Autonomous Mobile Robot with Chain-Driven Live Roller Top Module

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ABSTRACT

Robots that can navigate through their environment are termed mobile robots. Mobile robots are being utilized in various fields, such as agriculture, transport, package delivery, disaster recovery, military, surveillance, and warehouse management. In warehouses, the usage of Autonomous Mobile Robots (AMR) for intralogistics is becoming increasingly common. AMRs for intralogistics allow a safer work environment, less need for manual labor, and minimal downtime which translates to optimized productivity. Presently, warehouses in Pakistan do not use AMRs for intralogistics. One reason is that locally manufactured AMRs are not available. The only option is to import AMR which is very costly due to import duties. Aided by the availability of cheap manual labor, using imported AMRs is not economically justified. In this project, an AMR is proposed for use in warehouses in Pakistan. The AMR is made using locally available parts while keeping costs to a minimum. It is capable of driving autonomously through its environment while carrying the load. Another objective of this project is to solve mobile robots' loading/unloading issues in warehouses. Presently, AMRs in warehouses require assistance while loading and unloading packages in their storage compartments. A chain-driven live roller (CDLR) system is presented which is installed on top of the AMR. In addition to simplifying the loading and unloading process, the proposed mechanism optimizes the overall process as it can transport heavy loads without any torque reduction. The proposed system needs minimal human assistance and is more reliable and time-efficient as compared to existing systems.

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<u>ORIGINALITY REPORT</u>

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ABBREVIATIONS

AMR	Autonomous Mobile Robot
ROS	Robot Operating System
AGV	Autonomous Guided Vehicle
RPi	Raspberry Pi
FOS	Factor of Safety
CDLR	Chain-Driven Live Rollers

CHAPTER 1: INTRODUCTION

1.1 Background

Warehouses used to require manual handling of warehouse loads. In the modern context, transportation and handling of warehouse loads is a type of manual job that does not require any creative input. Automation in the current era targets such industrial areas that do not require human creativity because they can be automated using smart and intelligent solutions.

In the first attempt, line-following robots termed automated guided vehicles were developed for the transportation of warehouse loads. These robots required pre-defined paths physically laid out on the warehouse floor. This advancement significantly improved safety and accuracy because of the removal of the human factor and reduced the chances of error in the handling of warehouse items. Furthermore, they can work 24/7 with charging times in between. But the downside is that these vehicles offer less flexibility in the case when they encounter an obstruction in their way. They will stop and wait for their path to be cleared will ultimately require human intervention. They are also unable to keep up with industries that require regular changes in the routes and tasks to be performed because they are limited to be operated on fixed routes with set tasks.

These problems were addressed using the development of an autonomous mobile robot (AMR). AMRs are not limited to being operated on a fixed path. They are mobile and intelligent in terms of path planning. Using data from various sensors, they can sense and understand their environment, making navigation plans accordingly. They can reroute and reconfigure their paths when they encounter an object using obstacle avoidance techniques, therefore, offering increased efficiency in terms of transportation times and saving labor costs.

Despite much advancement in industrial automation, local industries in Pakistan have not quite kept up with the pace. Warehouse management is still largely dependent on human labor and the country hasn't seen the incorporation or development of local automation solutions. The import of such solutions offers a disadvantageous cost-benefit analysis. Therefore, this project aims at developing a locally manufactured Autonomous mobile robot thus enabling the local industry by providing a significantly cheaper automation solution.

1.2 Problem Statement

Keeping in view the context in which this solution will be developed, the following problem statement concisely describes the problem to be solved regarding this project:

"Design, fabrication, and programming of cost-effective AMR with CDLR top module for automating loading/unloading of packages in warehouses."

1.3 Objectives

This locally manufactured autonomous mobile robot aims at achieving the following objectives for its successful incorporation into the local industry:

1. The AMR can plan its path provided a destination and can react dynamically to changes in the environment.
2. The design is rigid enough in terms of mechanical strength to support and carry the load of the components, and modules attached to it while being able to carry a package with a FOS of at least 5.
3. The AMR has an automated CDLR top module attached to it for the loading/unloading of packages.

1.4 Summary of Work

Having the objectives clearly in place provides the processes that need to be undertaken to achieve the final product. The project begins with a selection of the components that will be used that includes both processing systems and other electrical and mechanical components. This is followed by the modeling of an appropriate design meeting the size and space requirements for all the components to fit appropriately while being capable of supporting the intended load and offering the required maneuverability and vehicle kinematics to best fit the intended application. The design is then analyzed for the requisite loads and necessary modifications are made. Alongside design and analysis, programming in Arduino is done in the C++ language. The algorithm plans the path required for the robot to navigate from point A to B. The path is updated in real time in case of obstacles along the planned route. When an object comes in significant proximity to the robot, the algorithm executes a code to go around the obstacle. This algorithm of motion towards the destination, and obstacle avoidance are uploaded to the Arduino, and assembly of the whole design physical resulted in the final requisite product.

After the AMR is finalized, the attachable CDLR module is designed. This module is installed on top of the AMR. The rollers are driven by a chain that is connected to the rollers via sprockets. The chain is driven by a motor that is powered by the battery of the robot, so no external power source is needed. The loading can be done by a conveyor belt dropping package to be transported on top of the robot. The robot prevents slippage of the package during transportation by using actuated braces that pop up as soon as the package starts moving over the live rollers. At the drop-off location, the braces drop down and the CDLR is driven automatically by the robot for the drop-off of the package. Chutes or containers can be used as the drop-off location.

1.5 Scope

This project addresses the local warehouses in automating the tasks of transportation and handling of loads between two points. It also tackles the issue associated with loading/unloading packages on top of the AMR. Thus, it aims at achieving a solution meeting the objectives mentioned above to consequently be incorporated into the warehouses resulting in automation, cutting labor costs, increased efficiency, and accuracy, while saving time during operation. A complete warehouse solution would require related technologies including charging stations and appropriately designed pick and drop stations from where to receive and drop the loads. However, this project concerns itself only with the movement of the warehouse loads and their loading/unloading with the help of the AMR and CDLR top module built using local resources to keep development costs to the minimum. For the prototype, this project also assumes that the robot is operating in an open space. Open space refers to an area with no surrounding walls.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Robots are evolving the production industry at an ever-rapid pace. They allow us to achieve great success in the industrial sector. One field that is being developed using robot is the use of autonomous robots. Autonomous robots continuously interact with their environment and make decisions based on the changes that are happening in it. This development allows for a system that can operate on its own with minimum manual intervention needed. This reduces the need for manpower and in turn reduces operational costs involved with the operation.

Mobile Robots are an important development in this regard. They can transport packages while reacting dynamically to changes in the environment. This provides a very efficient system with lower human supervision. This is especially a topic of interest in warehouse industry, where new system is being continually developed for more efficient transportation of packages. However, warehouse systems face another problem of placing the packages on the mobile robot from the initial position and taking them off at the final destination.

The following section discusses works that have been done with regards to automation of mobile robots, and the automation of loading/unloading process in mobile robots.

2.2 Related works

2.2.1 Automation of Mobile Robots

Mobile Robots are a topic that has been in development for over 40 years. The application of mobile robots spans multiple industries, and it is a topic that is being continually developed for application in various fields. Some of the applications of mobile robots are mentioned below:

2.2.1.1 Nursing Robot

Borenstein, J. and Koren, Y. [1] – developed a Nursing Robot, designed to perform nursing duties for bedridden patients. This robot is designed for use in a confined room. It performs simple tasks such as operating electrical appliances or bringing objects to the patient. However, since the robot cannot perform any medical tasks, a supervisor for the patient is still needed. The robot does make the life of the supervisor easier though, by carrying out simple tasks.

Since the environment is not necessarily a fixed one, the robot needs to be able to navigate through the environment while making sense of the surroundings through its sensors.

The platform they developed can be used for making robots for usage in warehouses too, but the problem with the said design is that it uses only odometry for localization which is inconsistent. Further development of this design is therefore needed to make it reliable for usage for intralogistics.

2.2.1.2 Autonomous Guided Vehicles

Autonomous Guided Vehicles (AGV) are robots that follow a predefined path. AGVs are commonly used in warehouses for intralogistics. Multiple robots are operated by a central processing unit that works in tandem with other robots. The central processing unit controls the robots such that they do not bump into each other.

Generally, AGVs travel along their predefined path and in case there is an obstacle in their path, they stop instead of going around it. The obstacle needs to be removed manually before the operation can be continued. To solve this problem, Fazlollahtabar, H. and Saidi-Mehrabad, M. [2] – developed a type of AGV that has additional functions such as following the motion of people. It can also avoid obstacles on the path and navigate back to the pre-described path after avoiding obstacles.

However, for AGVs, additional infrastructure needs to be installed in the warehouses for guiding the vehicle. This incurs additional costs for the layout. Therefore, AMRs are a better option for warehouses intralogistics. Despite being more technologically advanced, AMRs are a less-expensive solution than AGVs [3].

2.2.2 Automation of Loading/Unloading Process

2.2.2.1 Robotics Manipulators

Robotic Manipulators are commonly used for loading and unloading the package from the mobile robot. This can be done by using a manipulator that is attached to the top of the robot. The manipulator is equipped with sensors that detect and carry the object to be delivered. The manipulator drops the object at a specified spot when it reaches its destination. These models are useful for the transportation of small objects [3]. However, some models are being developed that can lift very heavy loads [4]. These models are flexible, in that they can pick objects from any location and specific pickup spots are not needed. However, the models are expensive and therefore are not suitable for small to mid-level warehouses.

Another way robotic manipulators are used for loading and unloading purposes is that they are installed at the location where the AMR package is placed on top of the AMR. A manipulator is also present at the drop-off location, which unloads the package from atop the AMR.

2.2.2.2 Autonomous Forklift

Autonomous forklifts are being developed that can autonomously lift the package to be delivered and drop it off at the desired destination. The forklift uses a combination of sensors to make sense of its surroundings [5] and uses the data gathered by its sensors to help pick up and drop off the package from its initial position to its destination. Autonomous forklifts are only suitable for the transportation of heavy loads and have a very high initial cost.

Considering the work done on this field, this project serves two purposes.

1. Manufacturing AMR using locally available components so that its use can be justified in warehouses in Pakistan.
2. Introducing a CDLR module that effectively automates the loading/unloading of packages on top of the AMR in warehouses.

There are several options that are to be considered before any work is done on the project. Certain processes and algorithms have been developed for AMRs using different sensors. The text below discusses the options that were studied before deciding on what methodology was to be used for the project.

2.3 Requisite Processes and Component Requirements

The development of autonomous mobile robots requires research in many areas of knowledge. The primary goal of an autonomous mobile robot is navigation through its environment. Path planning, localization, obstacle avoidance, map building, etc. are some of the areas which need to be studied to understand how an autonomous mobile robot operates [4]. Along with this, the sensors and processing units that are to be used also need to be studied in order to understand how AMR works.

2.3.1 Path Planning

Path Planning is a very important task for AMRs. The objective is to find a collision-free path from the initial position to the final position. Usually, various paths are used so that the robot can reach its destination. The most feasible path is selected concerning some defined guidelines. These guidelines include the shortest distance, smoothness of motion along the path, minimum time taken, etc. [5].

Path Planning is categorized into two parts:

2.3.1.1 Global Path Planning

In global path planning, the robot's location and the destination are known within a constructed map. This information is used to calculate an initial path for navigation [6].

This approach is expensive in implementation [7] as the techniques used for map building make use of expensive sensors.

2.3.1.2 Local Path Planning

In areas where dynamic changes in the environment are involved, local path planning is used. Local path planning is based on the robot's state estimation, and dynamically creates a local path towards the destination without collisions. As this method needs to be adaptive to changes in the environment, it uses a variety of sensors to obtain information about the environment.

2.3.2 Localization

For efficient navigation, the robot must have an accurate way of where it is located in the environment. The process to determine the current location of the robot is called Localization.

Localization is categorized into two parts:

2.3.2.1 Absolute localization

In absolute localization, we obtain the absolute location of the robot in the defined environment using beacons, landmarks, or satellite-based signals [8]. For indoor mobile robots, satellite-based signals cannot be used. Using landmarks can be time-consuming due to image processing computations. These techniques are also sensitive to dynamic changes in the environment [9].

2.3.2.1.1 Vision-Based localization

Vision-Based localization uses image processing and computer vision. This method recognizes features from certain objects in the environment. When those features are visible to the optical sensor, the robot recognizes the object and uses its location to calculate its localization. When this is done using landmarks/objects already present in the environment, it is called natural landmark-based localization. The process is time-consuming due to being computationally taxing. Instead, we can use artificially installed landmarks for this purpose that are easier to recognize. This method is termed artificial landmark-based localization [9].

2.3.2.2 Relative localization

In relative localization, the location of the robot is estimated using onboard sensors such as encoders, gyroscopes, accelerometers, etc. [8]. Relative localization can be performed using a process called Dead Reckoning.

2.3.2.2.1 Dead Reckoning

Dead Reckoning is the process of calculating the robot's position by estimating the distance traveled by it and the direction taken. For AMR, this can be done using wheel encoders, and is termed as odometry. Dead reckoning calculations are susceptible to error caused by wheel slippage, wheel skid while turning, and kinematic imperfections of the mobile robot [10]. The errors caused by kinematic imperfections can be considered in calculations. However, errors caused by wheel slippage accumulate over time.

Mobile Robots usually use a combination of relative and absolute localization techniques to accurately determine the location of the robot in the environment. Relative localization is the primary means and absolute localization assists it by resetting the errors accumulated by it. This is known as combined localization [11].

2.3.3 Components

Since one of the main goals of this project is for its cost to be justifiable in the Pakistani warehouse industry, some compromises must be made in quality to reduce the price of the AMR. Keeping in consideration their costs, the following components are used in the AMR.

Arduino UNO

Arduinos are microcontrollers-based devices that can be used to build digital systems. Arduino UNO is a version of these devices which uses ATmega328 8-bit Microcontroller [12] features 14 digital input/output pins. Out of these 14 pins, 6 can be used as PWM pins. Since each motor uses 2 PWM pins, 3 motors can be controlled by Arduino UNO simultaneously. Since the planned project uses 3 motors, Arduino UNO is suitable for use. The schematic diagram of Arduino UNO is shown below

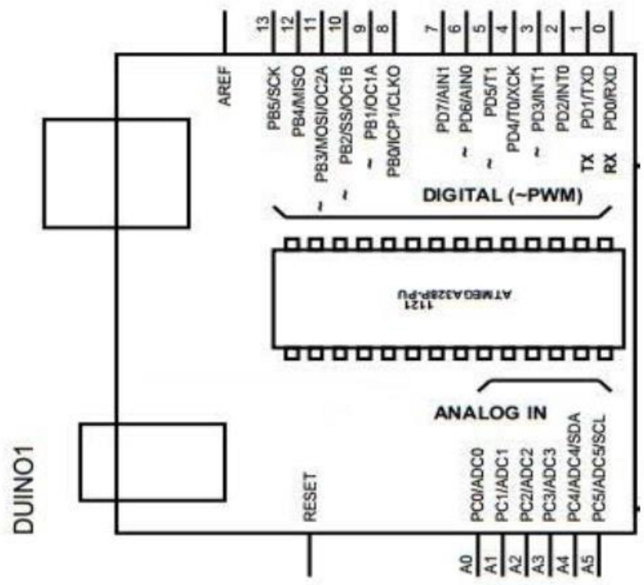

Figure 1 Arduino UNO Schematic Diagram

H-Bridge – BTS 7960

The H-Bridge is a microcontroller for the motors. H-Bridge allows us to control the supplied voltage to each motor, and to change the polarity of the supplied voltage. This controls the speed and direction of the wheels. It is also used to control the speed of the CDLR during loading and unloading. The H-Bridge used in this AMR is IBT2 BTS7960. Some key parameters of the H-Bridge are as follows:

- Input voltage: 6V-27V
- Maximum Current: 43A
- Input level: 3.3V-5V

Labelled diagram of BTS 7960 is shown below [13]:

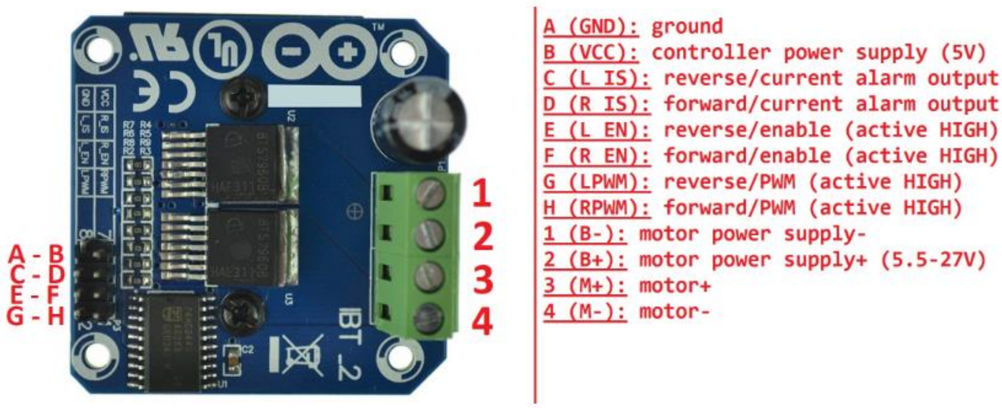

Figure 2 Labelled diagram - BTS 7960

BTS 7960 has a wide range of voltage that can be controlled using the Arduino. It uses PWM signals to control the motor speed. Even though it has 8 pins (A-H), which would cause a problem since the number of pins on Arduino is limited, we only need to connect the 2 PWM pins from BTS 7960 to the Arduino for motor control. Therefore, BTS 7960 is suitable for usage in this project.

2.4 Conclusion

The preexisting work regarding the AMR proves quite useful. It gives insight into what methodology is used to build AMRs and how to develop them. It provides valuable information about what processes can be used and the advantages and flaws of each of them.

The literature regarding the loading/unloading processes in warehouses shows that no effective method is available for automation of loading/unloading process and the available solutions are either very expensive, or unreliable. Thus, there is a gap in the intralogistics development of the warehouses that needs to be fulfilled. This project aims to deliver that by introducing CDLR top module for automation of the loading/unloading process.

The study into the processes for development of AMRs, and the study into the control components helps us identify the components to be used in the project.

CHAPTER 3: A) METHODOLOGY (AMR)

3.1 Project Overview

The general outline of how the components in the system interact with each other is shown via the diagram below:

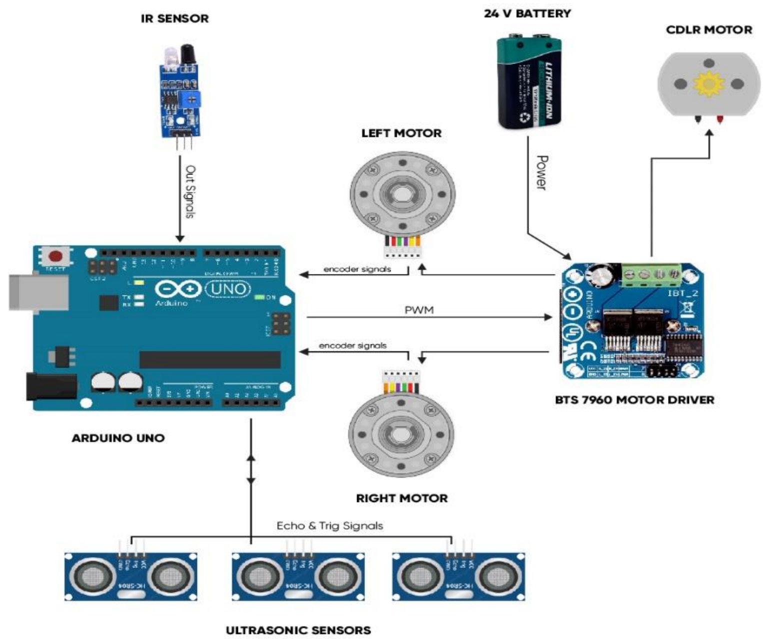

Figure 3 Circuit Connection Diagram

Figure 3 represents a simplified circuit diagram of the whole robot. Arduino UNO is used as the only processor for the robot for the overall programming of all the components. 2 DC motors with encoders, one for each respective wheel on opposite sides of the robot is represented alongside the Arduino. The motors receive power through the Motor drivers. 3 BTS 7960 Motor drivers were used. For simplicity, only one is shown here in the image. These motor drivers make the motors rotate at a certain speed in clockwise or counterclockwise direction. The 3rd DC motor represents the motor being used for powering the CDLR. All three motors are driven by the BTS 7960 Motor drivers. For making the connections, the power cables of the motor were connected to the power pins of the Motor driver. The power pins of the encoder were connected to the Gnd and 5 V pins of the Arduino. Lastly, for reading the encoder signals, one of the encoder pins were connected to the interrupt pin of the Arduino. Since there are two motors, therefore, Arduino digital pins 2 and 3 were used to read the encoder signals. Only these 2 pins are available to serve as the interrupt pins on the Arduino UNO. Signals from the other encoder pin determine the direction in which the motor is rotating but through PWM signals of the motor driver, the code controls the direction of the motor. Therefore, it already knows the direction in which the motor shaft is rotating. Hence, these pins were left as is. The first encoder pin gives approx. 200 signals per revolution of the motor shaft.

24 V battery powers all three motor drivers. Two 24 V, 1800 mAh batteries were connected in parallel to form a single 24 V 3600 mAh battery. Using wire splitters, various connections were taken out of this combined battery to power all the motor drivers.

The Drivers receive PWM signals through the Arduino to their respective LPWM and RPWM pins. These connections are made to the PWM pins on the Arduino as other pins don't support giving out PWM signals. These PWM signals control the speed and direction of rotation of the motor. Remaining six pins of the BTS 7960 Motor drivers including Gnd, Vcc, R_IS, L_IS, R_EN, L_EN are respectively connected to Gnd and 5 V terminals of the Arduino.

There were a lot of power connections to be made. For this purpose, two lines of a PCB board were connected to Gnd and 5 V pins of the Arduino turning the PCB into a power board. This power board was used to make all Gnd and 5 V connections of the robot.

The CDLR motor runs at 12 V. This motor is also connected to a BTS 7960 motor driver being powered by a 24 V battery. The voltage was stepped down using a lower frequency PWM signal to run this motor at its rated voltage.

Next, the IR sensors were powered using the power board and its output pins were connected to one of the digital pins on the Arduino board.

Finally, there are 3 ultrasonic sensors which were powered using the power board. Their trig pins were connected to 3 digital pins on the Arduino. Since the frequency of releasing echo signals is the same for all three sensors. Another line on the PCB board was used to common out all the echo pins. This way, only one Arduino digital pin was used to give out echo signals at the PCB line and 3 sensors were made to work conveniently in sync.

3.2 System Structure

The project specifications for the proposed AMR are discussed below

3.2.1 Components

3.2.1.1 Motor

DC geared motors are used to drive the AMR wheels and the CDLRs. The motor used to drive the wheels offers a maximum of 2Nm torque and 100 rpm. It has an inbuilt hall encoder which will be used for odometry calculations. The motor used for CDLR module offers a maximum of 3Nm torque and 300 rpm.

3.2.1.2 Power Supply

For the power supply of RPi, a small power bank of 2600mAh rating is used. It supplies power to only the Arduino and consistently supplies 5V. For the power need of the rest of the components, a Lithium-Polymer (Li-Po) battery is used. 2 packs of 12V, 8000mAh rated batteries are used. This power supply can run the AMR for at least 1 hour.

3.2.1.3 Ultrasonic sensors

HC-SR04 Ultrasonic distance sensors are used. It can measure distances up to 4m, using a transmitter and receiver. These sensors are used for obstacle avoidance by detecting the presence of obstacles and finding the distance between the AMR and the obstacle.

3.2.1.4 Arduino UNO

Used as the central processing unit of the system. Handles information from all components and makes decisions based on it. The programming for the AMR is implemented on the microcontroller of the Arduino.

3.2.1.4 BTS 7960

BTS 7960 acts as the motor controller of the system. It controls motor speed using PWM signals, based on the instructions it receives from the Arduino.

3.3 Working Algorithm

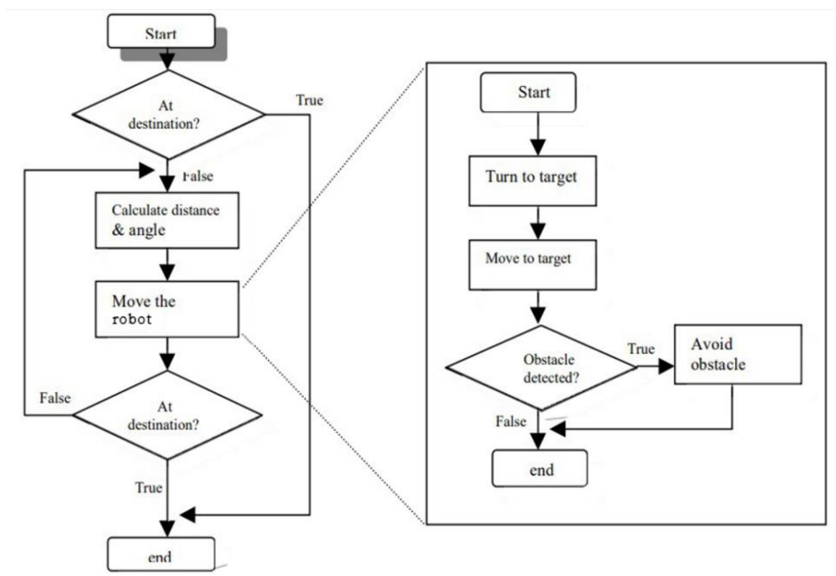

Figure 4 Process Flow Diagram

The Algorithm begins by receiving a destination command from the user. Afterwards, the code starts executing and the robot starts to get in motion. The algorithm first calculates the angle at which the destination lies with respect to the robot's current position. The algorithm then makes the robot turn for that certain angle facing straight the end destination. Now, it starts to move towards the destination. While the robot is moving, it's constantly receiving distance data from the ultrasonic sensors and encoder data from the dc motors' encoders. The encoder data gets converted into distance travelled by the robot. Therefore, at any point, the robot knows how much it has travelled, and it knows distance of surrounding obstructions if any encountered in its path. Now that the robot is moving, the algorithm is constantly comparing the distance travelled with the coordinates of the end destination essentially asking the question: am I at the destination? If that's true, break out of the code loop and stop. If false, keep moving.

In the case of an obstruction in the path of the robot while it is in motion, the algorithm runs the avoid obstacle function which consists of a series of motion commands. First the robot moves either to the left or right, depending upon where more space is available till the point it crosses the obstacle, it then takes a turn towards the end destination, moves parallel to the obstacle and finally makes a move towards its original path and once, upon reaching there, turning towards the end destination again and continuing its motion till it reaches the final position. At this state, the algorithm stops executing making the robot come to rest.

3.4 Chassis Design and Safety Analysis

3.4.1 Chassis Drawing

The AMR has a circular shape, designed for a differential drive system. The differential drive system enables us to have a smaller turning radius, increased maneuverability, and better load carrying capabilities with stress and displacements within safe zones. The following diagram shows the drawing of the AMR.

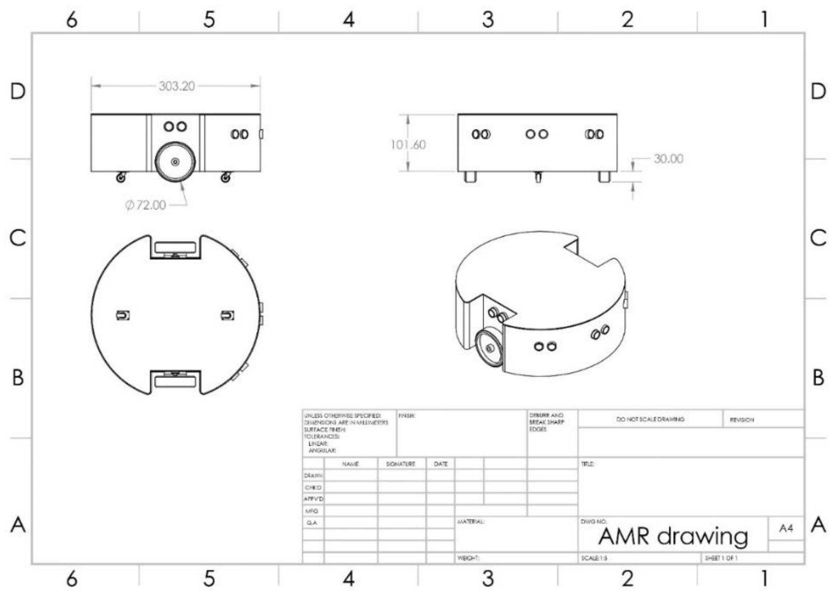

Figure 5 Engineering drawing of AMR

3.4.2 Safety Analysis

A Safety Analysis is performed to ensure that the AMR does not fail under loading conditions. The selected material is an Aluminum sheet with 16 gauge.

The model of the robot requires only static analysis as the intended process of loading to unloading does not involve external dynamic loading. Von Mises stress analysis is performed, along with a displacement plot.

3.4.2.1 Displacement Plot

An important aspect to consider is the maximum deflection that will take place when the load is applied to the top surface. The deflection must be within the elastic limit of the material so it must attain the original shape when the load is removed. From the plots, we can observe that at the 10kg load applied, the maximum deflection is only 0.2mm which is almost negligible and within the safe elastic limit.

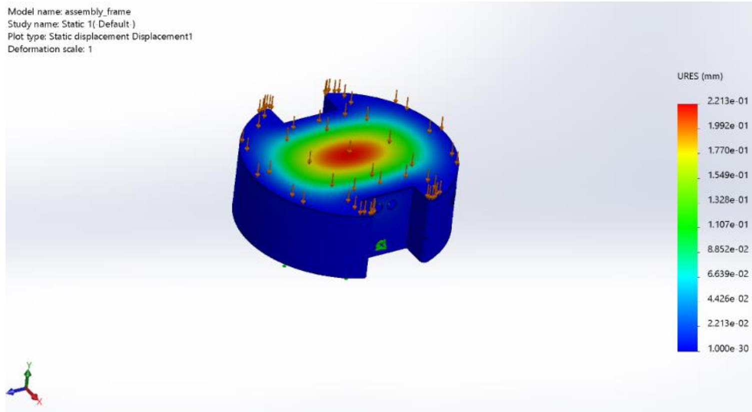

Figure 6 Displacement Plot (Chassis)

3.4.2.2 Stress Plot

The selected material has a yield strength of 90 MPa. With the applied load of 10kg as payload, 100N force is applied on the top of the robot. The applied maximum stress with this load as shown by the plot is 9 MPa approximately as maximum. With this load applied it can clearly observe from the plot that FOS related to mechanical design and strength is approximately 10. Provided that some external factors such as the quality of weld might reduce the FOS by a few numbers, the FOS is high enough to be not a problem that that needs to be considered. Thus, in terms of mechanical strength, the chassis design of the AMR is safe for prototyping

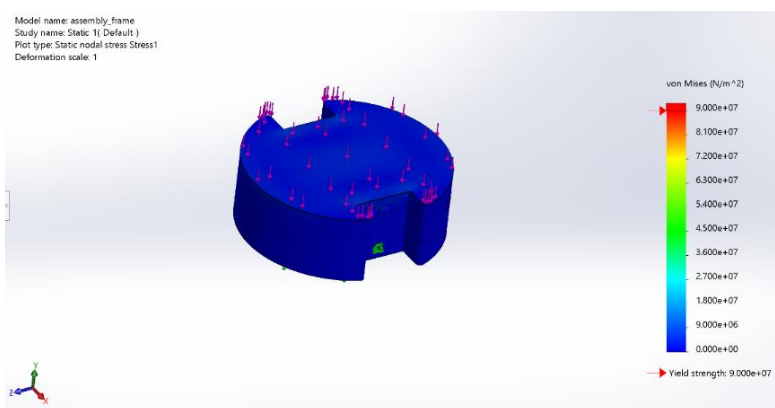

Figure 7 Von Mises Stress Plot (Chassis)

CHAPTER 3: B) METHODOLOGY (CDLR)

3.5 CDLR Module

3.5.1 CDLR Design

The proposed design is an autonomous mobile robot with a top module attached to it. The top module consists of chain-driven live rollers (CDLR) shown in figure 9. CDLRs are usually used for conveyor belts. Metal rollers are held in place by a strong base. The rollers are connected by a chain. The chain is connected to the rollers using sprockets, so the rotation of one roller causes rotation of all the connected rollers.

Figure 8 CDLR Module

The CDLR module is installed on a platform on top of the AMR. A motor drives the rollers of the CDLR module. The motor is powered by the battery of the AMR. The proposed system needs to be equipped with sensors that sense the presence of packages on the AMR. Figure 10 shows the proposed AMR model with the CDLR module.

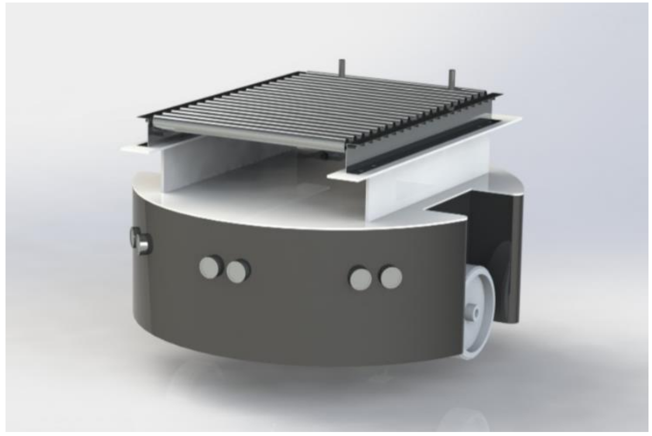

Figure 9 AMR with CDLR Module

3.5.2 CDLR Mechanism

The way the proposed system works is that AMR recognizes the pick-up location and positions itself in front of it. A conveyor belt is used to deliver packages to the top of the AMR. The conveyor belt and the AMR must be at the same height. The motor that actuates the CDLR makes the rollers move until the package is at the center. This is done using IR sensors attached to the module. The working mechanism is that once the package falls on the CDLR from the conveyor belt, it passes through the IR beam and its presence is detected by the system. The rollers are then actuated by a motor to drive the package towards the center of the CDLR module. Simultaneously, the algorithm notes the time taken for the package to cross the IR Sensor. A second IR sensor is placed at the center of the CDLR. The package after passing across the first IR sensor passes through the second IR sensor. After half the amount of time it took for the package to cross the first IR sensor is passed, the motor stops, placing the package at the center of the CDLR module. The AMR then navigates through the environment, towards the drop-off location. At the drop-off location, the motor attached to the CDLRs is driven. This causes the package to move along the rollers and onto the delivery platform. The motor can be driven either way therefore the package can be dropped in either direction.

3.5.3 CDLR Module Safety Analysis

Strength analysis plays an important part in the design of the CDLR. It provides us with quantitative figures regarding the stress and deformation experienced by the model when a load is applied to it [14]. For the proposed CDLR model, strength analysis simulation was carried out in SOLIDWORKS to study how the CDLR behaves under loading conditions. The study was conducted according to the Von Mises failure theory, which states that material will fail if the Von Mises stress of that material under load is equal to or greater than the yield limit of that material. This section defines the method used to study the response of CDLR under loadings.

3.5.3.1 Material Properties

The material is selected according to the application of the CDLR top module, i.e., it undergoes repetitive loading and unloading during its life cycle. The properties to be exhibited require elasticity, resistance to fatigue failure, and high strength to mass ratio. Market availability and cost is also an important consideration when selecting the material. Aluminum 5052 is applied to the CDLR module in this study.

3.5.3.2 Stress Plot

To simulate loading conditions, the following steps were applied to the strength analysis study:

- A simplified CDLR module is used for this study with constraints added to simulate loading conditions.
- The CDLR top module is fixed at the top of the AMR and has a bonded constraint with it. To simulate this criterion during the analysis, the base of the simplified CDLR model has been assigned the fixed geometry constraint.
- For loading conditions, a distributed load of 10 kg was applied to the rollers.
- The mesh used for this analysis is a very fine mesh having triangular elements, as shown in figure 12. The fine mesh was selected due to its complex geometry and minute design details.

After the application of constraints and meshing, the study was then solved for Von Mises Stress analysis. Figure 11 shows the simulated results.

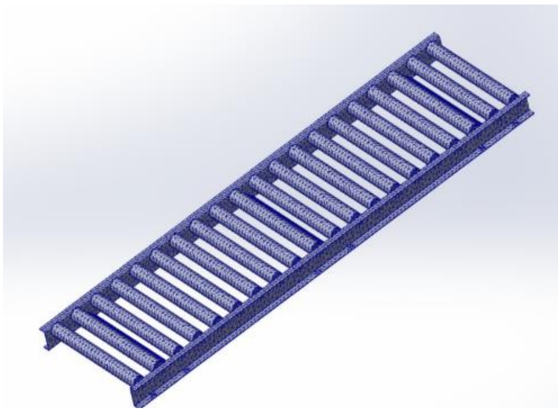

Figure 11 Mesh Diagram (CDLR)

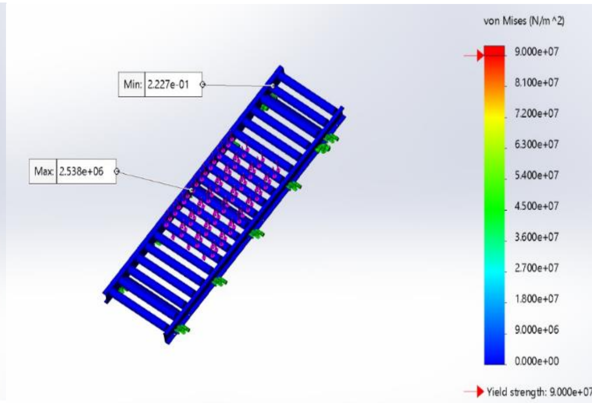

Figure 10 Von Mises Stress Plot (CDLR)

The Von Mises Stress analysis results are then compared with the yield strength of the material, by the Von Mises failure theory.

- Maximum Von Mises Stress: 2.538 MPa
- Ultimate yield strength of Aluminum 5052: 90 MPa

Since the maximum Von Mises Stress < ultimate yield strength of the material, the design will not fail under loading conditions, according to the Von Mises failure theory.

CHAPTER 4: CONCLUSION AND RECOMMENDATION

4.1 Result

The purpose of the project is to introduce automation to the warehouse industry in Pakistan by automating the transportation of packages from one place to another. An AMR is introduced for this task. The intended task of the AMR is to transport packages while avoiding collisions with any obstacle along its path. The project also introduces a CDLR module, that is attached on top of the AMR, for automation of the loading/unloading process of packages.

The total weight of the robot, along with its components, is 4.5kg. The robot can carry the intended load of 5kg with a factor of safety of greater than 2. The chassis of the AMR is a circular design, with distance between the two driving wheels being 300mm.

The AMR has two modes of operation: travelling in a straight line, and zero radius rotation. This method of motion is ideal as it allows for a simple control system with maximum maneuverability. Straight line motion requires no deviation between the motor speeds, and the COG needs to be along the geometrical central vertical axis. Both conditions were taken in consideration in the design phase, and the results are satisfactory. For zero radius rotations, wheel slipping should not occur, and the motors should rotate at the same speed. The robot has significant weight force that slipping of the wheels can effectively be ignored [15]. The encoder feedback system ensures that the motors are rotating at the same speed.

4.2 Benefits offered by the project

The project aims to introduce automation to warehouses in Pakistan. The extent to which productivity can be increased in a manual environment is limited without compromising on other important factors. Warehouse automation aims to automate the repetitive tasks in warehouses, as robots can perform these tasks more reliably, and with better management. The robot is build using locally available parts and is very cost-effective compared to the imported options available in Pakistan. Furthermore, the project also provides a solution to automate the loading/unloading of packages on the AMR using the CDLR module. The project offers the following advantages to warehouse operations:

1. Increased Productivity and reduced operational costs: robots can run for 24/7.
2. Reduced operational costs: reduces the need for manpower.
3. Accurate forecasting: helps predictability of internal logistics as it is easy to keep track of what is available as the number of packages transported can be easily tracked.
4. Ease of implementation: The AMR is very easy to implement as it does not need any additional infrastructure or present path lines to be installed.
5. Flexible operation: Obstacle avoidance allows the AMR to create its own course within the facility.

4.3 Recommendations:

1. Mecanum Wheels for Omni-directional drive system

   Mecanum wheels are a good option if more maneuverability is required, and less friction is critical. Mecanum wheels offer much better omnidirectional movements and numerous wheel orientations are possible if Mecanum wheels are added to the design.
2. Use Inertial Measure Units

   Inertial Measurement Unit (IMU) is a device that aids in localization. The data received using IMUs can be combined with the data received using encoders using sensor fusion. This is done so using The Extended Kalman Filter [16]. This method reduces the errors associated with odometry.
3. Since the project was more focused on the design and fabrication, there is room for improvement in the programming aspect. ROS can be used for better optimization options for path planning of the AMR.

4. Absolute Localization

   Currently, the robot only uses relative localization to track its motion. Absolute localization can be introduced and combined with relative localization for better tracking of the robot.

5. RFID Tags

   RFID tag reading system can be introduced in the AMR to allow for object identification. This helps the warehouse supply chain, by keeping a track of packages that are transported.

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