An Autonomous Industrial Robot for Loading and Unloading Goods

Article · March 2023

DOI: 10.1109/ICIEV.2015.7333984.

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An Autonomous Industrial Robot for Loading and Unloading Goods

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Abstract— **In industries loading and unloading of heavy loads manually is one of the most important task which turns out to be quite difficult, time-consuming and risky for humans. This 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. 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 in front of the robot so that the sensor can detect path by emitting and receiving signals allowing it to move in the pre-defined track having left and right turns while carrying goods from starting position to the destination. The main objective 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 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. 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.**

Keywords— industrial robot; loadding; unloadiing; differential mechanism

I. INTRODUCTION

For over many years, around the world labors working in manufacturing industries have been losing their lives doing dangerous and risky jobs. Frequent injuries while doing repetitive works using big machines have been common especially in the developing countries. While analyzing 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 labors, lack of proper safety precautions taken by owners of industries, lack of proper training to workers to operate machines and insufficient number of well-educated and skillful workers. Thus the present situation 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 develop and build up a robot that can imitate 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].

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 task can be increased, and risking human lives can be reduced. These unpleasant boredom and tiring jobs can be easily performed by this proposed 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 labors.

Industrial automation presents today's manufacturers with a host of unbeatable benefits. The entire purpose behind industrial automation is to increase the productivity and the 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 [4-6].

II. DIFFERENTIAL MECHANISM

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.

It consists of planet pinion, crown wheel, and gear such as sun gear. 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. Differential 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. We have mounted a 48V brushless DC motor with the differential by welding as shown in Fig. 1. 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 (P_{in}) gets transmitted to the differential which in turn delivers the power as P_{out} (output power) to both left and right rear wheels according to the 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

Fig. 1 Actual diagram of Differential mounted with 48V Brushless DC motor

"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 (P_{in}) and output power (P_{out}) 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.

III. ACKERMAN STEERING MECHANISM

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

$$\cot\delta_0 - \cot\delta_i = w/L \quad (1)$$

Where, δ_i= steer angle of inner wheel, δ_0= the steer angle of outer wheel, L= distance between center of rear wheels and front wheels, w= distance between two front steerable wheels. 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 the advantages of low 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 δ_0= 25.3 degree, its corresponding δ_i= 35 degree that has been found from the characteristic graph of δ_0 vs δ_i based on Ackerman condition. The graph of δ_0 vs δ_i has been shown in Fig. 2.

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

$$\cot\delta_0 - \cot\delta_i = w/L$$

$$\Rightarrow \cot 25.3^0 - \cot 35^0 = 35.7/L$$

$$\Rightarrow L = 35.7/\ (\cot 25.3^0 - \cot 35^0)$$

$$\Rightarrow L = 52\ inch$$

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 Fig. 3(a). 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 Fig. 3(b). 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.

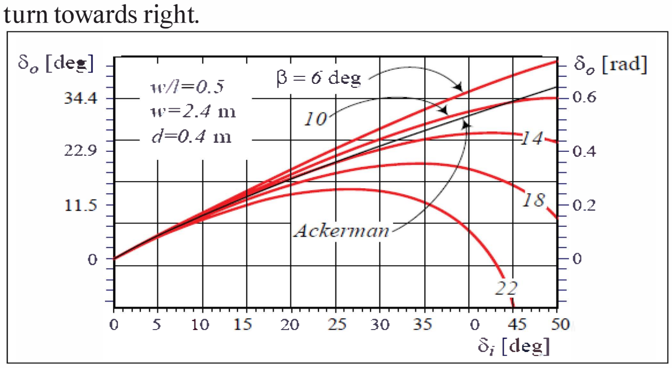


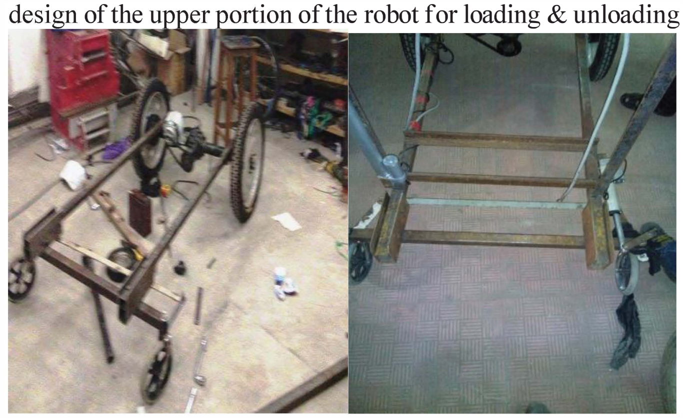
Fig 2. Characteristic curve of δ_o vs δ_i of Ackerman Steering

On the other hand, reversing the connection results both front wheels to turn left as extended actuator moves inwards.

IV. LOADING & UNLOADING MECHANISM

Since the objective 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 4 feet 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 manoeuvre 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. Fig. 4(a) & Fig. 4(b) show the design of the upper portion of the robot for loading & unloading



(a) (b)

Fig 3. (a) Actual Design of Ackerman Steering of Industrial Robot (b) Ackerman Steering Wheels with Linear Actuator attached sideways

Table 1 : Measurements of the size of the Industrial Robot

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

goods respectively as well as the whole design of the robot. Table.1 shows measurements of the designed rectangular frame and the chassis of the industrial robot.

V. AUTONOMOUS PATH FOLLOWING

Digital line following sensors have been used to allow the industrial Robot to follow the path and manoeuvre 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. 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. The purpose of these POTS is to calibrate sensors by tuning POTS after connection Vcc and GND to power supply. We have used an array of six digital line following sensors for path-manoeuvring. 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 manoeuvre 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 Arduino Uno. Besides, Fig. 5 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 manoeuvre 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 [7-9]. The path has got starting position which is known as "Goods Loading Place" as indicated in Fig. 5 as completely drawn white line. When the robot is at this starting position,

(a) (b)

Fig. 4(a) Whole design of the Industrial Robot during loading goods (b) unloading goods

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 manoeuvring this robot for loading and unloading purpose.

The Block Diagram/ Architecture (Fig. 6) show how the control circuit has been implemented to allow the industrial robot to serve its purposes which are: a) path tracking and manoeuvring, b) loading and unloading of heavy goods and 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)

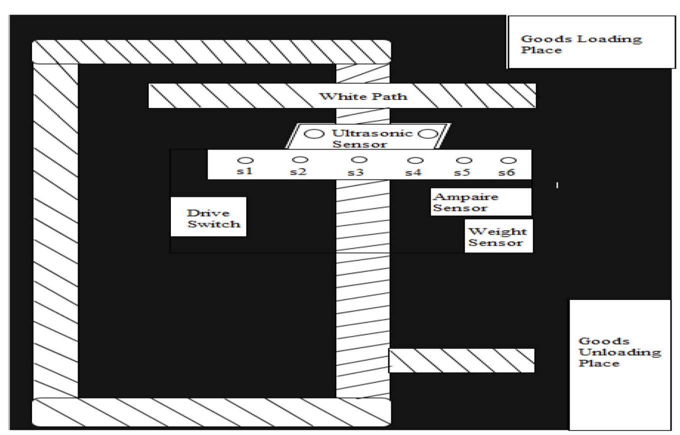


Fig. 5 Design of the path for path manoeuvring

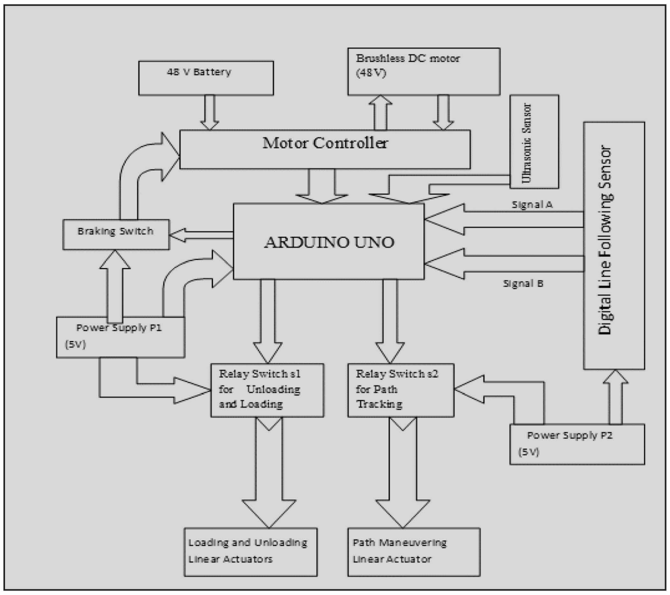


Fig. 6 Architecture/ Control Circuit Block Diagram of the System

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 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. 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. The 48V 1000W brushless motor controller has significant role in this mechanism 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.

VI. Result Analysis

i. Unloading 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 Fig. 7.

The tabulated data is plotted in a graph by using MATLAB to observe the effect of increasing weight on the unloading time by the industrial robot. Fig. 7 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.

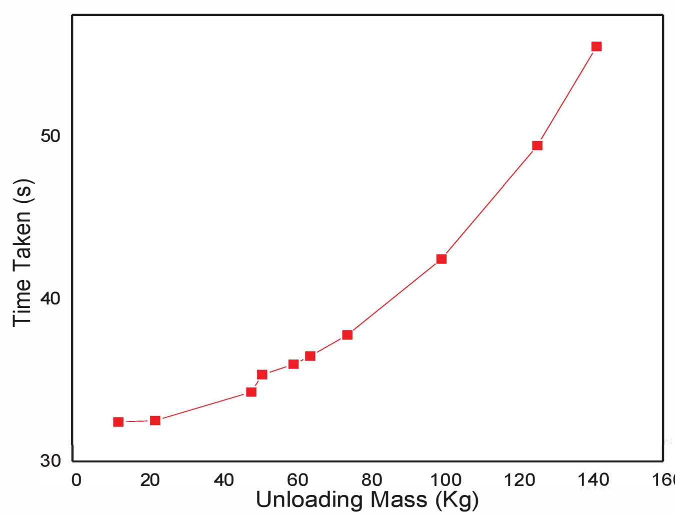


Fig. 7 Graph of unloading Mass against Time

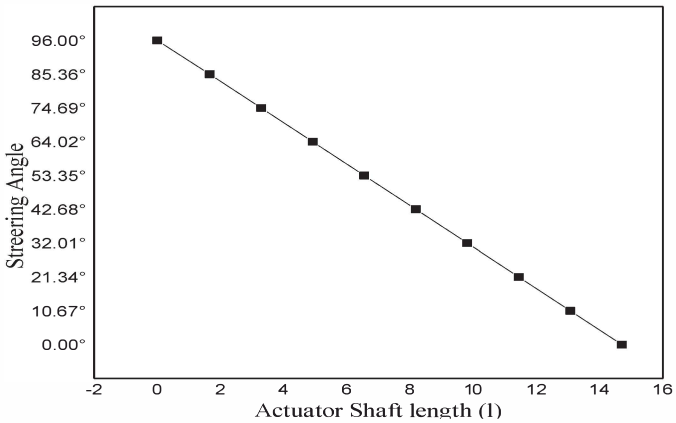


Fig. 8 Graph of Steering Angle against Actuator Shaft Length

ii.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.

While making both left and right turn steering angle (ϴ) of front wheels depend on the length (l) of Actuator Shaft. From the table a graph of Steering Angle against Actuator Shaft length is plotted as shown in Fig. 8. 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.

VII. Discussion

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 accomplish many tasks which seem to be too complex for humans. This paper describes all steps and procedures that has been followed to build up a line follower robot for the purpose 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 beneficial 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 [10].

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