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Mobile Robot for Automated Storage & Retrieval System

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Abstract: ***The automated storage and retrieval systems (ASRS) are major material handling support systems that are commonly used in the automated factories, distribution centers, warehousing, and non-manufacturing environments. These robot-based handling systems are increasingly applied in distribution centers and are of high demand in e-commerce operations because of their less space requirement, higher operational flexibility and continuous ability to work thereby continuously produce output 24/7. The study will be focused on the advantages and applications of this robotic system in the Automated Storage & Retrieval System, thereby comparing it with the robot operating on the ground.***

Keywords: ASRS, Robotic Handling System, E-Commerce Operations, Vertical and Horizontal Tracks

I. INTRODUCTION

The automated storage and retrieval systems (ASRS) are material handling support systems that are commonly used in the factories, distribution centers, warehousing, and non-manufacturing environments where automation is implemented. These robot-based handling systems are increasingly applied in distribution centers and are of high demand in e-commerce operations because of their less space requirement, higher operational flexibility and continuous ability to work thereby continuously produce output 24/7. The aim is to study this specific type of Robot based Automated Storage and Retrieval System developed by a company named "**Squid Warehouse Robots"** which uses vertical and horizontal tracks all along the inventory racks, thereby allowing the bot to traverse and reach up to any specific location on the rack and therefore providing certain advantages over other alternative methodologies. This system also requires development of a bot which is equipped with corresponding technology so as to fulfil the operational needs of climbing along the vertical and horizontal tracks installed on the inventory racks.

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II. LITERATURE REVIEW

A. History of ASRS:

Storage has a long history, stretching back to the early days of civilization and the wild berries that were picked at the time, as well as the beast that lay, and after the meal was no longer needed, people would store the surplus. However, the evolution of the proper word "warehousing" has been long and winding. "Automated warehouse" is strongly linked to the rapid development of logistics and its research and development as a higher stage of warehousing. From its conception to present, the automated warehouse has gone through about five stages: manual storage, mechanical storage, automated storage, integrated storage, and intelligent storage.

Fig: In the 1950s, there was a three-dimensional warehouse in the United States that used a bridge-type stacking crane

Fig: The end of the 1960s, the driver operation of the roadway stacker crane warehouse:

The United States was first to employ computer control technology in elevated warehouses, establishing the first computer-controlled three-dimensional warehouse in 1963. Since then, the automated warehouse has grown in popularity in the EU's established industrialized countries, forming a distinct discipline. In the mid-1960s, Japan began building automated warehouse. The automation, standardizing, and information of product logistics, as well as the creation of centralized distribution centers for urban commodities, have been strongly pursued by developed countries since the 1970s. In a series of steps, they all built large-scale automated three-dimensional warehouses. Automated three-dimensional warehouses grew fast throughout the world in the 1980s, and are now employed in practically every industry. The first bridge crane was developed by China's Ministry of Machinery in 1963, and the first computer-controlled automated three-dimensional warehouse was produced by China's Ministry of Machinery in 1980. Automation pallet trucks, shelves, and other items have advanced swiftly in our country in the twenty-first century. Large-scale state-owned companies, such as tobacco and pharmaceuticals, were the first to employ automated warehouses. Following 2010, the automated warehouse has permeated all aspects of life in our country, particularly during the Development period, creating a high demand for logistics and distribution centres, prompting a number of e-commerce companies to establish their own logistics and distribution centers, ranging from automated warehouses to formal intelligence.[3] The current state of the ASRS domain is highly advanced compared to a few decades ago. The first ASRS based system was developed in 1962 and was installed in a book club warehouse located in Guttersloh Germany, and was strictly manually controlled for performing its operations. The advancements in the domains every decade have been very drastic and the level of sophistication, for even the relatively smaller operation has increased significantly, let alone the highly complex and layered operations.

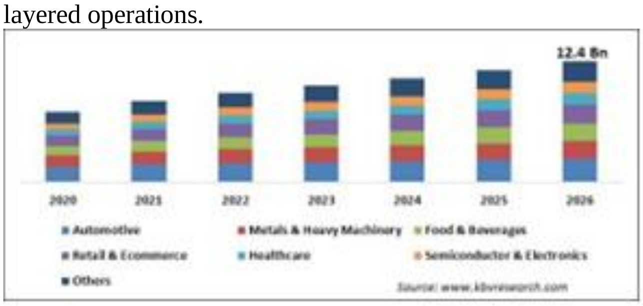

Fig: ASRS market size size projections by end-user. Img Courtesy of KVB Research

After reviewing multiple papers in the domain of Automated Storage & Retrieval Systems ranging from various time has enabled us to get an idea of the current state of the technology and its potential scopes for growth in the coming years. The various types and sub types of ASRS technologies developed until now are further discussed in the following segment.

B. Primary Advantages Associated with ASRS

I] High Density Storage

Space constraints affect a vast number of manufacturing and storage enterprises. These facilities are developed and built to meet immediate needs as well as some predicted future growth. However, when businesses grow and expand, their storage requirements frequently outstrip their current capacity. Continuing to extend horizontally by adding square footage to the building through construction in these instances can be expensive and, in some cases, impossible. When it comes to boosting storage capacity vertically, ASRSs are the most effective approach. To put it another way, ASRSs have the maximum volumetric efficiency, or storage capacity to square footage ratio. As a result, high-density warehouses are a common term used to describe them.

II] Better Safety Operations

Manipulation of a forklift is one of the most dangerous occupations in an industrial setting. Each year, about 100 forklift-related fatalities and 20,000 severe injury cases occur in the United States.

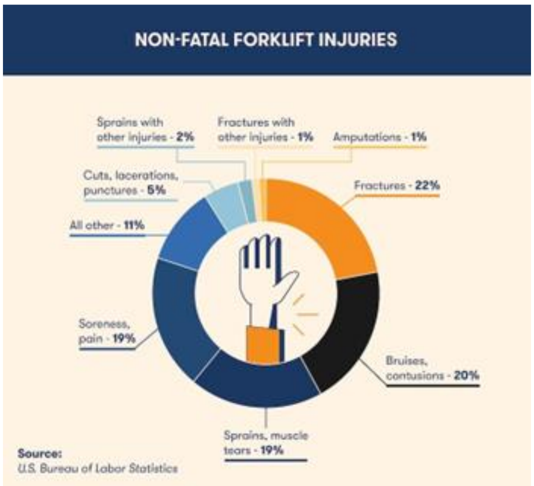

Fig: Most common non-fatal accidents involving forklifts. Img courtesy Big Rentz

III] Increased accuracy and efficiency

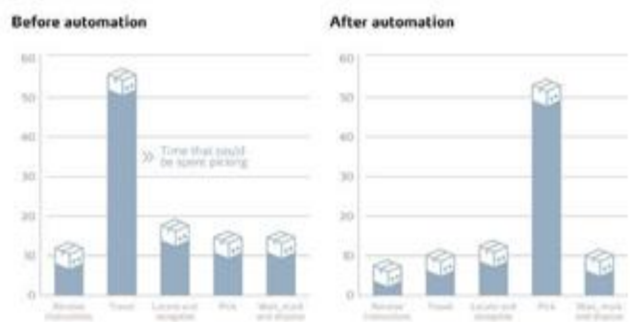

Fig: Efficiency improvements comparison. Img Courtesy: Kardex-Ramster.com

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ASRSs, like any other automated system, are configured to do precise repeated duties. When products are handled using an ASRS, they are much less likely to be damaged by human error than when they are handled with a forklift or other means. Aside from labour savings, reducing product waste is a cost-cutting factor that is sometimes neglected when deciding whether or not to install an ASRS. Another significant advantage of an ASRS is the greater accuracy with which product data is handled. Almost every ASRS operated by a warehouse control system (WCS) or warehouse management system (WMS) can automatically send product tracking data.

C. Primary Dis-Advantages Associated with ASRS

I] Initial Investment: The construction of an ASRS is a vast and complicated undertaking. Furthermore, unique materials and reinforcements are frequently required for the structure to resist the loads to be stored. As a result, some businesses that may greatly benefit from ASRSs are unable to use them today. Naturally, the corporations who build these warehouses have conducted extensive research to verify the investment's financial sustainability. II] Inflexible Tasks: Despite the fact that ASRSs are modular and expandable, they are often designed to fulfil a single task. Inside the ASRS, the automation is stiff. Stacker cranes, for example, can only move in a specific direction along each axis. Furthermore, the dimensions of the storage site cannot be changed. Within an ASRS, there can certainly be storage places of varied sizes, but they are selected during the design phase. Changing the structure once it has been erected would be prohibitively expensive. This may have a detrimental impact on a company that, for example, released a new product that exceeds one or more of the storage locations' restrictions. This is why, while deciding whether or not to install an ASRS, future forecasts of production volume and product lines must be factored in[6].

Robotized Warehouse Systems use the concept of shuttle based compact storage system. It requires installation of frames and tracks for the shuttle bot to travel on all over the warehouse. Racks and automated handling equipment, like as cranes or automated vehicles, make up such a system. Debjit Roy in his paper on Robotized Warehouse Systems Proposed the concept of shuttle based compact storage system. It requires installation of frames and tracks for the shuttle bot to travel on all over the warehouse. Aisle-captive (usually cranes) or aisle-roaming handling solutions are available. A crane lifts up a load, generally from a conveyor, and stores it in the 30-40m high racks to execute a storage activity. Driving and lifting in the aisle happen at the same time. For a retrieval operation, the procedure sequence is reversed. It's also possible to run a dual command cycle, which combines a storage and retrieval activity. Loads can also be stored double-deep in the racks using AS/R systems. Cranes with double-deep telescopic forks can be fitted to this end.

AS/R systems with Deep Lane, or compact, multi-deep (3D) storage lanes, can store loads even deeper in storage lanes. SBS/RS is becoming increasingly common since the combination of the two subsystems provides great flexibility, cheap operating costs, and enormous storage capacity, but it also creates the managerial issue of how to coordinate the shuttle and the lift. There are three reasons for putting idle shuttles in the first-tier. For starters, because retrieval activities are more vital in an e-commerce warehouse than storage tasks, their dwell policy makes retravel operations easier from the start. Secondly, while dealing with a sequence of outgoing jobs, it minimizes the overall number of shuttles moves. Finally, when all shuttles are at the bottom, inspection and maintenance work may be considerably easier. A shuttle can access any tier with the help of the lift. The lift and shuttles can both operate at the same time. Due of the uniformity of aisles, this paper examines the performance characteristics of the entire system by focusing on just one.[2]

D. Reinforced learning:

A clever technique called "Reinforcement learning" is used to improve the performance of an existing system in this study. Changing the configuration of an established system is often challenging because it is a costly and time-consuming process. As a result, the scheduling control should be tweaked to optimize the system's performance. Because the rack of an SBS/RS has different columns and tiers, the make span of storing a load at a certain storage site in the rack is specific to that place. Reinforcement learning is one of three basic machine learning paradigms, with supervised learning and unsupervised learning being the other two. Reinforcement learning is currently widely employed in a variety of domains, including image recognition, data processing, and decision making.[3].

Ya-Hong Hu, in his paper discusses about detailed research on the development of travel time analytical model, in order to further design and develop a new type of S/R System[4]. J. Dupuis in his paper presents an original framework for evolving a vision-based mobile robot controller using genetic programming. The paper primarily focusses on developing complex algorithms and methodologies for implementing a wide array of operations with a substantial rise in efficiency. However, the mass implementation of the same is a costly affair and thereby a cost in-effective process considering the cost sensitive nature of the domain[5].

Smita U Chakole has presented a research paper discussing the design and development of an ASRS based bot specifically for flexible manufacturing applications[6]. J. Thirumurugan in his paper discusses about line following robot(LFR) for library inventory management system using a barcode scanner [7]. Vijayaragavan, E proposed a unique lead screw mechanism based bot in his paper on ASRS based Bots.

The Primary mechanism proposed for performing loading and unloading operations uses a lead screw mechanism arranged in a specific way with the help of a gear system. However, an electric differential drive is used for locomotion of the bot from one point to another[8]. Russell D. Meller and Anan Mungwattana made a multi shuttle-based S/R system where it can perform the two storage and retrieval operations in an interval [9].

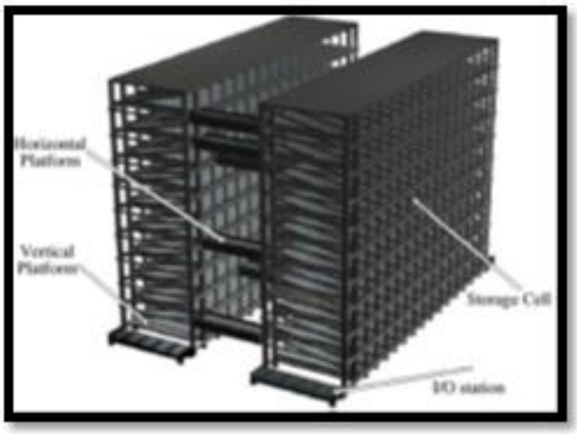

Fig: The new S/R mechanism of AS/RS

III. CASE STUDY: SQUID WAREHOUSE ROBOTS (BY BIONIC HIVE)

The Concept: Squid is an autonomous robotic fleet developed by Israeli startup Bionic HIVE for structured packing and storage in warehouses. The robot can select anything from the ground up and adapt it onto any existing warehouse infrastructure. According to the company, the robot adapts to any warehouse's working environment by utilizing existing facilities, packages, and storage racks.

Nature of Disruption: Squid is a synchronous autonomous robotic fleet with three-dimensional movement capabilities that can perform a variety of tasks. BionicHIVE's ML-based algorithmic engine can learn issues caused in one warehouse and apply resolutions to all warehouses within the network thanks to its embedded control system with real-time data analysis. It may be installed immediately on any standard pallet rack in any warehouse to automate all package handling from receipt to shipment. Squid has floor-to-ceiling picking capabilities, which means it can select the packet from any spot, whether it's on the floor or 20m/60ft up. BionicHIVE says that its service-based model may help warehouses lower operating costs while also meeting the growing demand for higher stock-keeping unit amounts and dynamic pick face selecting.

Outlook: Existing autonomous mobile robot warehouse automation solutions are unable to address the fundamental warehouse inefficiency problem. Furthermore, because these solutions necessitate dedicated space, considerable implementation effort, and significant financial expenditures, they cannot be executed at scale by warehouses. Squid, according to BionicHIVE, is the first robotic fleet that can retrofit automation on existing warehouse infrastructure with minimal change and downtime, allowing existing operations to continue while offering automation as a service. Squid is fully autonomous with 3-dimensional movement and can learn problems using smart real-time data analysis. Movement on the ground is possible through image processing of QR codes to identify pathways and avoid obstacles. The unique guided rails help them to climb vertically and move horizontally to locate the products. The specially designed robotic arms with suction cups make it easy to handle the products from the pallet box to the rack and vice versa. This system complies with the universal safety standards to ensure the safety of human-robot collaboration (HRC). Also, the Squid robots are capable of learning seamlessly and improvise performance using Machine Learning. These bots climb the racks using the vertical channels installed on the racks and therefore can reach any location on the racks, thereby providing excellent inventory assortment methodology while reducing the efforts taken by a human(employee) for the same process. For implementing the Squid robots in a warehouse, the racks present in the warehouse need to be modified. The racks in which the inventory is stored, are modified by installing vertical and horizontal channels along every rack. Also, at the bottom of the rack is installed a curvy inclination for the bot to climb into the vertical channels. These channels help the bot to grip its one pair of wheels which is used for climbing purpose while the other remains inactive in this process and are basically driven(wheels) when the bot is moving from one point to another on the ground.

Fig: Squid Bot Working

The electronics of the bot include a custom built highly advanced on-board computer, wireless communication module, 3 pairs of motors for locomotion(1 pair for the drive,1 for the turning on ground and one for keeping the bot upright while climbing the racks), sensors for object detection and mapping, load sensors, small sized robotic limb with suction cup end effector, power backup, camera sensor for adjusting itself wrt the curved inclination for climbing vertically along the racks as well for product code scanning purposes.

IV. METHODOLOGY

The methodology proposed for the development of an ASRS bot is as follows:

- Defining the concept and idea
- Research and Survey
- Designing Software Model
- Software Model Mechanical Simulation
- Prepare Code
- Fabrication of chassis
- Procurement of components
- Performing Control System Simulation
- Installation of components on Chassis
- Testing and Validating the Robot

Some of the options for the Lifting Mechanism

A] Scissor Platform using Pantograph Mechanism

i]Single pantograph Hydraulic/Motorized

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ii] Multi pantograph Hydraulic/Motorized
B] Multi-linkage gear, pinion & screw mechanism
C] Tandem – Hydraulic Cylinder
D] Telescopic Hydraulic Cylinder
E] Vertical Columnar Frame Based Mechanism

V. PROPOSED CAD MODEL MADE IN FUSION 360

Fig: CAD Model of the Bot

Fig: CAD Model of the Bot with the Rack

Sr. No	Component	Dimensions
1.	Platform	20cm(dia),0.5cm(thickness)
2.	Lead Screw	12cm(len), 5cm(dia)
3.	Lead Screw Gear	75(teeth), 7.5cm(inner dia)
4.	Platform Rotation Gear	35(teeth),4cm(inner dia), 6cm(len)
5.	Motor Driven Wheels	15cm(dia), 5cm(thickness)
6.	Overall Bot	40cm x 40cm x 30cm(Retracted) 40cm x 40cm x 38cm(Extended)

Fig: Important Dimensions associated with the Design

VI. FUNCTIONAL OPERATIONS AND EXECUTION PROCEDURES:

The Bot travels from point A to Point B. Here, the point A is the loading location and point B is the unloading location. Once the bot detects the location of the loading point (with the help of a color sensor placed right under the chassis of the bot), the electric motors stop so that the linear actuator can initiate loading the operation along the height thereby lifting the load up to a certain desired height. Further, once the linear actuator retracts to its maximum actuation, the actuation stops. Next the bot is operated to travel to the desired unloading location. The bot in its loaded state, operated to travel from the point A along the suitable path and once the desired location is detected again by the color sensor, it stops again. Now, once that the desired location is reached, the unloading operation can be initiated.
Below is a proposed layout for the for the floor. This proposed environment is subject to changes according to the specific requirements

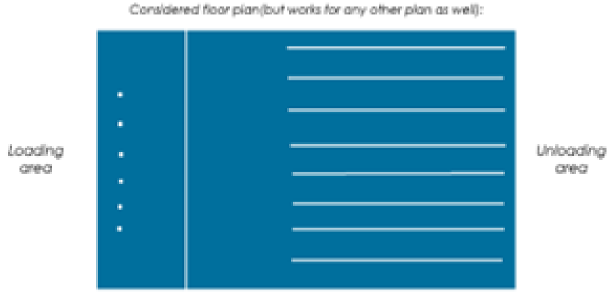

Fig: Proposed Floor Plan

VII. DRIVE

The mobile robot shall use a differential electric drive. It has two driven wheels. A differential drive allows the robot to have very high mobility and freedom of movement. It equips the robot with the ability to move in any direction on the X-Y plane. One of the main advantages of using a differential drive is its ability to perform 'zero-axis' rotation i.e., the robot is able to rotate about the z-axis which lies midway between the two drive wheels. This makes turning and cornering very efficient.

A. Electronic Subsystem

- The entire electronics of the bot is mainly based on Arduino Nano.
- The bot will be fed instructions for traversing from one point to another. Further, after reaching the required location, the bot will detect the location points using color sensor system which further allows the bot to initiate the loading operation.
- Ultrasonic sensors will be used for obstacle avoidance and in order to prevent the collision with both static as well as dynamic kind of obstacles.
- The system will also incorporate a closed loop feedback system via a force sensor which will be used to measure and estimate the limits to which it can sustain load and work with efficiency.

B. Electronic Components

- Arduino Nano
- Linear Actuator (Lifting Mechanism)
- 2 BLDC motors (2 Driving Mechanism)
- 2-4 Castor Wheels
- Relay Module (Motor Drivers)
- Voltage Regulation Circuit
- Sensors
  I] 2 Ultrasonic Sensors
  II] 1 IR Sensors
- Sound Beeper
- Battery Pack
- Switches

C. Analysis

The analysis and simulations performed on the bot can be broadly classified into two major categories:

- Mechanical Simulation
- Electronic Simulation

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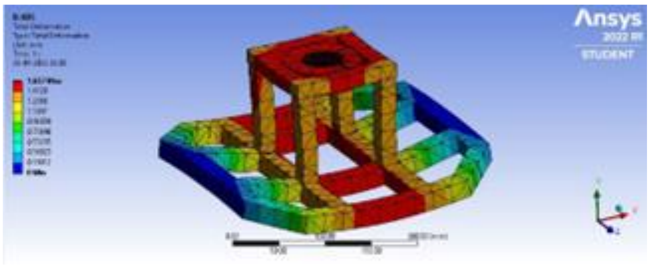
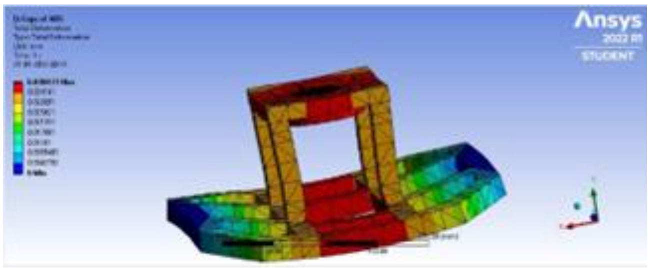
VIII. MECHANICAL SIMULATION:

A simulation based on the stress-strain analysis of the primary load bearing mechanical component, i.e., the chassis was performed. The load applied due to self-weight and the externally applied load is not expected to exceed 20 Kgs. Accordingly, a point load was applied on the various points on the chassis where the stresses will be at peak in loading conditions. The analysis was performed with various material variants in order to select the material considering optimum strength, rigidity and cost effectiveness. Below are few figures portraying the same. The software used for performing the analysis is ANSYS 2021 R1 Student Edition. Different materials considered for analysis are:

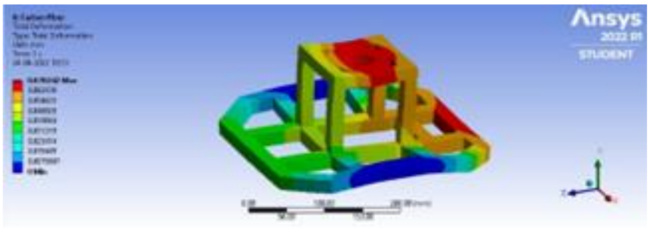
- ABS Material



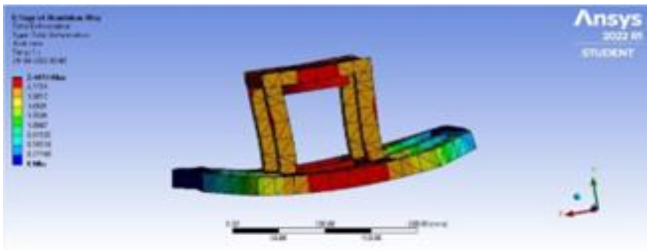
- Aluminum Alloy



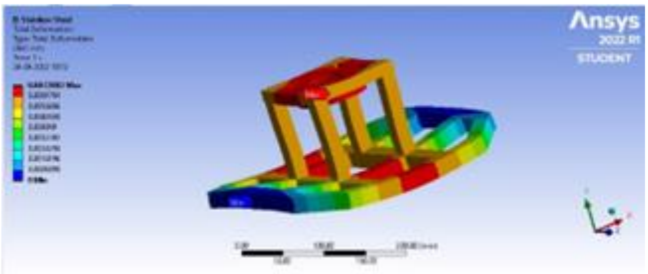
- Carbon Fiber



- Polyethylene



- Stainless Steel



IX. ELECTRONIC SIMULATION

The Electronic simulation comprises of the software simulation of the control system used in the bot. The electronic system includes of various electronic components connected in the circuit. The programming fed to the controllers should produce the desired outcomes and therefore an electronic simulation analysis is necessary. The control system used in the bot has been simulated virtually in a software which allows us to develop a virtual control system and operate it the way it will be operated physically. Below are few figures which describe the same from the actual software. The software used for this purpose is Proteus Pro.

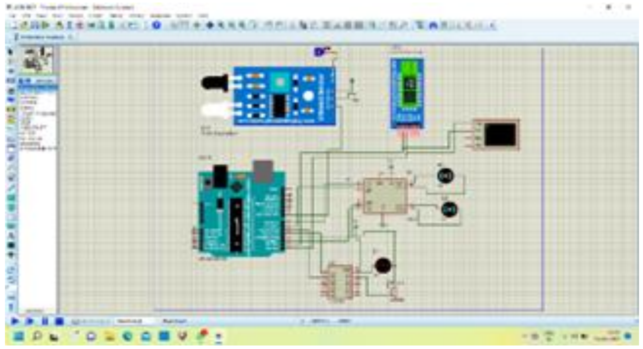


Fig: Control System Simulation performed on Proteus Software

X. RESULTS AND DISCUSSIONS

The Mechanical and Electronic simulations performed in the development phase of the bot show that the proposed models for the bot are safe enough to be implemented. The results of the mechanical simulation have proven the loading bearing capabilities of the bot. Also, the electronic simulation performed on the control system of the bot proves that the proposed control system performs in accordance with the instruction fed to it and thereby sufficing the operational and functional requirements of the bot.

XI. CONCLUSION

The proposed ASRS bot is an integrated approach utilizing the mechanical as well as the electronic elements to provide a solid tool to reduce the time and efforts required in the inventory assortment and warehouse management operations as compared to the already existing system for warehouse management. The proposed bot is a potential product for small scale to medium scale industries trying to implement the ASRS technology into their warehouses, distribution centers or store houses, etc.

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