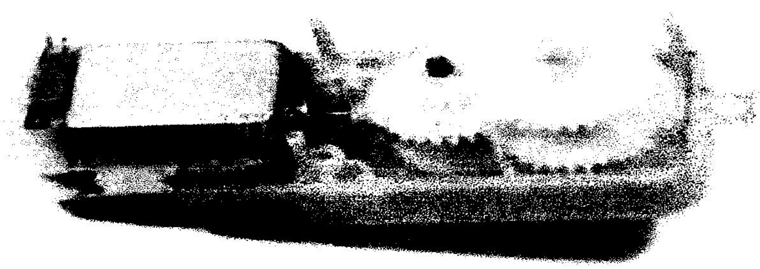


Figure 3.7: Internal Gear Arrangements

Source: Alliexpress.com

Using compound gear train consisting of spur gears (Gear ratio 1:48))

Since,

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} = \frac{N_2}{4320} = \frac{1}{48}$$

Then,

$$N_2 = \frac{4320 \times 1}{48} = 90rpm$$

Hence, the **output speed** has been geared down to 90rpm

Moreover, since torque is inversely proportional to speed, then

$$T \propto \frac{1}{N}$$

So that the **output torque** would be: $T = (1.63 \times 10^{-3}) \times 48:1$

$$T = 0.0784\ Nm$$

Other factors considered include;

2. The total weight of the Robot
3. Number of drive motors
4. Radius of the robot wheel

The steerable standard wheel (passive wheel) was chosen based on the fact that it can:

- Deliver smooth and easy maneuverability
- It is omnidirectional
- Easy steering control

Therefore, the behavior of the wheels to different robot movement is described below;

Table 3.4: Behavior of the wheel's movement

ROBOT MOVEMENT	LEFT WHEEL	RIGHT WHEEL
Move straight	Rotating	Rotating
Turn Left	Stop	Rotating
Turn Right	Rotating	Stop
Stop	Stop	Stop

3.1.2.3 Sensor Placement for Smooth Turning

Just as a driver needs to know when to turn into a junction, the robot also needs to know when to turn when it reaches a junction point and stop accurately at a loading point. Exact placement of the sensor will ensure a smooth transition when turning in curvy areas and bends. As a result of this, a robot will know when to turn depending on the location of the sensors. Thus it is very important that the placement of the sensors correspond to the method of turning.

In order to avoid the dilemma of sensor positioning, the equation below (proposed by Zafri.*et. al.* 2008) was utilized to determine the exact distance between the sensors.

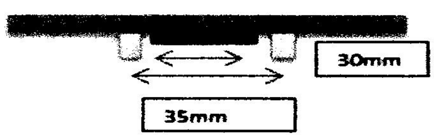
$$w < |S_{RR} - S_{LL}| < \frac{w}{tan\theta_c} \qquad \text{.....................equ.3.1}$$

Where;

$|S_{RR} - S_{LL}|$ is the distance between the left most and right most sensor in mm,

w is the width of the line being detected in mm and θ_c is the critical entry angle of the robot.

Thus;



Front view

Figure 3.8: Front Schematic View of the Robot

Source: Self

The width of the line has been determined by measurement to be **30mm.**

Setting the distance between the two front sensors to be **35mm**, and rearranging inequality equation to calculate the critical entry angle:

$$w < |S_{RR} - S_{LL}|tan\theta_c$$

$$\theta_c < tan^{-1}\frac{w}{|S_{RR} - S_{LL}|}$$

$$\theta_c < tan^{-1}\frac{30}{35}$$

$$\theta_c < tan^{-1}\, 0.85714$$

$$\theta_c < 40.6^{\circ}$$

This yields θ_C to be 40.6 degrees.

This implies that, if the robot attempts to enter a curvy path at an angle above this value, it will not be able to follow the line. Therefore, reduction in the distance between the two sensors would result to greater critical entry angle during transition to curvy routes or paths and improved sensitivity to following the line thereby achieving better performance.

3.1.2.4 Kinematic Model of the Wheeled Mobile Robots

In designing mobile robot, it is quite necessary to understand the robot motion as a result of the wheels constrains involved. Hence, a model of the robot as a rigid body on wheels, operating on a horizontal plane is considered. The total dimensionality of the robot chassis on the plane is three; two for position in the plane and one for orientation along the vertical axis, which is orthogonal to the plane as shown below;

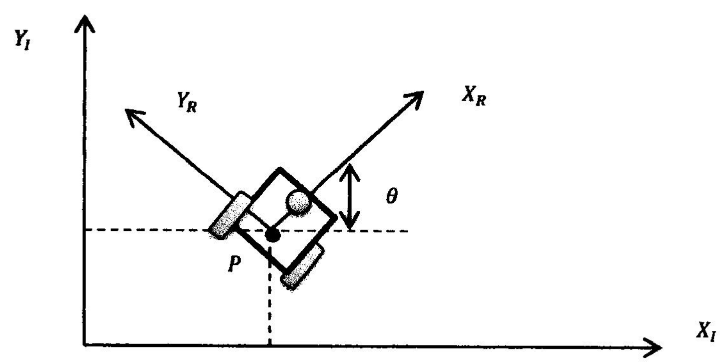


Figure 3.9: The global reference frame and the robot local reference frame

Source: Self

In order to specify the position of the robot on the plane, a relationship between the global reference frame of the plane and the local reference frame of the robot is established

The position of *P* in the global reference frame is specified by coordinates *x* and *y*, and the angular difference between the global and local reference frames is given by $\boldsymbol{\theta}$.

This follows that; the position of the robot can be described as a vector with these three elements;

$$\xi_1 = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \quad \text{.................................equ.3.2}$$

And mapping is accomplished using the orthogonal rotation matrix:

$$R(\theta) = \begin{bmatrix} cos\theta & sin\theta & 0 \\ -sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{.............equ.3.3}$$

From equation (2) the robot's motions in the global reference frame can be obtained with respect to its local reference frame using; $\xi_R = R(\theta)\xi_1$

Hence, if the robot is aligned with a global reference frame shown below;

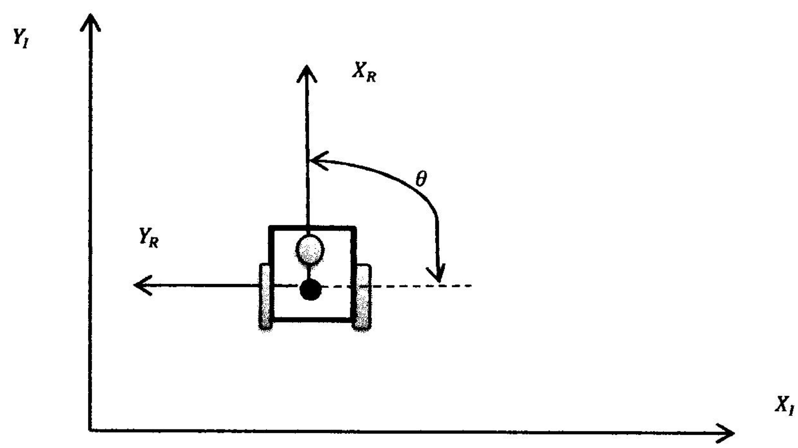


Figure 3.10: The mobile robot aligned with a global axis.

Source: Self

Then, the instantaneous rotation matrix R would be;

Since $\theta = \frac{\pi}{2}$

$$R\left(\frac{\pi}{2}\right) = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Therefore, given some velocity $(\dot{x}, \dot{y}, \dot{\theta})$ in the global reference frame, the components of motion along the robot local axes X_R and Y_R can be derived as follows;

$$\xi_R = R(\theta)\xi_1 = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{y} \\ -\dot{x} \\ \dot{\theta} \end{bmatrix}$$

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

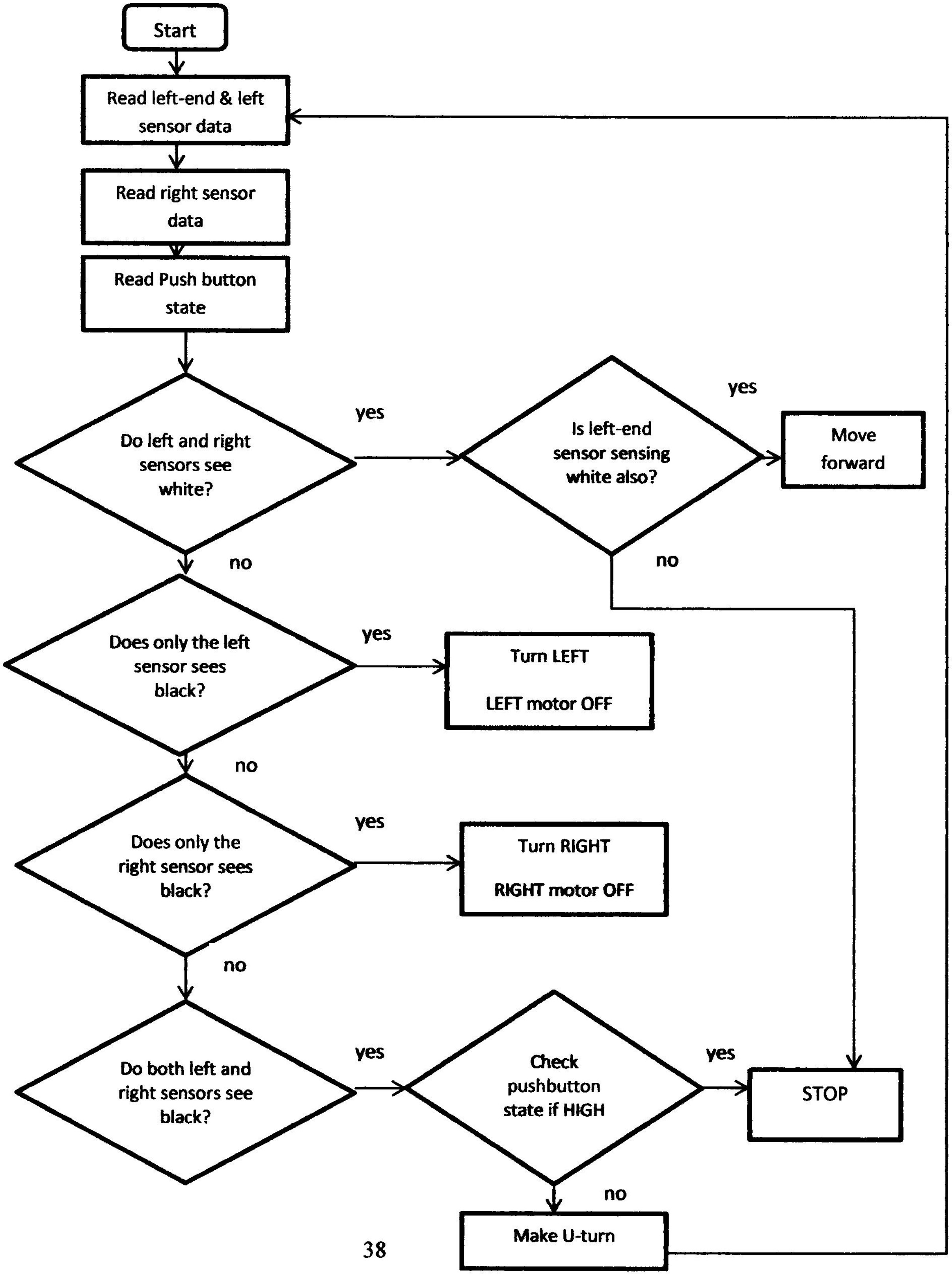
The automated guided line follower robot which features a carrier overhead was basically built with aluminum material. It has three wheels mechanical drive ability with a steerable standard wheel at the front, an Arduino UNO R3 as the microcontroller, a L293D driver module, three infrared sensors, a push button, status LED and a power source of 3600mAh (output 5V, 1A) integrated to its design. As a result of the methodology adopted, the following results were achieved.

4.1.1 Mode of Operation of the Line Follower Robot

The line follower robot moves autonomously on its path and uses information received from the environment to adjust itself accordingly. The path created for this robot has a loading point, reset point and a destination. The cycle of the robot starts from the loading point. When a load is placed on the robot at the loading point, it responds by moving momentarily to the destination by following the created path (black line). The created path may have sharp curves, bends, turning as the case may be, which is required for the robot to follow strictly. When the robot gets to the destination, it stops its movement until the load is offloaded. This state of the robot is supported by a green LED which remains steady from an initial blinking condition.

As a result of this, the robot makes a U-turn after the load is removed from the carrier and then, follows the line back to the loading point. Moreover, the robot passes through a reset point before heading towards the loading point. Hence, the movement of the robot from the loading point to the destination then, passing through the reset point back to the loading point makes the robot completes a **Cycle.**

4.1.2 Automated Line Follower Navigational Strategy Flow Chart



4.1.3 Major Maintenance of the Robot

The following maintenance tasks are to be observed regularly in the cause of the usage and operation of the automated line follower robot:

a) **<u>Re-charging the Battery:</u>**

At regular intervals depending on the usage, it is necessary to charge the battery after five (5) hours of operation for smooth and optimum performance (estimated effective working hour from design analysis). As a result of this, since the robot features a charging circuit, the charger provided can be used to perform the charging operation.

b) **<u>Path Inspection:</u>**

A well created and connected path contributes to smooth movement of the robot during operation. Hence, the paths need to be inspected to correct any breakage or distortion that may have occurred over time. This should be done before setting the robot on track.

c) **<u>Sensor re-positioning and cleaning:</u>**

As a result of vibration caused by different loads placed on the carrier, the sensor tends to react to this effect and gradually misalign from its designed position thereby, making it less- sensitive to the path. Thus, depending on the usage, the sensors needs to be checked if they are still properly positioned and dirt free

4.1.4 Troubleshooting

Table 4.1: Faults, Causes and Remedy

S/N	Faults	Causes	Remedy
1.	Robot fails to move	i. Disconnected wire from the DC power source ii. The motor driver module not ON iii. The left-end sensor sensing a black line when it's not supposed to	i. Check wires from the battery ii. Check the L293D driver Vcc supply port iii. Make sure the left- end sensor only senses black line at the loading point.
2.	Load placed, and robot fails to move	i. Push button not pressed ii. Load is too light iii. Low battery	i. Place the load at the center of the carrier so that the load center of gravity lies on the pushbutton ii. Make sure the load weighs above 80g
3.	Robot does not follow path	i. IR Sensors misaligned to the width of the path ii. Sensor wires loosed iii. Breaks and distortion in path	i. Check the sensor wires and make sure they are firm ii. Position the sensor in a reflective way iii. Inspect path properly

4.1.5 Testing and Evaluation

The automated line follower robot with a unit load carrier was tested and allowed to run repeatedly as it was designed to operate. Thus, the following parameters were obtained as a function of time. The below mathematical model can be used to describe the operation of the robot from a loading point to a specific destination. Moreover, assuming constant velocity throughout the environment and ignoring the effect of acceleration, deceleration and other speed difference. The time for a typical deliver cycle system is;

- Loading at the pickup station
- Travel time to the drop-off station
- Unloading at drop off station
- Empty travel time

$$T_e = T_1 + \frac{L_d}{v} + T_u + \frac{L_e}{v}$$

T_e = delivery cycle time (min/delivery)

T_1 = time to load (min) is 0.05min

L_d = distance travel from load to unload station is 0.25m

v = carrier velocity is 0.31m/s; ($v = \frac{\pi DN}{60}$) where N = 90 rpm and D = 65mm

T_u = time to unloading station is 0.17min

L_e = distance the robot travel until the start of the next delivery station is 320cm

Therefore, the delivery cycle time is

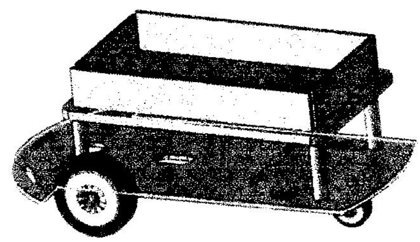
$$T_e = 0.05 + \frac{0.25}{0.31} + 0.17 + \frac{0.320}{0.31}$$

$$T_e = 0.05 + 0.80 + 0.17 + 1.03$$

$$\boldsymbol{T_e = 2.05\ min/delivery}$$

Thus, the robot delivery time per cycle is **2.05min/delivery**.

4.1.6 Views of the Robot



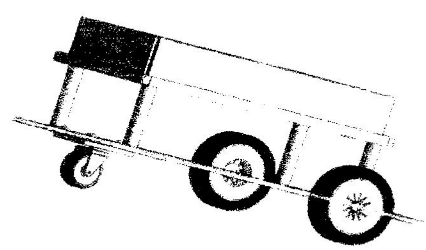


Figure 4.1: Views of the Robot

Source: Self

CHAPTER FIVE

5.1 SUMMARY AND CONCLUSION

The goal of the project was to design an automated line follower that can deliver unit loads from a loading point to an offloading point by following a designed path strictly. Moreover, the essence of the work was to facilitate automation processes in the industry. Thus, the goals were achieved. Hence, a path has been provided for the robot to follow and the operation of the robot has been tested.

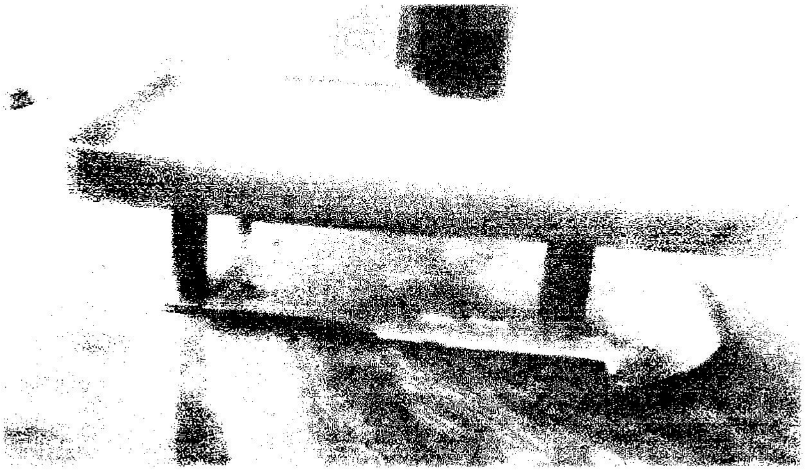
In a nutshell, I have been able to design a robot that moves over a black to white surface thereby, increasing the flexibility of material handling system and eliminating strenuous and repetitive tasks that may be boring when carried out by human in the industry with the help of the robot in a typical manufacturing environment.

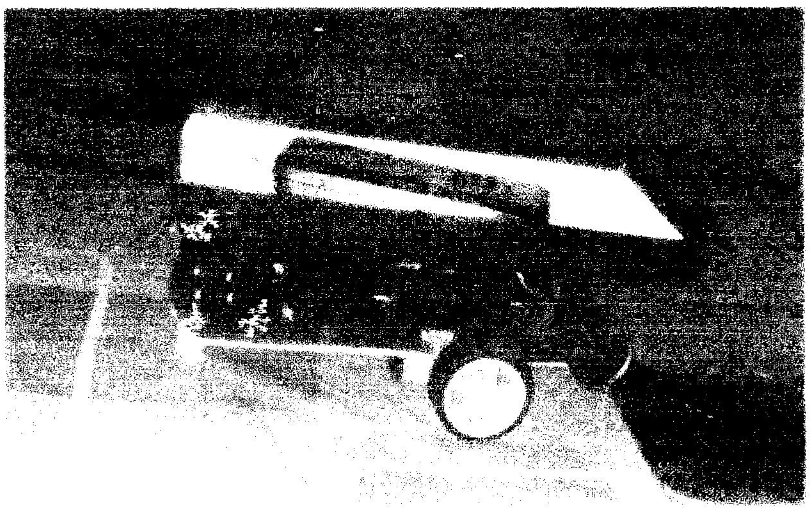
5.3 Applications of the Robot

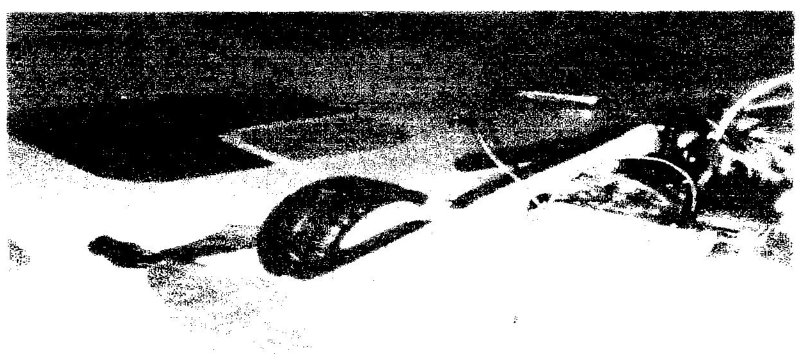
- The robot can be used to deliver mail within an office building
- It can be used to deliver medications in a hospital.
- The technology has been suggested for running buses and other mass transit systems and may end up as part of autonomous cars navigating the freeway.
- The line follower can be used in guidance system for industrial robots moving on shop floor. An example might be in a warehouse where the robots follow 'tracks' to and from the shelves they stock and retrieve from.
- It can be used in military as spy kids or in many other applications.

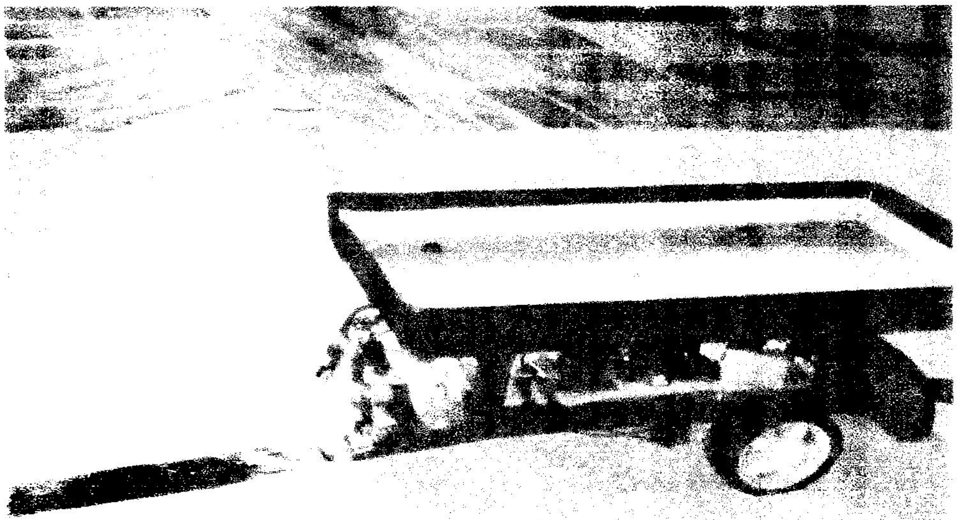
5.2 Future Implementation

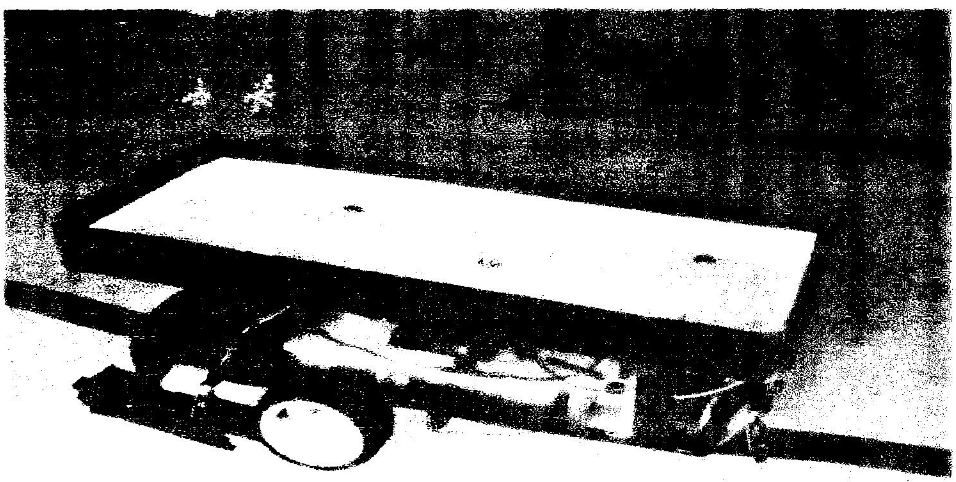
- In this system, we can make use of a sensor instead of a push-button to detect when a load is placed momentarily.
- An alert system can be integrated to the design to notify the user receiving the load at the destination without any delay.
- The robot can be designed to detect obstacle on its path and take intelligent decision appropriately.
- The number of infrared sensors can be increased to improve the sensitivity of the robots to sharp turns like acute angles











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APPENDICES

Line Follower with a Unit Load Carrier Autonomous Code:

```
/*------ Arduino Line Follower Code----- */


/*-------deffinning inputs------*/
#define LS1 2                    // left sensor
#define LS2 9                     // left-end
#define RS 3                     //right sensor
#define buttonPin  8             //push button for unit load


/*-------deffinning Outputs------*/
#define LM1 4                    // left motor
#define LM2 5                     // left motor
#define RM1 6                     // right motor
#define RM2 7                    // right motor
#define ledPin =  13;            // the LED pin



int ledState = LOW;            // ledState used to set the LED
int buttonState = LOW;


//defining variables for the LED
unsigned long previousMillis = 0;       // will store last time LED was updated
const long interval = 300;          // interval at which to blink (milliseconds)


void setup() {
```

```
 // set the digital pin as output/input:
pinMode(LS1, INPUT);
pinMode(LS2, INPUT);
pinMode(RS, INPUT);
pinMode(buttonPin , INPUT);
pinMode(LM1, OUTPUT);
pinMode(LM2, OUTPUT);
pinMode(RM1, OUTPUT);
pinMode(RM2, OUTPUT);
pinMode(ledPin, OUTPUT);
}

void loop(){
 unsigned long currentMillis = millis();
 if(currentMillis - previousMillis >= interval) { // save the last time you blinked the LED
  previousMillis = currentMillis;
  if (ledState == LOW) // if the LED is off turn it on and vice-versa:
   ledState = HIGH;
  else
   ledState = LOW;

  digitalWrite(ledPin, ledState); // set the LED with the ledState of the variable:
 buttonState = digitalRead(buttonPin);

  //movement of the robot
}
```

```
if(digitalRead(LS1) && digitalRead(RS)) // stop and make U-turn
if(buttonState == LOW)
{
digitalWrite(LM1, LOW);
digitalWrite(LM2, LOW);
digitalWrite(RM1, LOW);
digitalWrite(RM2, LOW);
digitalWrite(ledPin, HIGH);
delay(1000);
digitalWrite(LM1, LOW);
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
delay(2000);
}
else // stop
if(buttonState == HIGH)
{
digitalWrite(LM1, LOW);
digitalWrite(LM2, LOW);
digitalWrite(RM1, LOW);
digitalWrite(RM2, LOW);
digitalWrite(ledPin, HIGH);
}
if(!(digitalRead(LS1)) && digitalRead(RS)) // Turn right
{
digitalWrite(LM1, LOW);
```

```
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
}
if(digitalRead(LS1) && !(digitalRead(RS))) // turn left
{
digitalWrite(LM1, HIGH);
digitalWrite(LM2, LOW);
digitalWrite(RM1, LOW);
digitalWrite(RM2, LOW);
}

if(!(digitalRead(LS1)) && !(digitalRead(RS))) // move forward
{
digitalWrite(LM1, HIGH);
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
}

if (digitalRead(LS2) && !digitalRead(RS)) // At the loading point
if (buttonState == LOW)
{
digitalWrite(LM1, LOW);
digitalWrite(LM2, LOW);
digitalWrite(RM1, LOW);
digitalWrite(RM2, LOW);
```

```
delay(3000);
}
else
if (buttonState == HIGH)                    //loaded
{
 digitalWrite(LM1, HIGH);
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
}

  }
```