“An Autonomous Industrial Robot for Loading and Unloading Goods.”

A Thesis submitted to the Department of Electrical & Electronic Engineering, BRAC University in partial fulfillment of the requirements for the Bachelor of Science degree in Electrical & Electronic Engineering

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Declaration

We do hereby declare that the thesis titled "An Autonomous Industrial Robot for Loading and Unloading Goods" is submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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Abstract

In industries loading and unloading of heavy loads manually is one of the most imporant task which turns out to be quite difficult, time-consuming and risky for humans.In this modern era robots are being developed for various purposes to accomlish many tasks which seem to be too complex for humans. Benefits of using robots, for industrial purpose have been immense in terms of speed and efficiency of doing required tasks compare to that of humans. The paper illustrates the mechanical design of the industry based automated robot which include: Ackerman Steering Mechanism and Differential Mechanism.Ackerman Steering allows front two wheels to turn left and right in the track without going out of the track.Differential has been mounted with two back wheels and a DC motor has been used with its controller to start motion of the robot. This industrial robot has got three features and they are: Path-Tracking, Avoiding Collision, Loading and Unloading heavy industrial goods. The autonomous robot is designed to start its movement from a starting position where goods are loaded on it, then follow a path of white line drawn on black surface and unload goods by itself after reaching a destination place. Digital Line Following sensor has been mounted infront of the robot so thar the sensor can detect path by emitting and receiving signals alowing it to move in the pre-defined track having left and right turns while carrying goods from starting position to the destination. Arduino Uno has been used for programming and the required control circuit of the robot has been designed for controlling the robot's movement within the defined path. Relay Switches have been used to control the braking, and actuator movement during left and right movement of the industrial robot. The main aim is to load and unload heavy goods that has been achieved by two large linear actuators for producing required torque and force necessary to unload heavy loads (up to more than 150kg) sideways to the ground safely.Besides, the robot has been built up having the ability to avoid collision with any obstacles that come in its way. Ultrasonic sensor has been attached with the robot to send the signal and detect the presence of any obstacle that may appear in its path and stop momentarily for certain time until the obstacle move away. Building an industrial robot with moderate Speed, good Efficiency for loading and unloading purpose within a short time to ease human suffering has been the main focus of this paper.

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Chapter 1:Introduction

1.1 Motivation

Over many years, around the world labours working in manufacturing industries have been loosing their lives doing dangerous and risky jobs. Frequent injuries while doing repititive works using big machines have been common especially in the developing countries.While analysing and finding out reasons for cause of accidents in industries during production as well as in loading and unloading goods from production line to warehouse, experts have come up with some reasons which are: Lack of proper healthy working environments for labours, lack of proper safety precautions taken by owners of industries, lack of proper training to workers to opearte machines and insuffient number of well-educated and skillfull workers.Thus the ***present situations*** in industries have been remained worse and needs to be dealt properly. In many industries, such as: Soap manufacturing industries use various chemicals to prepare soaps, and bags containing these chemicals are carried by workers.This repetitive work has caused many workers to suffer from shoulder pain and also they gradually get infected by skin diseases.Hence, the realization to minimize sufferings of these workers has been the main motive to dvelop and build up a robot that can immitate this action of loading and unloading loads. Besides, we can see some existing system in industries that use trolleys to carry loads from one place to another. These trolleys are run by humans. However, the problem arises as these are hazardous tasks for humans, takes a lot of time to shift goods from one place to another and requires a lot of space[1]. Such existing system can be ***improved*** by the development of technology and use fully autamated sysytem in industries replacing additional unskilled workers. A line follower collision avoiding robot can be the ideal choice for this purpose. It saves time taken for loading and unloading, efficiency of performing the taks can be increased, risking human lives can be reduced.These unpleasant boredom and tiring jobs can be easily performed by this robot as the robot is untiring, obedient and useful in these routine jobs for industries[2][3].Thus cost of production can also be increased and cost of manufacturing goods can be reduced due to use of less labours.

1.2Literature Review

Line Following: Over many years, there has been several works on designing and implementing intelligent and efficient line following robot to serve many different purposes.Roman Osorio C. et.al designed an intelligent line following robot which can modify the performance of the movement with the help of dfferent type of magnetic sensors. The robot was based on the V2X sensor which is a type of digital compass[4]. However, in our design of the line following robot we have not followed this method. Instead, we have used IR sensor with transmitter & receiver to send signal emitted from LED and receive the signal. This is because of the availability of this sensor compare to magnetic sensor and to reduce complexity of the designing of the control of the robot.Further research has been carried out by several researchers to improve design of the system to enable robot follow the path more efficently and effectively. An intelligent robot system is designed by Bajestani S.E.M which can give different colours of light[8]. They used a comparator circuit to improve the sensitivity of the system and this comparator compares the voltage with the predetermined amounts from which a robot can move in accurate real time.[8] Still considering the complex processing algorithm that might require to achieve the desired result such method is avoided by us. Furthermore, some extensive works had been made while defining the type of path to be followed by the robot. Two different types of path we have not defined and they are: Landmarks without explicit paths because it requires large number of landmarks and if the number of landmarks changes the programming will need to be altered[9]. The other one is Landmarks with explicit paths which has the major problem in terms of the fact that if the robot misses a landmark it will not be able to recover and hence if the environment changes the robot has to be reprogrammed. Hence, We have drawn few cm thick black line on the white floor to define a certain single line pathway for the robot to follow from source to destination carrying certain amount of loads on it. The path which we have followed is a single curved path and hence complexity of programming the robot hs been reduced, number of motors require to turn wheel of the robot has also been reduced.

Obstacle detection and avoiding collision: There has been numerous works on designing the line follower robot with the ability to detect obstacle if occurs in its track of movement. Different techniques have been implemented to detect presence of any object in the path of the robot. Dr. Bindu A Thomas et.al has designed an industrial based robotic arm to lift loadthat can also detect obstacle. Obstacle detection of robotic arm was based on the IR proximity sensor[5].The sensor is able to detect obstaclesin the front, as IR LED is connected along with three pin sensor or receiver. IR LED will be continuously transmitting signal and whenever an obstcle appears IR is light is reflected whic is sensed by a sensor which in turn sends signals to microcontrller to take necessary actions which include to stop the motor driven by motor driver nd hence the robot remain stationary[5].Similar works have also been carried out by Deepak Punetha et.al to detect obstacle that appears in the path of the line following robot based on Health Care Mangement System which has been designedusing IR proximity sensor for stopping the robot if any obstacle appears[6]. It is the IR sensor, due to the presence of the obstace signal the IR transmitter and IR receiver then give its output[6].The output can then be used as making device automatic and set the flag bit of the microcontroller[6]. This method lacks efficiency and chance of collision is considerably high. Lack of efficiency is due to using IR proximity sensor because the sensor sends signal only in the IR range and it’s range up to which the signal can be transmitted by the IR transmitter is low. So, in this method obstacle can be detected if the distance between the robot and the obstcle is small. The robot can’t detect the presence of the obstacle from a large distance unlike the method of using ultrsounic sensor which we have used for obstacle detection. Besides, use of IR proximity sensor makes it difficult for the robot to avoid collision with dynamic object as well static object because if the object appears suddenly infront of the robot, time delay to receive the signal by IR receiver from the IR trnsmitter and also the time delay to send signal to microcontroller makes it difficult to achieve desired performance from the line following robot which is to stop its movement instantaneously by avoiding collision. In order to get rid of this problem, we have used ultrasounic sensor which best serve the purpose of detecting and avoiding collision with the object.We have preferred to use ***Ultrasonic Sensor*** attached with the line follower robot to detect presence of both static and dynamic object.Ultrasonic sonar sensors actively transmit acoustic waves and receive them later[7]. It is performed by ultrasonic transducers,which transform an electrical signal into an ultrasonic wave and vice versa[7].Ulrasonic sonar sensors are of two types depending on how ultrasonic signal has been changed in its path from trnsmitting transducer to receiving trnsducer[7]. They are: 1) Distance sensor(reflection) and 2) the propagation sensor. We have used Distance sensor(reflection) to serve the purpose of detecting obstacle(both static and dynamic). This sensor can detect the presence of any stationary object or dynmic object by the method of reflection. The transmitter sends the signal which reflect back in opposite direction and the received detected by the receiver. By Using the method of doppler effect, we can use this sensor to calculate the distance of the object from the moveable robot very easily by using the travel time and amplitude of the received signal. Furthermore, we use this ultrasonic sensor as it allows to detemine the speed and motion of the dynamic obstacle and also determine the object structure by partial echo separation which can be done as future improvement of this work. In addition to this reason for choosing ultrasounic sensor over IR sensor for obstacle detection, there are also some other reasons and they are: It has long term stability unlike IR sensor, directional sensitivity,sensitivity to virtually all kinds of objects, remote measurement compare to IR sensors[7].

1.3 Objective and Outline

A Robot is an automated programmable multifunctional operator that has been designed to perform various tasks, which are complex, at a faster speed and with greater efficiency than human beings.This paper focusses on designing and developing a line follower robot which has been instructed to follow a pre-defined path starting from a particular staring point to the destination point. This objective has been fulfilled by using Line Following sensor having IR(infra-red) receiver and emitter. The sensor has been attached with the robot, the sensor emits IR rays, the receiver receives its signal sends to the Arduino Uno being connected with the Control Circuit of robot.The Arduino is programmed such that the robot follows the white path on the floor. The second objective is to implement obstacle detection and collision avoiding ability in the line follower robot. While the robot is following its defined pathway, at any moment if any static or moveable object appears in its path the robot detect it by the use of obstacle detection sensor attached to it and is stops momentarily until the object goes away from its path. The ultra sound sensor is used to send signal for the presence of any obstacle. The “Doppler Effect” method is used for detection of any obstacle from a distance. by sending and receiving signal distance between the robot and the obstacle can be calculated. Hence, its speed and movement is controlled in such a away by use of motor to provide electrical power to run the robot as well as stopping the robot at the right instant when any obstruction appears suddenly during its movement. The main objective of this path-tracking robot is to rise vertically upwards to a certain height where a person will load goods of certain weight onto its empty weight carrying space. This lifting is accomplished by the help linear actuator acting as piston. DC motors are used to provide required load torque necessary for loading puproses. Once the required load is placed on the robot, its piston again lowers down and start following its path until it reaches to the destination point. After reaching the finishing line, the robot unload the load by itself without the need of any human effort.Hence in the way the time required for loading and unloading goods in industries has been minimized by the use of this robot and efficiency of performing this task has been improved signifcantly hence reducing the additional cost of labours.

1.4 Benefits

Industrial automation presents today's manufacturers with a host of unbeatable benefits. The entire purpose behind industrial automation is to increase productivity and quality. Our Industrial automation robotic systems allows companies to achieve faster cycle times, greater efficiency, and repeatability. Robotic offer a quick return on investment via dramatic increases in productivity and efficiency. Industrial automation not only simplifies labor-intensive tasks, thereby reducing workforce costs significantly, it also minimizes the production hours. Robots and other types of industrial automation are capable of providing consistent, repeatable results. When manufacturers utilize industrial automation, they eliminate the quality control issues involved with human error. With industrial automation, processes can be carefully regulated and controlled, so the quality of the end product is not only reliable it is often vastly improved. So, whether the company is a manufacturer looking to create exact, consistent welds each and every time, or a pharmaceutical company that requires hygienic, clean room results each and every time, industrial automation provides consistent, reliable results. Industrial automation effectively improves workplace safety and protects workers from injury. Robotic systems can endure extreme work environments and work around hazardous substances. By removing workers from limb and life-threatening settings and placing them in more challenging operating and programming jobs, industrial automation improves quality of life and protects the company from costly insurance claims. Industrial robots are made to work in frigid, explosive, foundry, cleanroom, and other environments that involve potential hazards for human workers. Robots are oblivious to toxic paint and weld fumes. When tending machines, robots move in a pre-programmed manner, so accidents are fewer. In another way, industrial automation used in food and pharmaceutical applications keeps end-users safe from contamination. In order to survive in today's global economy, companies must remain competitive.

Chapter 2: Differential Mechanism

2.1Construction and Functions

A Car **Differential**has been used to ensure that the industrial robot can move smoothly in road without slipping. Differential mechanism is a very fascinating and useful to ensure rotation of wheels of our robot without skidding through the road surface while it makes a turn. Hence **differential**allows our robot carrying heavy loads not to topple and slip over while it makes a sharp turn. A Differential distributes power from car transmission shaft to a pair of Left-Right wheels while allowing wheels to rotate at **different speeds.** The figure 1 below shows different parts of differential. It consists of Planet Pinion, Crown wheel, and gear such as: Sun Gear.

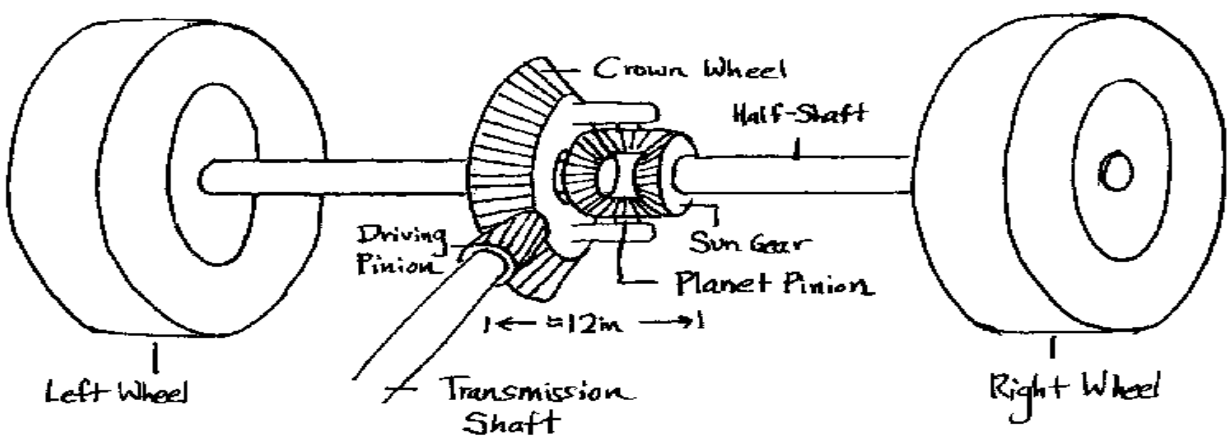


Figure 1: Different parts of Differential

2.2 Purpose and How it works

Instead of using two DC motors to control two rear wheels independently, a single DC motor with a differential has been the best choice in terms of cost-effectiveness while designing the robot as well as to fulfill the purpose of path following carrying heavy goods. **Differentia**l has been used because to ensure rotation of wheels of the robot without skidding through the road surface while it makes a turn. The main purpose for us to use the Differential is to prevent the robot wheels from slipping and spin out of control.When the robot is traveling straight, both wheels travel at the same speed**.** Thus, the free-wheeling planet pinions do not spin at all. Instead, as the transmission shaft turns the crown wheel, the rotary motion is translated directly to the half-shafts, and both wheels spin with the angular velocity of the crown wheel (they have the same speed). When the industrial robot is turning, the wheels must move at different speeds. In this situation, the planet pinions spin with respect to the crown wheel as they turn around the sun gears. This allows the speed of the crown gear to be delivered unevenly to the two wheels. The figure 2 below shows how differential motion occurs while making a turn.

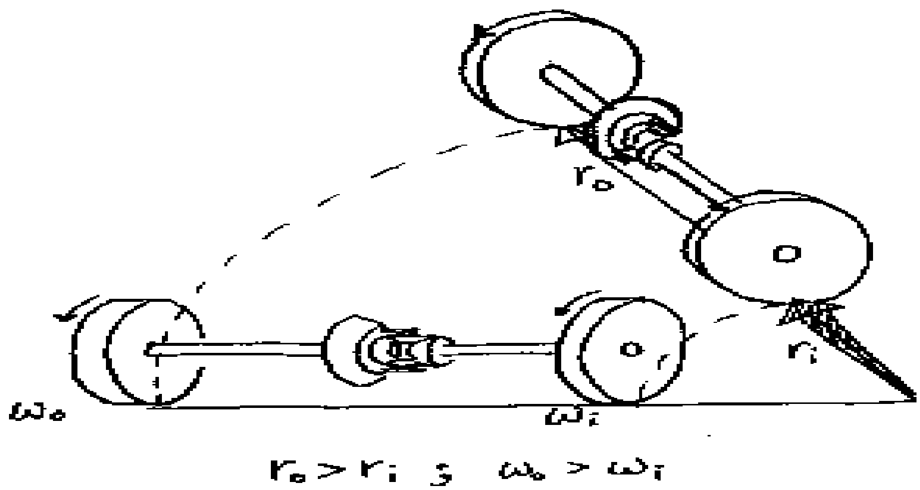


Figure 2: Differential position during making a turn

2.3Design using Differential and Brushless DC motor

We have mounted a 48V Brushless DC motor with the **Differential** by welding as shown in the figure 3 below. The motor is connected with the controller, and a chain is used connecting the motor with the differential. Hence, when the motor starts, the chain connecting with the differential rotates allowing the differential to work accordingly. Thus, both rear wheels attached with the differential move at required speeds. During the motion, the input power (**Pin)** gets transmitted to the differential which in turn delivers the power as **Pout** (output power) to both left and right rear wheels according to angular velocity ***w1***and ***w2*** of each gear respectively. When the industrial robot makes a turn, one of the front wheels goes inside and the other goes outside. Since, one of the rear wheels of our robot goes “inside” the arc, while the other wheel goes “outside” the arc during the turning of the robot, consequently in order to travel the greater distance the outer wheel (the one that goes outside the arc) travel at faster speed compare to the “inner” wheel for the same period of time. In order to ensure both wheels rotate at different speed the use of **Differential** is very essential. The “inner” wheel move at lower speed than the “outer” in order to turn the robot without slipping and to turn smoothly without the losing the balance of the robot. Hence this method is much better compared to that of using two DC motors separately at two rear wheels as **differential** allows our robot carrying heavy loads not to topple and slip over while it makes a sharp turn. Mathematically the input power (**Pin)** and outputpower**(Pout)** can be expressed as: $P_{in} = (T_1 \text{ x } w_1) + (T_2 \text{ x } w_2)$, where T is the torque supplied to each half-shaft.

Figure 3: Actual diagram of Differential mounted with 48V Brushless DC motor

Chapter 3: Ackerman Steering Mechanism

3.1Ackerman Steering Condition

An accurate, precise and efficient steering mechanism has been of great importance in order to maneuver the industrial robot within a desired path for the purpose of loading and unloading goods. The main objective for us to design such steering mechanism is to ensure that both front wheels of our industrial robot turn freely on a curved road without slipping. A device that provides steering according to the **Ackerman condition** is called Ackerman steering or Ackerman geometry. It has been essential to ensure that when the robot makes turn either towards right or left, steering angles of the front inner wheel and outer wheel is such that**Ackerman Condition** is obeyed to prevent slipping of front wheels. Theoretically the condition can be explained as in order to prevent slip-free turning of wheels steering angles must be such that by drawing normal from center of each tire-plane must intersect at a common point O. The condition can be expressed mathematically as:

$\cot\delta_o - \cot\delta_i = w/l$.-----------------(1)

Where, δ_i= steer angle of innerwheel, δ_o= the steer angle of outer wheel**,** **L**= distance between center of rear wheels and front wheels, **w**= distance between two front steerable wheels. The diagram below depicts clearly position of Ackerman Steering wheel that can be designed by obeying Ackerman Steering Condition.

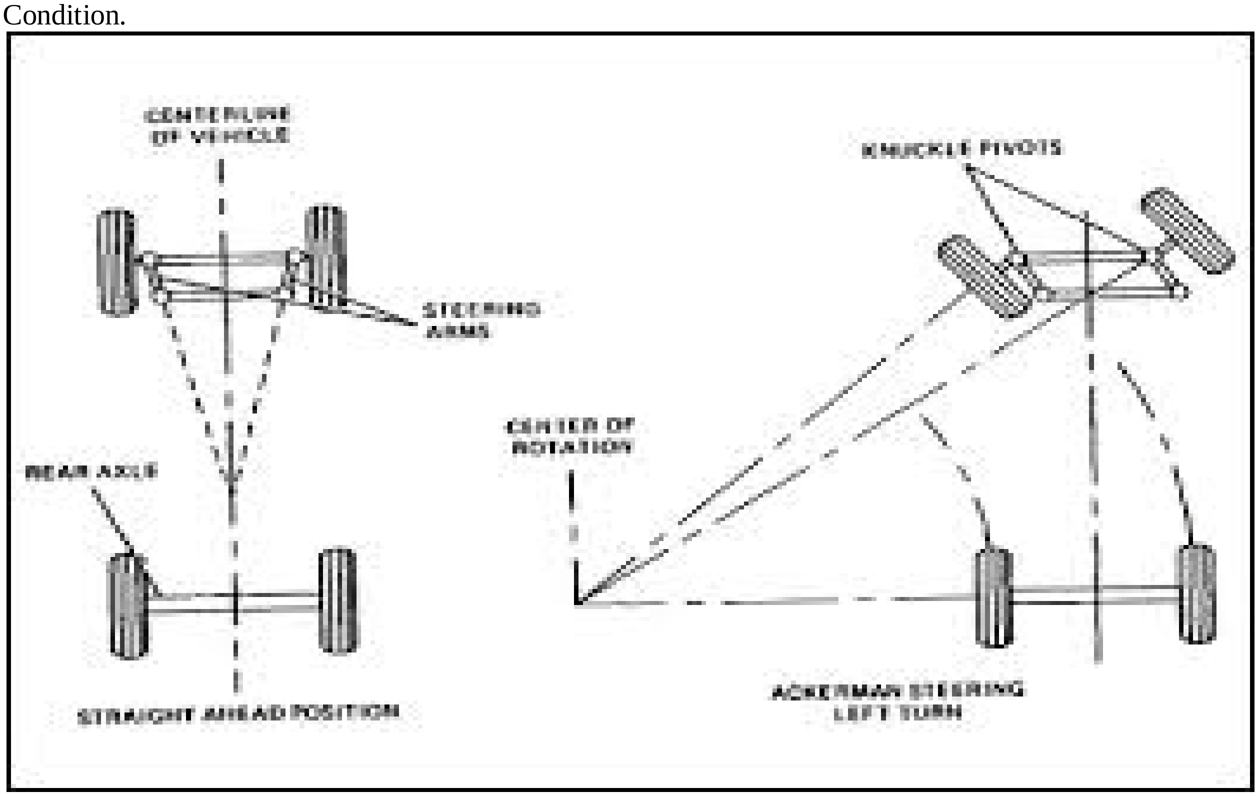


Figure 4: Position of Ackerman Steering wheel during moving in straight line and making a turn

3.2Steering Design & Measurements

"Ackerman Steering" has been designed to control smooth turning of front wheels of robot whenever the robot faces a turning path ahead. Both front wheels are free to turn towards right as well as to left at same time without slipping. . Ackerman steering mechanically coordinates the angle of the front two wheels. In order to maintain all wheels in a pure rolling condition during a turn the wheels need to follow curved paths with different radii originating from a common center [10]. It has been the best choice compared to other steering mechanisms due to following advantages. They are: Lower drive power during steering maneuvers, Low control complexity and medium maneuverability with accurate steering angles while turning [11]. It has been essential to ensure that when the robot makes turn either towards right or left, steering angles of the front inner wheel and outer wheel is such that Ackerman Condition is obeyed to prevent slipping of front wheels. In our design we have followed precise measurements of length (**L**) of the vehicle and width (**w**) of the vehicle accurately to ensure **Ackerman Condition** is maintained. The path that has been designed with radius of curvature **R,** has enabled us to consider steering angle is ***δo=25.3degree,*** its corresponding **δi=35 degree** that has been found from the characteristic graph of ***δovsδi***based on Ackerman Condition. The graph of***δovsδi***has been shown below**:**

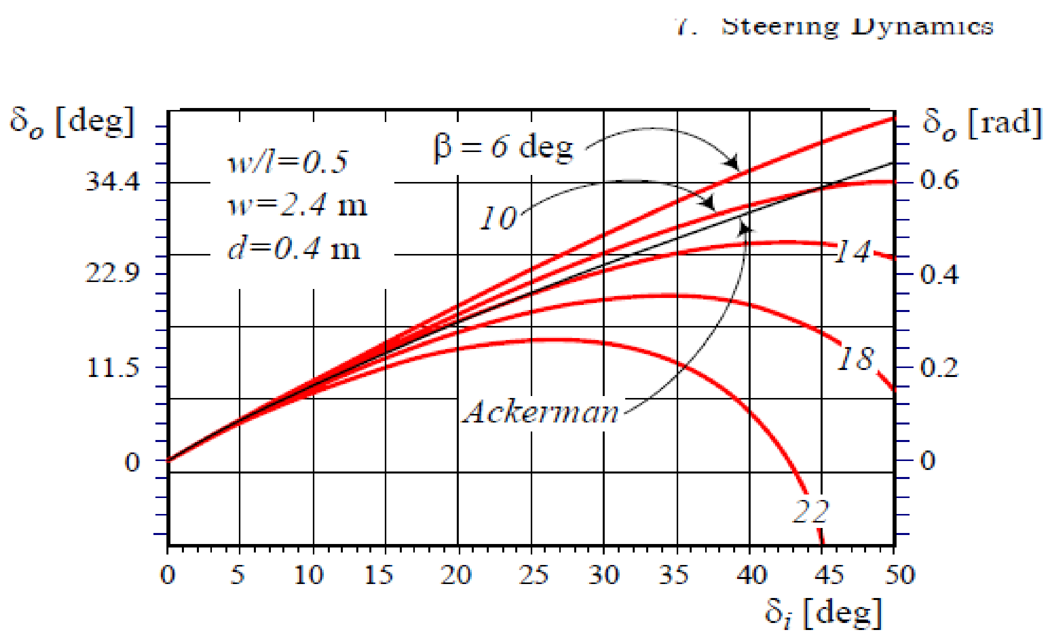


Figure 5: Characteristic curve of ***δovsδi*** of Ackerman Steering

The design of the steering is such that the Width (**w**) is same as Differential length and therefore **w**=35.7inch. Thus length (**L**) can be found by applying following formula:

$$\cot\delta_o - \cot\delta_i = w/L$$
$$\Rightarrow \cot 25.3° - \cot 35° = 35.7/L$$
$$\Rightarrow l = 35.7/(\cot 25.3° - \cot 35°)$$
$$L = 52 \text{ inch}$$

We have been able to build up such steering using Flat bar. Two front wheels are small in size and diameter compare to rear wheels. Two Flat bars are positioned at an angle such that extending two straight lines from both flat bars intersects at the midpoint of the differential. Wheels are adjusted with flat bars using nuts, and flat bars are also welded precisely as shown in diagram below.

Figure 6: Actual Design of Ackerman Steering of Industrial Robot

A medium-sized linear actuator has been attached at the side of the steel bar which has been used to make the chassis of the industrial robot. This actuator has been supported with screws and welded with its one end fixed tightly with the front wheel of the Ackerman Steering as shown in the figure below. Bottom end of the actuator has been fixed tightly with screws and welded while the other end has been fixed touching one of the front wheel. This linear actuator has been the ideal choice for us because it has 12V DC gear motor which uses a worm drive to move shaft back and forth along its length. It has two limit switches allowing the motor to be stopped after reaching the end of its range, and diode allow to reverse its direction after a limiting point is reached. Hence we have connected a 12V battery with two terminal of the linear actuator allowing it come outwards resulting both Ackerman steering (front) wheels to turn towards right. On the other hand, reversing the connection results both front wheels to turn left as extended actuator moves inwards.

Figure 7: Ackerman Steering Wheels with Linear Actuator attached sideways

Chapter 4: Loading & Unloading Mechanism

4.1 Designing upper part of the robot

Since theobjective is to load heavy goods on the weight carrier of the robot from a certain height above the ground, four steel bars of around 3.5 feet have been used. The lower part of the robot a chassis has been designed with steel sheet to make the body of the robot strong. A rectangular frame has been designed at the upper part of the industrial four-wheeler robot to carry weight. This frame is made of steel known as “Angled Steel”. This rectangular frame is supported by four additional steel bars whose are of same height **around 3.5 feet** such that the resulting total height of the upper rectangular frame is **around 4feet** above the ground. All these four bars act as pillars to withstand the force of loads as well as frame. All these bars are placed vertically and are welded at the bottom with the steel sheet which is used as chassis of the four-wheeler industrial robot. Thus before the robot is allowed to maneuver in the desired track until it reach its destination place for unloading goods, it is possible to place loads on it from mini truck round 4 feet above the ground. On the rectangular frame strong thick PVC hardboard has been placed and it has been tightened at all sides by hammering big screws inside the hardboard. The purpose of this hardboard is to act as weight carrier and withstand the force exerted by these loads easily without cracking and breaking the frame. Two medium sized linear actuators are placed vertically above a certain height from the bottom of two vertical steel bars and the bottom part of both actuators are fixed by welding. The circular top parts of both actuators have been kept free and touch the lower part of the frame. Each linear actuator is 22 inch when closed and has got two terminals. Since both these actuators are connected with 12V battery, at the destination place when the robot unload goods to the ground both these actuators shaft come outwards vertically at the same time. During this ongoing process it has been observed that both linear actuators shift sideways due to moment of inertia allowing the rectangular frame to tilt sideways and goods kept on the frame slide off to the ground by itself without any human intervention. Hence heavy goods fall to the ground safely without being damaged as the risk of falling to the ground from a high distance above the ground has been minimized. The figure shows the design of the upper portion of the robot for loading and unloading goods as well as the whole design of the robot.

Figure 8(a): Whole design of the Industrial Robot during Loading Goods

The following table below shows measurements of the designed rectangular frame and the chassis of the industrial robot.

Measurements	Length/(inch)
Length of rectangular frame	49.7 inch
Width of rectangular frame	26.3 inch
Height of rectangular frame above the ground	25.3 inch

Table (a): Measurements of the size of the Industrial Robot

Figure 8(b): Position of the Industrial Robot during Unloading

4.2 Linear Actuators

A single small linear actuator with feedback **10"**travel has been used for steering purpose. It has got 12V DC gear motors that use a worm drive to allow its actuator shaft move back and forth along its length. Since this actuator is placed horizontally, its shaft move horizontally outwards and inwards depending on whether the four-wheeler robot has to turn right or left. This actuator has a maximum speed of 1.3cm/s[a]. Besides it has got gear ratio of 20:1 and free-run current of 500mA[a].The figure below shows the small-sized linear actuator that has been used for maneuvering the industrial robot.

Figure 9: A small-sized linear actuator for steering purpose

However, for unloading purposes large-medium sized linear actuators have been used. Each actuator has got dynamic load rating of 100 kg. This means it can withstand this load while the shaft is stationary and the worm drive makes sure that the shaft remains in its position when it is unpowered.It has got two limits switches safely stop the motor at either end of its range, while diodes allow it to reverse direction after reaching a limit point[a]. Thus connecting its two terminals with battery allows the shaft to come outward during unloading goods and reversing the connection causes inward movement of the shaft of actuators.

Figure 10: Position of Linear Actuators during Loading Goods

The above figure shows how two medium-sized linear actuators have been used and its position during loading goods.

Chapter 5:Autonomous Path Following

5.1 Sensors & Designed Path

Digital Line Following Sensors have been used to allow the Industrial Robot to follow the path and maneuver within the designed path automatically without any human interruption. Each Digital Line Following Sensor has two LTH-1550 reflective object sensors. These are similar to IR sensors. Each Infra-Red Sensor has got an emitter and a receiver. The emitter emits infra-red signal which gets reflected back from the surface and gets detected by the receiver. Since IR sensors have been used for path-tracking, the path has been designed by drawing thick white line on the black surface so that the emitted signal is reflected back from the white surface and is received by the receiver. The figure below shows such a Digital Line Following Sensor that has been used in the control circuit.

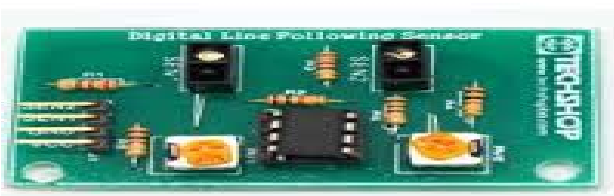
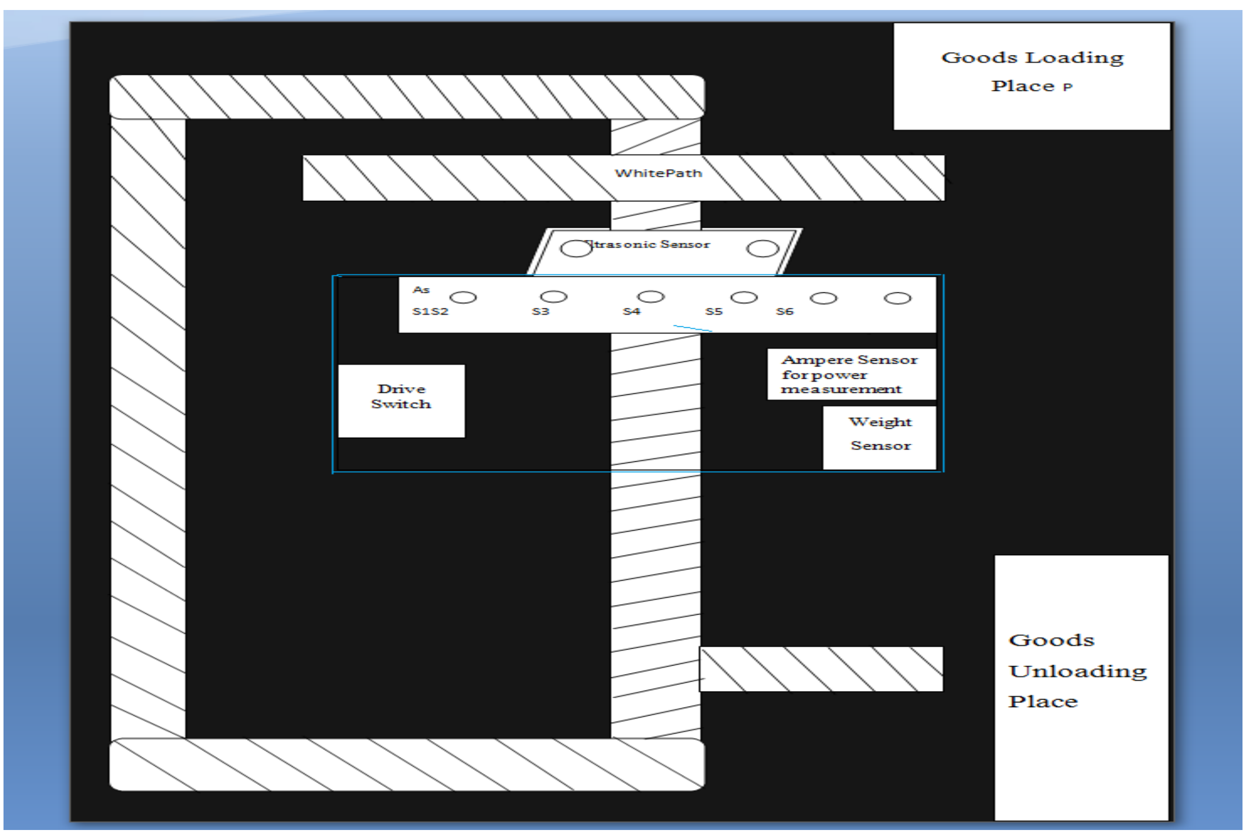


Figure 11(a): A Digital Line Following Sensor

This sensor is really useful compare to Infra-Red sensors because the Analog signal from its IR sensors gets converted into Digital Value (0, 1). That means we get digital output from sensors to be further used to the Arduino Uno. This sensor has got an opamp which LM358 that acts as a comparator with two reference voltage by two POTS [b]. The purpose of these POTS is to calibrate sensors by tuning POTS after connection Vcc and GND to power supply[b]. We have used an array of six digital line following sensors for path-maneuvering. The diagram shows pictorial representation of the designed path for the industrial four-wheeler robot. This desired path has been developed and built up in such a way so that it is suitable for the industrial robot to maneuver on the path for carrying heavy loads from the starting position to the destination position. The path consists of thick white line which has been drawn on the black surface. White line has been drawn so that Infra-Red sensors of digital line following sensor can detect this and send digital output to ArduinoUno. Besides, the figure shows the bottom view of the four-wheeler industrial robot which clearly shows position and arrangements of digital line-following sensors which has been used to detect white line on the path and allow the robot to maneuver within the path. An array of six digital line following sensors which are represented as S1,S2,S3,S4,S5,S6 have been placed at the front side of the robot and very close to the white line so that sensors can detect white line enabling smooth movement of the robot within the track. Each digital line following sensor has got two IR sensors and each having receiver and emitter and signal which is emitted by emitter gets reflected by the white line and received by the receiver and for this purpose white line is drawn. The path has got Starting position which is known as "Goods Loading Place" as indicated in the figure as completely drawn white line. When the robot is at this starting position, sensors represented as S3, S5 detect the white line and thus brake is applied. Furthermore, it can be said from the diagram that when the robot has reached its destination place known as "Goods Unloading place", sensors S5,S6, S1 detect the white line and motor brake is applied after the output from the signal is sent to the Arduino Uno. The path is rectangular and has got both left and right turn. During left turn, sensor S2 fall in the white line and during right turn S4 detects the white line. While moving in straight line sensor S3 is above the white line. Hence developing this type of plain and smooth surface is suitable and has been essential for maneuvering this robot for loading and unloading purpose.

Figure 11(b): Design of the path for path maneuvering



5.2 Block Diagram of the System

The Block Diagram/ Architecture show how the control circuit has been implemented to allow the industrial robot to serve its purposes which are: a) Path Tracking and Maneuvering. b) Loading and Unloading of heavy goods. c) Obstacle detection and avoiding obstacle. In the block diagram Arrows are used to indicate sending and receiving of signals from different components that are used in the control circuit. These signals are classified as two types and they are: Input signal and Output signal. Inputs are distinguished from Outputs by the direction of arrows. Input signals are those which are represented as arrows that enter a block while output signals are represented by arrows leaving a block. Digital Line Following Sensors that are assigned to detect the path read changes to the surroundings and output of sensor value (indicated as Signal A) is send to the Arduino Uno. Arduino Uno is the main and central block of the system which is programmed to make decisions depending on the output sensor value. These decisions are then send to Relays to take necessary actions. Signal B is the output value of two sensors which go as input to the Arduino. Depending on Signal A, Arduino transmit output signal to the Relay Switch (s1) which control the single linear actuator for path tracking. Similarly, the output from the Relay Switch (s2) goes to two Linear Actuators for loading and unloading purpose after an output of Arduino goes to the input of that relay switch. Brushless DC motor (48V) is driven by using rechargeable battery (48V). The motor send signal to the motor driver as well as the controller send signals to both DC motor to drive the motor as well as to the Arduino. Sufficient power source (5V) has been used to operate two Relays as well as to provide power to the Arduino. The following diagram shows actual control circuit of the system.

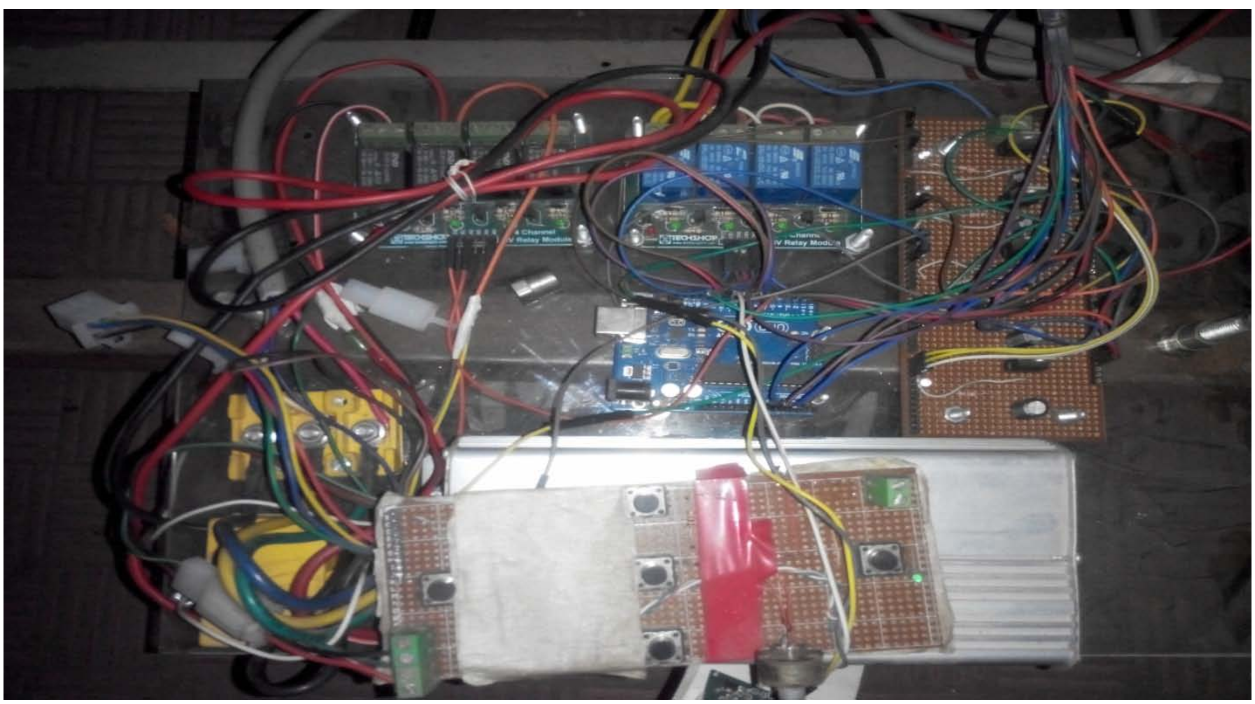
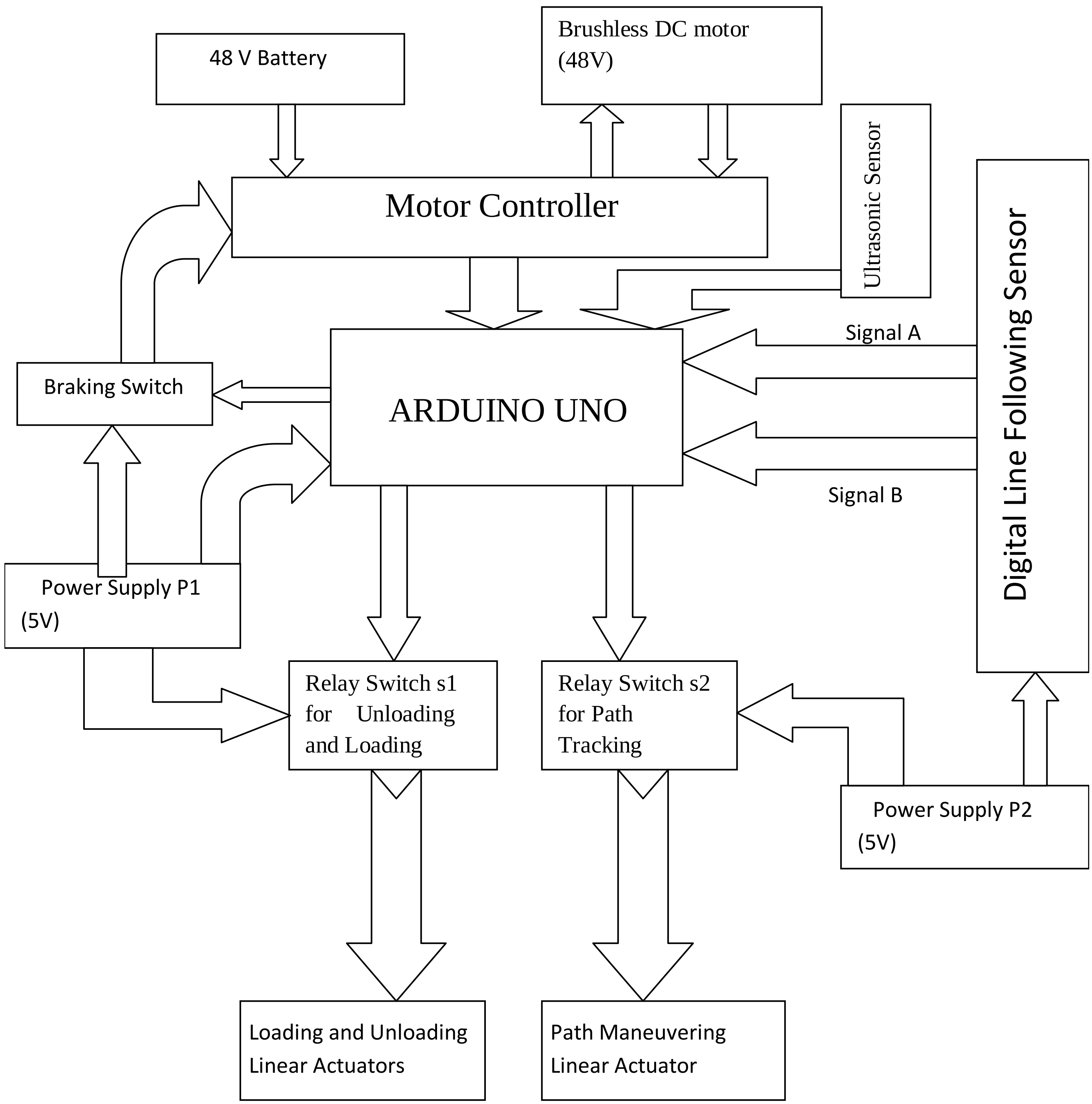


Figure 12(a): Actual Control Circuit Of System

Figure 12: Architecture/Control Circuit Block Diagram of the System

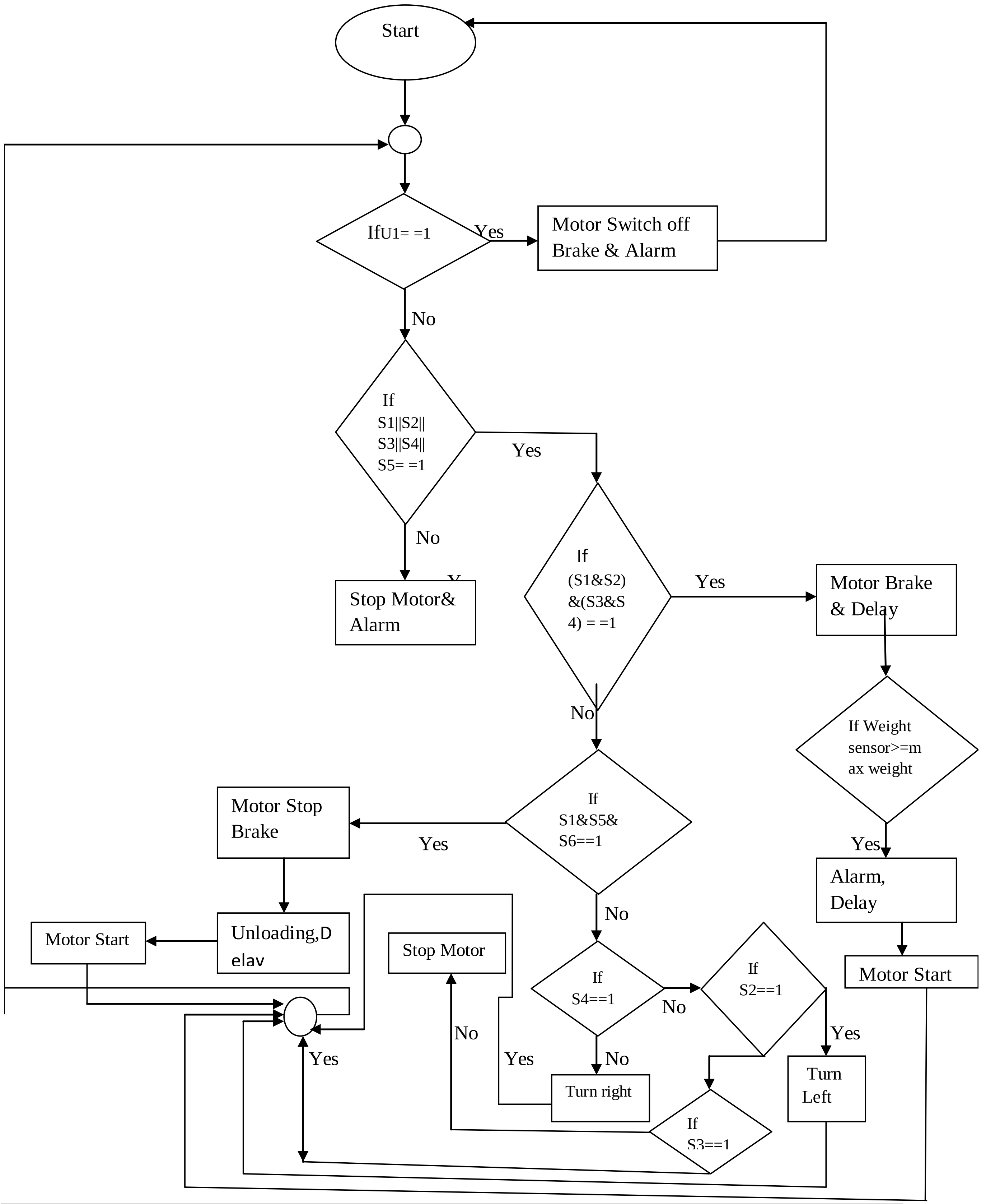


5.3Flowchart

The flowchart shows in detail how the industrial robot is programmed to maneuver in the designed track for loading goods and unloading purpose. The white line has been specified in a predefined path such that the thick white line is drawn on the black surface. An array of six digital line following sensors have been attached in front of the robot and they are assigned as sensors S1,S2,S3,S4,S5,S6. Two sensors S2 and S4 read sensory inputs and have been designated for left as well as right movement of the robot respectively. An ultrasonic sensor (represented as U1) has been used to detect presence of any obstacle in front of the robot. The flowchart depicts that if there is any obstacle detected by the ultrasonic sensor, the receiver receive the reflected signal and hence U1 is high (1), the signal is send to the motor controller and the motor is off and that is brake is activated. When no obstacle is detected, check if any one of the sensors (S1, S2, S3, S4, and S5) is above the white line then sensor value is 1 which means the robot is in the goods loading place. The motor is turned off for some time if all only sensors (S1, S2, S3&S4) are on the white line and give sensor value 1. Thus the loading procedure begins and continues until the weight measure from weight sensor doesn't exceed maximum weight. After weight is loaded on the weight carrier motor starts rotating and robot moves. While deciding whether the robot is to make either right or left turn, check if the sensor S4 placed at the right position is S4= =1, then the robot has to make right turn. On the other hand, if the condition is false, then check if the left sensor S2= =1, then the robot make turn towards left. While the middle sensor S3 is above the white line, the signal gets reflected and S3= =1for which it moves in a straight line. In order to detect if the robot has reached the goods unloading place, check sensor value of these sensors S4, S5, S6. If all of these sensors output value is high (1), brake is applied and motor stop momentarily with some delay until unloading of goods by help of actuators is completed. After completion of unloading goods, motor starts again and robot starts motion. All above procedures are repeated which has been shown by the close loop in the flowchart. The 48V 1000W brushless motor controller has significant role in the flowchart as it has been used for braking purpose when required. Moreover the motor controller has also got some essential features such as: Current limit protection, Short circuit protection & Blockage protection[c]. The figure below shows the 48V brushless motor controller that has been used to start the motor.

Figure 13(a): A 48V brushless motor controller

Figure 13: Flowchart of the Automated Industrial Robot



5.4 Arduino Code

The Arduino Uno has been programmed with the code and it has been loaded in the Arduino Uno before connecting Arduino with Relays, Digital Line Following Sensors, Motor Controller and Linear Actuators in order to serve the purpose of path following and loading as well as unloading heavy goods. The Arduino code has been given below:

```
int ch1=11;
int ch2=12;   // all output
int up1=7;
int up2=8;
int brake=6;
intbiper=15;
intobsOut=9;

intobsIn=10;
int irSensor1= 2;
int irSensor2= 3;
int irSensor3= 4; //all input
int irSensor4= 5;

void setup() {
  pinMode (ch1,OUTPUT);
  pinMode (ch2,OUTPUT);
  pinMode (up1,OUTPUT);
  pinMode (up2,OUTPUT);
  pinMode (biper,OUTPUT);
  pinMode (brake,OUTPUT);
  pinMode (obsOut,OUTPUT);


 pinMode (obsIn,INPUT);
 pinMode (irSensor1,INPUT);
 pinMode (irSensor2,INPUT);
 pinMode (irSensor3,INPUT);
 pinMode (irSensor4,INPUT);

}
```

```
void loop() {
   while(1){
    if(digitalRead(obsIn)==1){
     obstacleFront();
    }
   //  }
   else if ((digitalRead(irSensor1)==0 )||(digitalRead(irSensor4)==0)){
       if((digitalRead(irSensor1)==0)){
        //    if(digitalRead(irSensor1)==0){

         parking();
        }         //if((digitalRead(irSensor4)==0)){
        else if(digitalRead(irSensor4)==0){

        actuatorUp();
       }
   }
   else if((digitalRead(irSensor2)==0)||(digitalRead(irSensor3)==0)){
          if(digitalRead(irSensor2)==0){
            turnLeft();

           }\ //   }
          else if(digitalRead(irSensor3)==0){
           turnRight();
          //digitalWrite(obsOut,HIGH);


          }


    }



     /*   if(( digitalRead(irSensor2)==0)){

        turnLeft();
       }
       else if (digitalRead(irSensor3)==0){
```

```
            turnRight();
          }

    }

}*/


}
}

void actuatorUp(){

  digitalWrite(brake,HIGH);
  digitalWrite(up1,HIGH);
  digitalWrite(up2,LOW);
  delay(20000);
  //digitalWrite(brake,LOW);
  digitalWrite(up1,LOW);
  digitalWrite(up2,HIGH);
  digitalWrite(brake,LOW);

}

void turnLeft(){
  digitalWrite(ch1,HIGH);
  digitalWrite(ch2,LOW);
 // delay(1000);
 // digitalWrite(ch1,LOW);
 // digitalWrite(ch2,LOW);
 // delay(10);

}

void turnRight(){
  digitalWrite(ch1,LOW);
  digitalWrite(ch2,HIGH);
 // delay(1000);
 // digitalWrite(ch1, LOW);
 // digitalWrite(ch2,LOW);
 // delay(10);
```

```
}

void obstacleFront(){

   //digitalWrite(brake,HIGH);
  // digitalWrite(biper,HIGH);
   while(digitalRead(obsIn)==1){
    digitalWrite(brake,HIGH);
   digitalWrite(biper,HIGH);
   while(digitalRead(obsIn)==0){
      digitalWrite(brake,LOW);
   digitalWrite(biper,LOW);
   break;
   }

   }
 }

  void steringoff(){
    digitalWrite(ch1,LOW);
    digitalWrite(ch2,LOW);
 }

  void parking(){

    digitalWrite(brake,HIGH);
    steringoff();
    delay(30000);
    digitalWrite(brake,LOW);


 }
```

Chapter 6:Graphs & Analysis

6.1Unloading Mass versus Unloading Time

Since the amount of weight that can be loaded and unloaded successfully by the industrial robot has been one of the main challenges, several test run has been successfully carried out to find out the time it takes for the robot to completely unload goods of different weights. After loading goods of different weights on the weight-carrier of the robot, it is allowed to move in a designed path and unload goods by help of two Linear Actuators. The amount of time taken to completely unload goods of different weights is shown in the table 1.

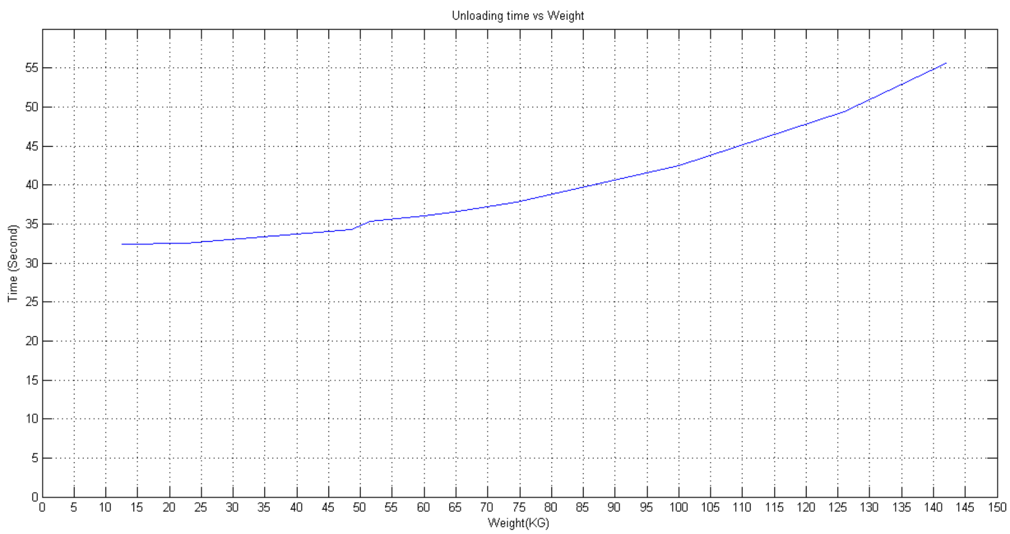
Unloading Mass(kg)—x-axis	Time Taken/(sec)—y-axis
12.5 kg	32.44 sec
22.5 kg	32.53 sec
48.5 kg	34.29 sec
51.5 kg	35.35 sec
60.0 kg	36 sec
64.5 kg	36.5 sec
74.5 kg	37.8 sec
100 kg	42.48 sec
126 kg	49.45 sec
142 kg	55.55 sec

Table1: Time taken to unload goods of different mass

The MATLAB CODE for the above data has been shown as follow.

```
x=[12.5 22.5 48.5 51.5 60 64.5 74.5 100 126 142];
 y=[32.44 32.53 34.29 35.35 36 36.5 37.8 42.48 49.45 55.55 ];
plot (x,y);xlabel (' Weight (KG)');ylabel (' Time
(Second)');Title (' Unloading time vs Weight');
grid on
```

The tabulated data is plotted in a graph by using the above MATLAB to observe the effect of increasing weight on the unloading time by the industrial robot. The above graph clearly shows that there is non-linear relationship between time taken (t) to drop the load to the ground and mass (m) of load on the robot. By increasing the weight, amount of time taken to take down the weight also increases significantly resulting the curve to rise upwards. Initially increase in time has been slow and hence the graph is flat but exceeding around 75 kg, the graph has become steeper and moves upwards as the time increases significantly. This is because increase in mass of goods results increase in downward force F=mg to act on both linear actuators. This downward force is opposite to upward force exerted by both actuators. Hence speed of linear actuators gets reduced.



Graph 1: A Graph of Unloading Mass against Time Taken

6.2 Steering Angle versus Linear Actuator Length

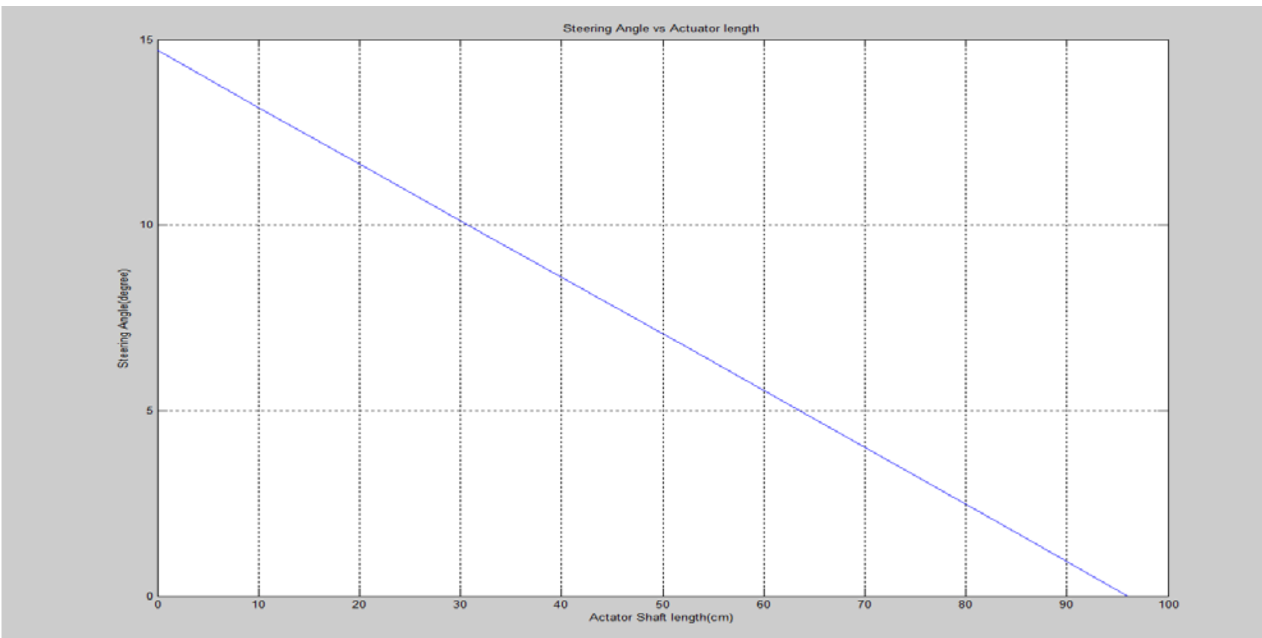
The path that has been designed for the industrial robot has got both left and right turn with radius of curvature R. While making both left and right turn, steering both front wheels has been done by the help of a single linear actuator. During the test run while moving the robot in a straight line the linear actuator shaft has been kept stationary in mid position. The shaft of the linear actuator move outward allowing the robot to turn right and the actuator shaft go inwards while the robot turns left. Experiment has been conducted allowing the robot to track the path. Consequently several data of actuator shaft length (l) and its corresponding steering angle (Θ) have been measured accurately and recorded in Table 2 as shown.

Actuator Shaft length (l)	Steering Angle (Θ)
14.70 cm	0.00°
13.07 cm	10.67°
11.44 cm	21.34°
9.81 cm	32.01°
8.18 cm	42.68°
6.55 cm	53.35°
4.92 cm	64.02°
3.29 cm	74.69°
1.66 cm	85.36°
0 cm	96.00°

Table2: Steering Angle of front wheels due to Actuator Shaft Movement

A graph of above reading is plotted in MATLAB and its code is shown as follows.

```
time=[0 1 2 3 4 5 6 7 8 9];
angle=[0 10.67 21.34 32.01 42.68 53.35 64.02 74.69 85.36 96.00];

plot (angle,length)
xlabel (' Actuator Shaft length (cm)');ylabel (' Steering Angle
(degree)');Title (' Steering Angle vs Actuator length');
grid on
```



Graph 2: Graph of Steering Angle against Actuator Shaft Length

While making both left and right turn steering angle(θ) of front wheels d epend on the length (l) of Actuator Shaft. From the table a graph of Steering Angle against Actuator Shaft length is plotted as shown in graph 2 above. The graph shows inverse relationship between the steering angle measured in degree and Actuator shaft length measured in cm. It can be analyzed that the actuator completely has come outward having at its maximum length of 14.07 cm. At this position both front wheels are at the leftmost position. From the left-most position, as both front wheels move towards right the actuator shaft length decreases due to inward horizontal movement of the shaft and corresponding steering angle increases with respect to the 0° line. The

0° line is considered as the reference line when both front wheels are at its leftmost position. Hence the steering angle has been measured with respect to this 0° line.

6.3 Steering Angle versus Time Taken

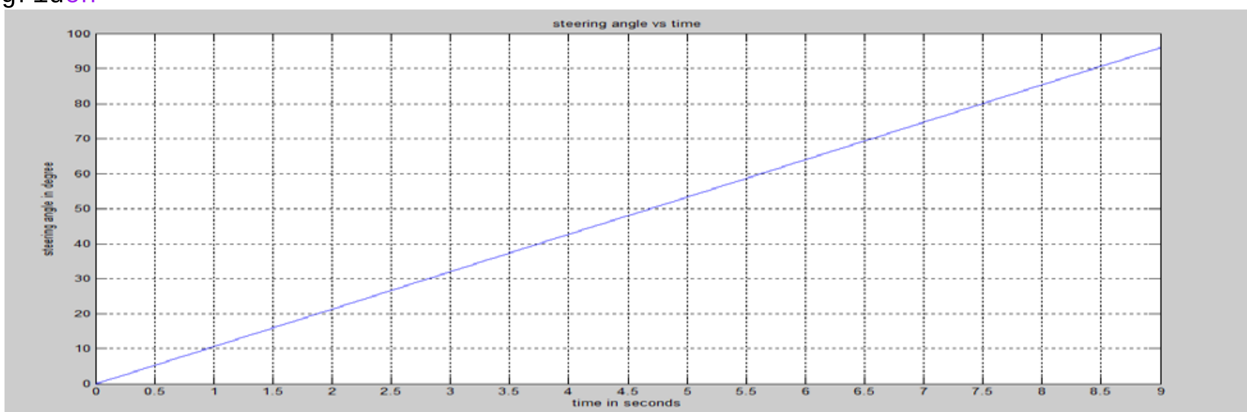
When both front wheels are at maximum leftmost position, the time t=0sec and the stopwatch is started. It has been recorded that the total time it takes for both front wheels to turn right and reach at rightmost position is t=9sec. After interval of every t=1sec, both actuator shaft length and corresponding steering angle is recorded. At t=9sec the maximum steering angle is 96°. These data have been programmed in MATLAB and graph of steering angle against time is plotted as well as graph of actuator length vs time is obtained.

Time(t)/sec—x-axis	Steering Angle(degee)—y-axis
0 s	0°
1 s	10.67°
2 s	21.34°
3 s	32.04°
4 s	42.68°
5 s	53.35°
6 s	64.02°
7 s	74.69°
8 s	85.36°
9 s	96.00°

Table 3: Tabular Data showing Time taken and Corresponding Steering Angle

The Matlab Code has been shown to develop the graph as shown below.

Code:
```
t=[0 1 2 3 4 5 6 7 8 9];
angle=[0 10.67 21.34 32.01 42.68 53.35 64.02 74.69 85.36 96.00];
length=[14.7 13.07 11.44 9.81 8.18 6.55 4.92 3.29 1.66 0];
plot(t,length);
xlabel('Time(sec)');ylabel('Actuator length (Second)');Title('Actuator length vs Time');
gridon
```



Graph 3: Steering Angle against Time Taken

This graph shows a linear relationship between steering angle and time taken.Mathematically the relationship can be expressed as: $\Theta = kt$, where k is proportionality constant which can be found from the aboveas the slope of the graph. After every 1 second interval, angle which front wheel makes has been recorded. Thus from the graph it is possible to find the corresponding angle for any arbitrary time taken measured in seconds.

6.4 Actuator Shaft Length versus Time Taken

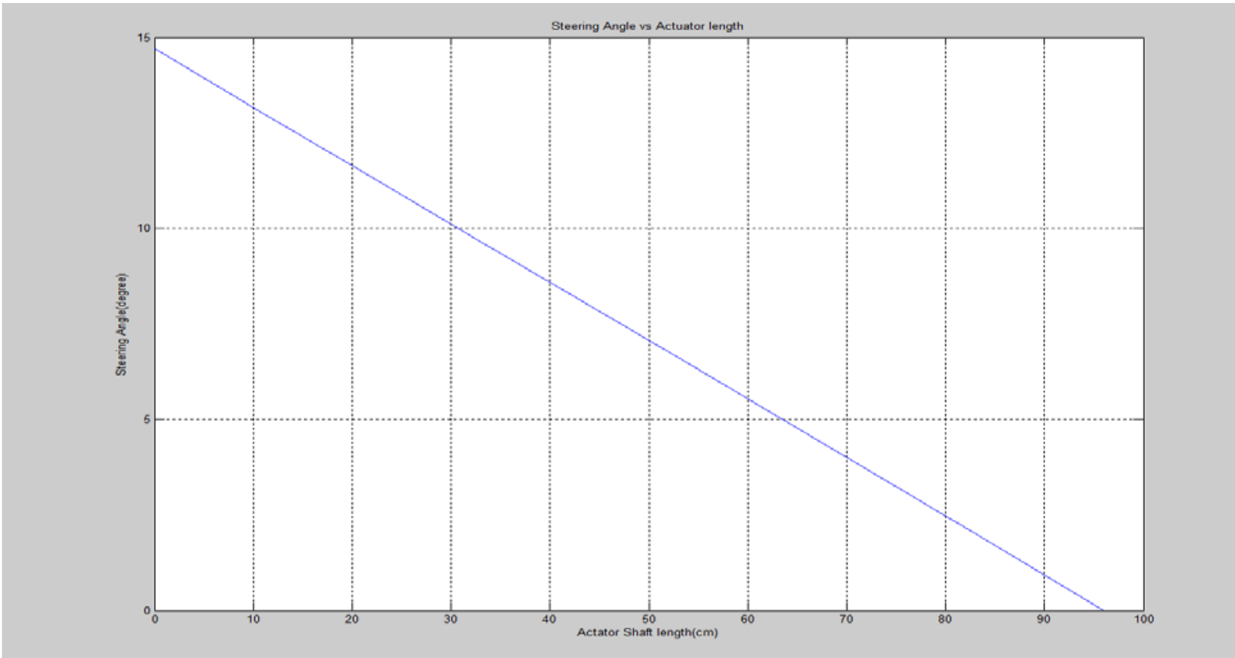
The speed of the linear actuator shaft has been remained constant. Hence the horizontal movement of the actuator shaft remains constant with respect to time. When two wheels are in straight positions, the actuator is almost in its mid position. After every 1 sec the actuator shaft length has been measured which decreases because of rightward movement of front two wheels. The opposite effect of increase in actuator length occurs as both front wheels turns leftwards. The following table shows readings of time taken & corresponding actuator shaft length.

Time Taken(t)	Actuator Shaft length (l)
0 sec	14.70 cm
1 sec	13.07 cm
2 sec	11.44 cm
3 sec	9.81 cm
4 sec	8.18 cm
5 sec	6.55 cm
6 sec	4.92 cm
7 sec	3.29 cm
8 sec	1.66 cm
9 sec	0 cm

Table 4: Tabular Data of Actuator Shaft length and Time taken

A MATLAB graph of Actuator Shaft Length versus Time Taken has been generated using MATLAB code which has been given below.

```
time=[0 1 2 3 4 5 6 7 8 9];
angle=[0 10.67 21.34 32.01 42.68 53.35 64.02 74.69 85.36 96.00];
plot (time,length)
xlabel (' Time in seconds');ylabel (' Actuator Shaft
length');Title (' Actuator Shaft length vs Time');
grid on
```



Graph 4: Actuator length against Time taken

This graph depicts an inverse relationship as with increase in time front wheels turn from leftmost position to rightmost position resulting decrease in shaft length proportionally due to constant speed of the actuator during its inward horizontal movement.

6.5Speeds versus Angle for different Radius of Path of Curvature

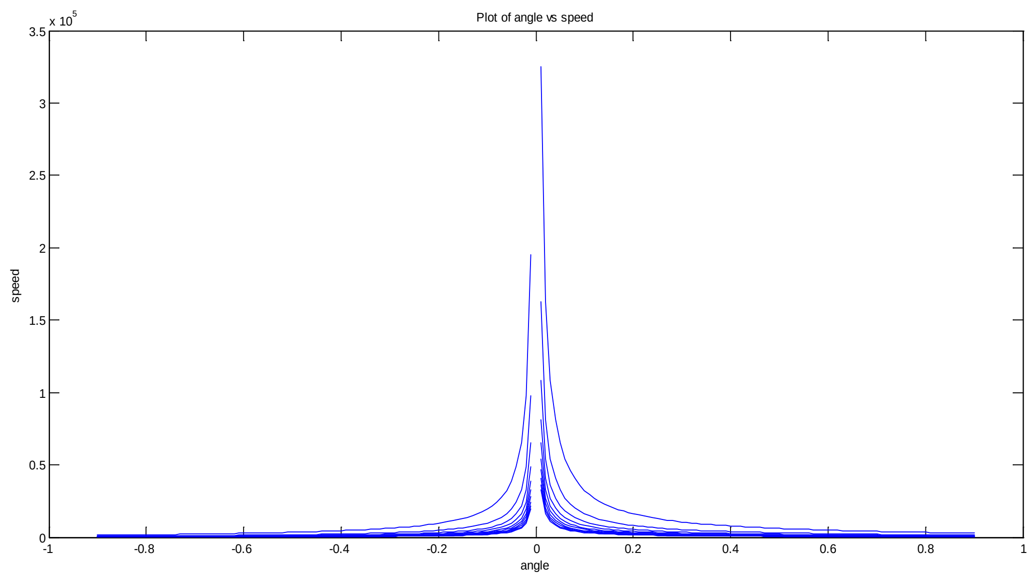
Speed at which the Industrial Robot should be driven to ensure proper turning depends on the radius of the path of the curvature. Speed control has been one of the main challenges that have been required to take into consideration while maneuvering in the designed path. Each path has a specific radius and depending on the radius the steering angle is determined. Based on Ackerman Steering mechanism the radius of the path has been mathematically expressed as: $R^2 = a^2 + lcot^2\delta$----(1)& for angular speed we can express it as w=Θt ---(2). From the equations of radius of curvature, the expression for speeds(Vs) for different steering angle at different path of radius of curvature has been obtained as:

Vs=$(1)/((lr) \div \sqrt{a^2 + l^2 \times cot^2\delta}$)---------(3)

The following MATLAB code has been completed to obtain a number of graphs speeds versus steering angle for different path of radius of curvature.The code and the graph has been given as follows.

```
clc
```

```
clearall
d=-0.9:.01:0.9;
R=1:1:10;
l=51;
a=(l/2)^2;
s=zeros(length(R),length(d));
lr=0;
for j=1:length(R)

for i=1:length(d)
s(j,i)= 1/((d(i)*R(j))/((a+((l)^2)*(((cot(d(i)))^2)^(.5))*d(i))));
end
end
for k=1:1:10

plot(d,s(k,:))

holdon

end

xlabel('angle')
ylabel('speed')
title('Plot of angle vs speed')
```



Graph 5: Speed against Angle for different path of radius

The above graph depicts for a particular radius of curvature of the path with increase in angle the speed increases non-linearly up to a maximum level. The maximum speed is at angle $\delta = 0°$ which represents the industrial robot is moving in straight line. Further increase in angle, the speed falls as the four-wheeler industrial robot is turning. For a new similar path having an increased radius of curvature, speed is greater while turning as well as moving in straight line.

Chapter 7: Conclusion and Future Plan

The advancement of technology in the field of robotics has been quite remarkable in recent years. In this modern era robots are being developed for various purposes to accomlish many tasks which seem to be too complex for humans. This paper describes all steps and procedures that has been followed to built up a line follower robot for the puprose of loading heavy loads from a fixed place, then carrying goods to the destination where these goods to be unloaded by the robot itself. While carrying loads, the robot has been designed and programmed to follow a pre-defined path on the floor from source to destination.Besides, the robot has been built up having the ability to avoid collision with any obstacles that come in its way. Experimental results which have been obtained shows efficient performance of the industrial robot in terms of the capability of the robot to unload heavy loads in a short time. This industrial robot promises to be benefitial to industries where the importance of such type of robot as explained in this paper is immense. This robot that is used as a trolley to carry heavy loads from one place to another is very helpful to the society in terms of reducing risk of accidents that usually happen to labors while working in industries and carrying heavy goods on foot. In this paper the mechanical design is explained for the industrial robot which has proved to be feasible based on the movement on the desired track. Differential and a single Brushless DC motor usage has been the best choice instead of using two DC motors connected with two rear wheels because this robot has been able to make both right and left turn smoothly while carrying heavy loads.

Further advancement of technology can be performed by those who plan to elaborate this project in future to improve efficiency and effectiveness about the performance of the industrial robot. Instead of drawing path, metal line such as: Aluminium can be used to design the path for industrial purpose for maneuvering the robot. This path will remain fixed and won't disappear unlike the white path on black surface. Inductive Sensors can be used to detect this metal line which works better comparatively than Infra-Red sensors.

Furthermore, Path Tracking needs to be more smooth movement we hope to use **Image Processing.** The curved track the robot going to follow is programmed such that the robot going to follow it by processing the track as an image which is understandable for the robot. This process is comparatively much better than the traditional way of path following using IR sensor. Traditional method by the use of IR sensors need a lot of sensors to be used yet the chances and risks that the robot might get out of track is quite high compare to use of "Image Processing" method.

Besides, voice communication and alarm system can be installed to prevent collision. Further enhancement of technology can be accomplished by setting up voice recognition system allowing the robot to communicate and command "Please move from the path". An alarm system is also designed such that after a desired time if the obstacle doesn’t move away from its path then the alarm will be activated so that the surroundings get notified for the emergency situation that needs to be handled immediately. Another future improvement that can be done is the installation of an robotic arm in front of its front wheels. The purpose of this arm is to pick up any static objects lying in front of the path of the robot for longer time than expected. Since, the robot has been designed to avoid collision with any obstacle, if it senses any object acting as an obstacle the robot is going to stop momentarily and wait for a desired period of time, however if any static object still remain unmoved then the robotic arm will be going to swipe it sideways to clear the obstacle from its path. Hence, the need of any person to remove such static object isn’t required. The robot itself will take care that the path remains clear.

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