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[1] Krishna Vamshi Ganduri

[2]Bhargav Prajwal Pathri

[3]Shivaji Rathod

[4]Koganti Sojith

[5]Kusuma Yanna

[6]Bakka Shravya Reddy

[7]Praveen Kumar Pudi

Adaptive Intelligence in Warehouse Robotics: Efficient Pick-and-Place Robot for Dynamic Environments

Abstract: - This paper explains the design and implementation of an adaptive, intelligent pick-and-place warehouse robot. A collaborative 6-DoF robotic arm with attached inventory pods handles items in a very efficient, highly automated manner through an advanced object identification and collision avoidance system. It is capable of picking and placing items of all sizes and weights, transferring them between inventory, work, and delivery stations while maintaining real-time communication with a control center. Path planning is optimized through the Particle Swarm Optimization (PSO) algorithm, which enhances movement precision and efficiency within the workspace. Additionally, the robot is equipped with ultrasonic sensors for real-time object detection and collision avoidance. Unlike other classical pick-and-place robots that rely on stiff grippers or suction cups for picking, this one utilizes an idea inspired by octopus tentacles. Its highly flexible form allows it to follow the shapes of various objects, regardless of the shape or texture of the objects being lifted. A minimum cost optimization with 4 DOF design could only prove ineffective for the required dynamic picking settings, proving a good case for implementing the adaptable 6 DOF. This research work aims at the development of a more adaptive end effector as well as an adaptive mechanism of control to improve on the precision and efficiency of real-time warehouse management adaptability.

Keywords:auto-picking, object detection, End effector, pick-and-place robot, Warehouse.

I. INTRODUCTION

Robotics has made fascinating advances in recent years, resulting in a wide range of adaptable robots [1].The rise of adaptable robots is particularly significant due to their ability to effectively address the obstacles posed by current automation requirements, thereby satisfying and meeting needs efficiently in a variety of jobs. Efficient usage and transportation of products to satisfy customer demands is of the highest significance to maintaining seamless operation in contemporary warehouse management [2][3]. An essential part of warehousing is the transfer and pick-and-place procedure, which enhances the speed, accuracy, and variability attained. Mobile robots intended for warehouse pick-and-place activities include enhanced procedures, sensors, and cognitive algorithms [4][5].These robots move independently or semi-autonomously throughout the warehouse floor, precisely identifying pickup and delivery areas. They can adapt to changing environments, avoid obstructions, and plan ideal routes to decrease trip time [6][7].

One of the critical jobs involved with any warehouse is to organize it. Choosing orders is perhaps the most expensive operational function, accounting for up to 50% of a distribution center's overall operating expenses. The arrangement of the picking area is crucial for effective operations and customer service[8]. Only pick-and-place robots, widely used in various fields, can accomplish this during the processing phase. There is always a

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[1]*PhD Research Scholar, School of Technology, Woxsen University, Hyderabad, Telangana, INDIA, *kvganduri@gmail.com*

[2] Associate Professor, School of Technology, Woxsen University, Hyderabad, Telangana, INDIA, *bhargavpathri@gmail.com*

[3]Assistant Professor, Department of Electronics& Telecomm, Engineering in Jagadambha college of E&T, Yavatmal, shivaji147@gmail.com

[4]Mechatronics, School of Technology, Woxsen University, Telangana, Hyderabad, Telangana, INDIA, *kogantisojith@gmail.com*

[5]Data Science & AI,School of Technology, Woxsen University, Hyderabad, Telangana, INDIA, *yannakusuma5@gmail.com*

[6]Data Science & AI, School of Technology,Woxsen University,Hyderabad, Telangana, INDIA, *shravyareddy2004@gmail.com*

[7]Data Science & AI, School of Technology,Woxsen University,Hyderabad, Telangana, INDIA, pudipraveenkumar10@gmail.com

gap in this area where they can be implemented effectively and efficiently. Effectiveness is achieved by reducing the use or consumption of resources, which is where the use of new methods and technology comes into play[9][10].

Automation in this business is difficult owing to the intricacy of the jobs and the surroundings. One of the aims of automation technology research is to develop a system that can function autonomously, and different sorts of items provide different obstacles[11]. The design of this robot mainly includes a small crate-like design to hold some orders and a manipulator with an octopus-shaped end-effector for more precision. Significant breakthroughs are being made to increase innovation and automation in the industrial industry, as discussed in the article[12]. These techniques and technologies assist boost efficiency and production in manufacturing[13]. Fig.1 depicts a real-world warehouse layout with narrow picking aisles. This type of layout is commonly found in warehouse research[14]. The image does not show any robots or other equipment operating within the aisles[15].

Warehouse robotics and Warehouse Management Software are almost an epitome of the change that is happening in logistics and supply chain operations. These developments bring much greater efficiency, safety, and accuracy in warehouse environments. The use of term robotics in warehouses implies unmanned machines to achieve work. This reduces pressure on employees while doing mundane jobs as it could be risky for them at times. Advanced software integration allows these robots to efficiently streamline operations, avoid errors, and maintain safe working conditions, a holistic replacement for mundane manual labor.

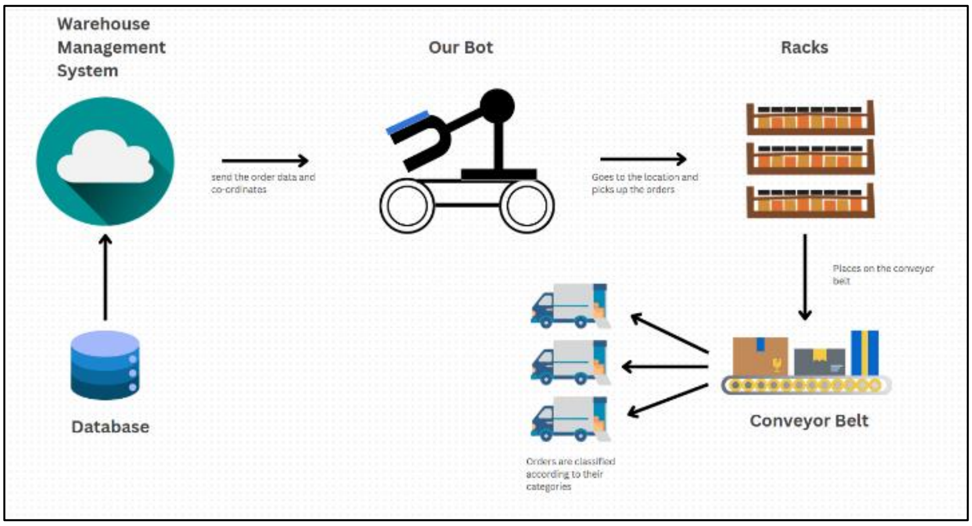


Fig.1 Flow process in the warehouse.

Evolution of the Warehouse Robotics Concept The history of warehouse robotics begins in the 1950s with early development in manufacturing, mostly related to making robotic arms, which could handle heavy and dangerous materials. These pioneering machines built the basis for the sophisticated technology one sees today. Long-term advancements in AI, machine learning, and sensing technologies have been driving this industry into warehousing. Hence, modern sensors that enhance environmental awareness along with their ability to learn from data and make decisions in real-time, combine all of these technologies with WMS and let fully autonomous robot operations take place in the warehouses. It radically changes warehouse efficiency at a new level and limits dependence on human labor.

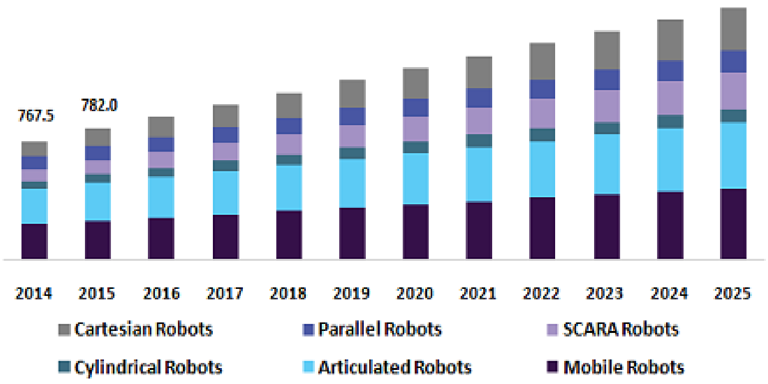


Fig.2 Robots in warehouse

Warehouse robotics takes place in several forms and therefore has different capabilities. AGVs operate continuously throughout the day and night with little downtime, thus well suited for large facilities. AMRs, by contrast to AGVs, do not rely on pre-laid paths, but instead rely on sensor data to create routes and thereby avoid obstacles shown in Fig.3. They are particularly strong on exact sorting and doing the regular daily inventory count that significantly reduces labor costs as it cuts down errors. Probably best known as delivery devices, aerial drones also exploit their velocity and precision to rapidly access places that are high and difficult to access, in order to manage inventory in a warehouse. Orderfulfillment optimization continues with the automation of inventory movement in and out of storage by employing Automated Storage and Retrieval Systems (AS/RS), directly delivering items to the worker when interfaced with WMS[16][17]. Nesting robotics in warehousing brings many benefits. Robots eliminate errors in picking, packing[18], and sorting and save labor; they allow warehouses to work around the clock. In addition, safety is improved due to the takeover of hazardous operations, workers get a chance to engage in more complex tasks, and indeed, in terms of order fulfillment, satisfaction to the customer is improved. Robotics as a Service (RaaS) gives flexible, subscription-based access to robotic technologies. Businesses can now adopt automation step by step without any major initial investment, which brings down financial risks and raises the flexibility quotient. Implementation for success requires bringing robotics within the WMS. WMS alone provides the accurate and timely data that robots will need to make optimal decisions and match changes in the workflow. Planning needs also involve the measurement of accuracy of the data, layout of the warehouse and the possibility of compatibility with existing systems. Integration of robotics into WMS has been a paradigm change in the world of warehousing, wherein extremely efficient and responsive warehouses have reduced operational costs by up to 70%. Companies build resilient, future-proof warehouses that can meet all demands of today's dynamic supply chains[9].

A. Problem Statement

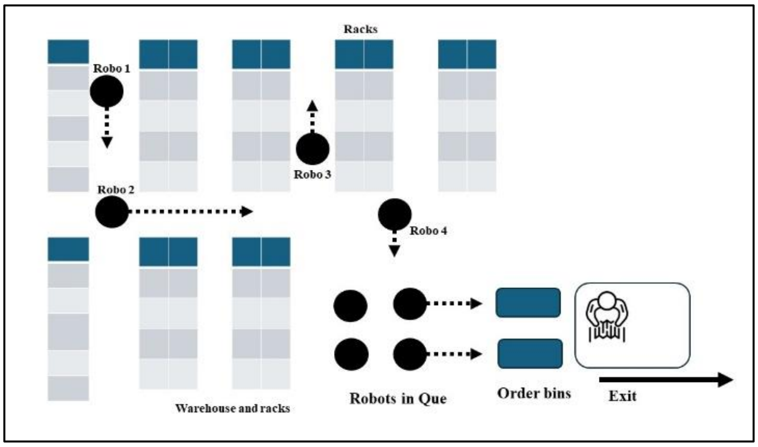


Fig.3 Real warehouse arrangement where the vehicle needs to move around.

This article covers the usual arrangement of a warehouse with a limited pick lane as shown in Figure 1. Due to manual unloading and high mistake rates from human weariness, warehouse operations are difficult to manage slowly. The risks of safety that come with doing lifts repeatedly make inefficiency worse. the creation of mobile pick-and-place robotic devices for warehouses as a solution to these problems as shown in figure 2.[19][20]. The scalable clients will enable this system to precisely recognize goods, explore the warehouse autonomously, and arrange the products for further processing. The robots will improve selection and inventory updates by connecting with warehouse management systems. The advantages are clear: possible labour cost savings, enhanced worker safety, higher manufacturing precision, and quicker order fulfilment. Simple integration, adaptable grippers, and reliable conveyance nevertheless face obstacles. Developing scalable, reasonably priced robotic systems that improve warehouse accuracy, efficiency, and safety is the ultimate objective[14].

II. LITERATURE REVIEW

A thorough investigation has been conducted on design and operations for order picking and placing in warehouses[21]. It issues in terms of short-term, medium, and long-term decisions, this system is for layout, workforce, and equipment handling. When the chance of visiting each aisle for one or more selects approaches 1.0, the traversal routing strategy is almost optimum under the randomized storage policy[16].A crucial aspect that might affect the efficiency of picking orders, often with the use of traditional end-effectors. were the first to assess the effects of varied pick densities on in-the-aisle blocking in a picking system made up entirely of narrow aisles.They discovered that when pick density grew, or picking got busier, congestion diminished. A coauthor expanded on these blocking models by generating analytical formulations to estimate blocking with k workers moving at an unlimited pace in a continuous loop and choosing at most one stock-keeping unit. Investigated the performance of picking operations in a warehouse system with several pickers. This work proposes a technique for modelling pick-and-place operations for wafer-handling robots. The work includes creating algorithms to estimate the distance between the robot's end-effector and silicon wafers, as well as testing the vacuum condition. A SolidWorks API-based simulator is used in a virtual environment to do realistic object manipulations that mimic real-world substrate handling[22]. This study describes a robot operated by a phone application, which includes a low-cost Microcontroller (ESP32 Node Mcu) and a cleaning arm[23]. The robot, controlled by an Android smartphone on the Blynk platform, performs pick-and-place and floor-cleaning chores according to user directions. The system's affordability and convenience make it ideal for home automation[2][24].

This work investigates pick & place[25] operations in a non-visual world utilizing proximity sensors and Reinforcement Learning (RL). The problem is presented as a Markov Decision Process and solved by off-policy. Q-Learning. The RL algorithm works effectively in pick-and-place tasks on goods traveling down a conveyor belt in industrial environments.[26]. Addressing cooperative manipulation, this article develops a supervisory control architecture for two robotic manipulators with pick-and-place capabilities[7]. The architecture enables real-time planning and reconfiguration of subtasks, allowing the agents to handle complex manipulative tasks collaboratively using deep reinforcement learning for task execution[27]. Object detection is critical for pick-and-place solutions, particularly in resource-constrained applications. This study presents an accurate and efficient object detector based on TensorFlow Lite that is ideal for pick-and-place applications operating on platforms with limited computing capabilities, such as embedded computers[28]. Multipurpose industrial robots are gaining popularity due to their capacity to execute a variety of jobs. These robots are designed to execute a wide range of jobs in a variety of situations. This literature study addresses four essential strategies that are frequently combined in multi-purpose in medical assistance robots[29] and industrial robots: Pick-and-place operation[30], floor cleaning, solar panel maintenance, and product use of ultrasonic sensors. assess the present state of research in each domain, shedding light on major obstacles, new possibilities, and potential research initiatives for the future[31][32][33]. The trials undertaken in this paper reveal a considerable reduction in energy usage, with a reduction of around 72% when compared to systems without solids. Furthermore, the suggested approach includes an edge solution for modifying the start and end positions of the pick-and-place process. Higher speeds, however, will necessitate stronger elastics with faster response times. The durability of the electronic brakes is a crucial factor to consider since it might impair the system's precision, and speed. More study is required to completely understand these constraints and optimize the system for actual engineering applications [34][35].

This research gives vital insights into the creation of energy-efficient industrial robots by integrating complicated, flexible equipment. Despite these challenges, the proposed concept demonstrates the feasibility of developing cost-effective adaptive robotic manipulators for pick-and-place controllers that allow access to materials aimed at themselves, and its convolutional neural network (CNN)-based Orientation detector accurately identifies orienting objects[36][37]. The installation of a sliding train enhances the robot's operating range and improves its accuracy in pick-and-place actions. A CNN-based orientation detector has a resolution limit of 15 degrees, which may not be adequate for applications that need great precision. Furthermore, while the system is excellent for defect detection, selection, and installation, it may not be ideal for more sophisticated applications that need significant machine learning or substantial robotics. All talents in 2010, and the project is a potential solution for mistake detection and location duties, however, additional research and development is required to overcome its inadequacies and improve its capabilities[38].

III. EASE OF USE METHODOLOGY

A. Mathematical equations

The Denavit-Hartenberg (DH) characteristics shown in equations can be used to calculate the forward kinematic model for the RRR process[39].

$$T_1^0 = A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & a_1c_1 \\ s_1 & c_1 & 0 & a_1s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$T_2^1 = A_1 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$T_3^2 = A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & a_1c_1 \\ s_1 & c_1 & 0 & a_1s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$T_3^0 = T_1^0 T_2^1 T_3^2 \tag{4}$$

$$T_3^0 = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & 2_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

This model is then stated as a homogeneous transformation matrix, as illustrated in equations (1) through (5), which is a map space linked to 3D Cartesian space. At this point, A1 represents the transition matrix for joint 1, A2 represents joint 2, and A3 represents joint 3. Equation (5) determines the motion along the x and y axes[40].

B. Battery

Fig.4 Battery

For a battery long time, need to balance the power for that,

$$\boldsymbol{5200mAh \times 40C = 208A}$$

$$\boldsymbol{14.8V \times 208A = 3078.4W}$$

$$\boldsymbol{Battery\ life(hours) = \frac{Power\ usage\ (watts)}{Battery\ capacity\ (watts)}}$$

$$\boldsymbol{Battery\ life = \frac{93}{3078.4}}$$

$$\boldsymbol{Battery\ life = 33.10\ hrs}$$

This figure presents the angular velocity profiles of the joints in the proposed robotic arm during a sample pick-and-place operation. The x-axis represents time (t) in seconds, while the y-axis represents angular velocity (ω) in radians per second (rad/s). The five curves correspond to the individual joints of the arm, denoted as Joint 1, Joint 2, ..., Joint 5.

C. Mathematical Analysis

The angular velocity (ω) of a joint relates to its angular displacement (θ) and the rate of change of displacement (θ'), as described by the following equation:

$$\omega(t) = \theta'(t)$$

The desired trajectory for each joint (θ(t)) can be predefined based on the pick-and-place task requirements. These trajectories are typically planned using techniques like motion planning algorithms or inverse kinematics.

Through mathematical differentiation of the planned trajectories (θ(t)), the corresponding angular velocity profiles (ω(t)) for each joint can be obtained.

D. Block Diagram

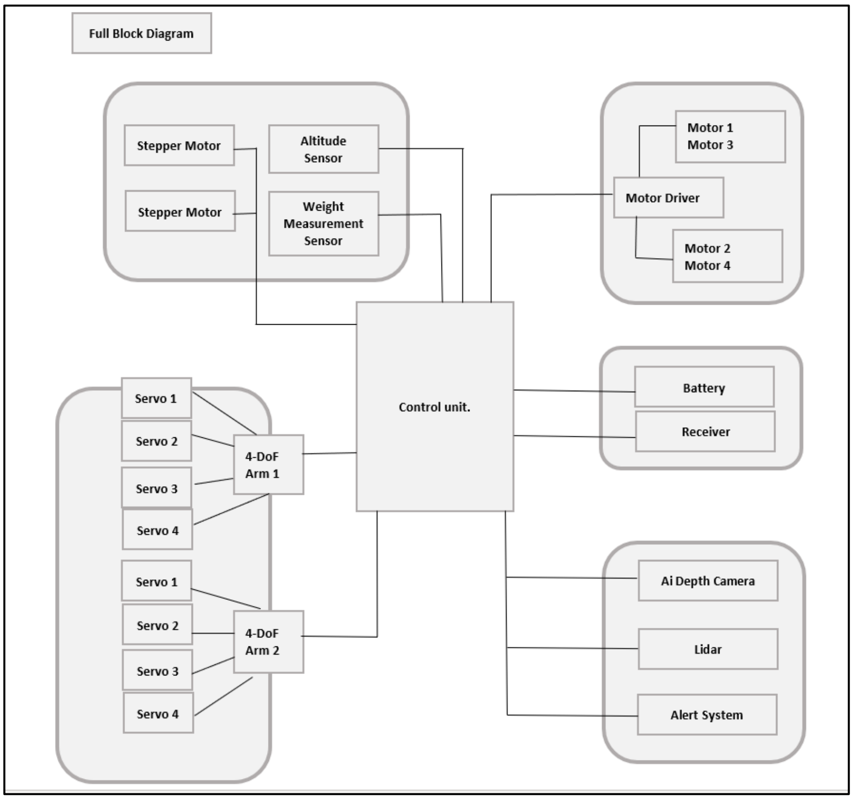


Fig.5 Block diagram of control unit

- Sensors are included in the system to provide feedback on altitude, weight, and depth. These sensors provide data on the position of the end effector of the robotic arm shown in Figure 3.

- Motors including stepper motors and servo motors are responsible for the movement of the robotic arm. The stepper motors provide precise movement while the servo motors provide continuous rotary motion.
- Motor Drivers are electronic circuits that are used to regulate the speed and direction of the motors.
- The Control Unit is the computer or microprocessor that controls the entire robotic arm system. It receives signals from the sensors, processes them, and then sends commands to the motor drivers.
- Battery provides power to the entire system.
- The receiver receives signals from a transmitter and converts them into electrical pulses that can be understood by the control unit.
- 4-DoF Arm 1 and 4-DoF Arm 2 represent the two robotic arms with 4 degrees of freedom each[23].
- Al Depth Camera and Lidar are most likely additional sensors used for depth perception and obstacle avoidance.
- Alert System is likely a security feature that can signal when there are issues with the robotic arm system.

IV. PREPARE YOUR PAPER BEFORE STYLING [DESIGN OF A PICK-AND-PLACE ROBOT]

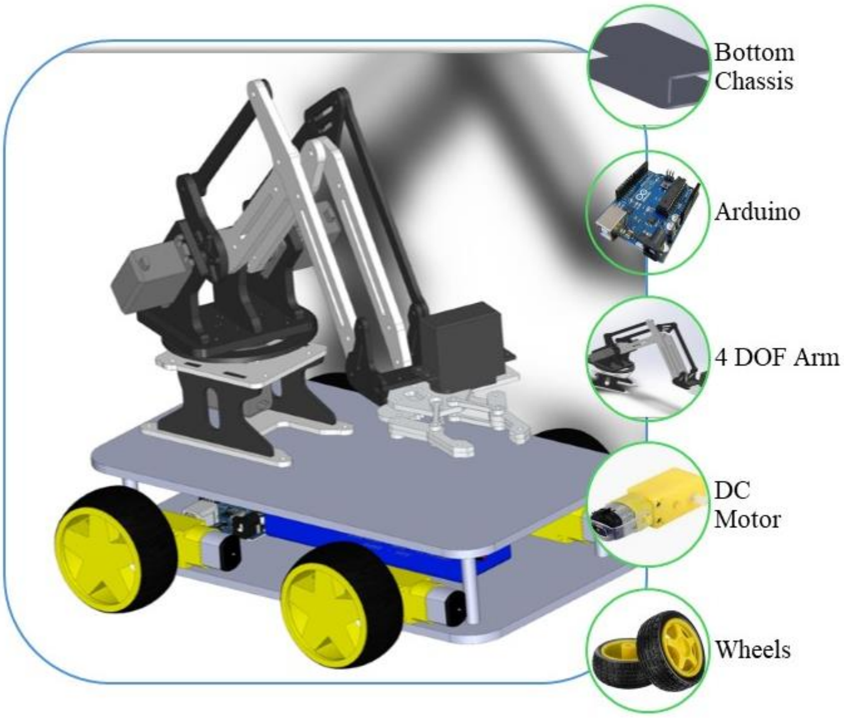


Fig.6 Assembly of pick and place robot

SolidWorks software is what makes this pick-and-place robot a reality. Every piece's design, from the body to the intricate mechanical propulsion, was heavily influenced by concrete functions. The robot's brain is represented by an Arduino microcontroller, which is powered by an 11-volt battery. Servo motors provide the nerves that propel the robot; an Arduino uses precise control over the motors to allow functions to be chosen and configured. Robotic accuracy, easily accessible electronics, and software programming work together to enable the robot to carry out specified jobs.

V. USING THE TEMPLATE [EXPERIMENTAL SETUP AND COMPONENTS]

A. Arduino

While the mathematical modelling and planning provide a foundation for the robot's movement, real-time control during operation necessitates the use of a microcontroller. Arduino, a popular open-source platform, can be effectively integrated into the proposed pick-and-place robot to achieve this real-time control. Arduino can be programmed to interact with various sensors like encoders on the robot's joints. These encoders provide real-time feedback on the actual joint positions, allowing for closed-loop control and ensuring the robot's movements align with the planned trajectories.

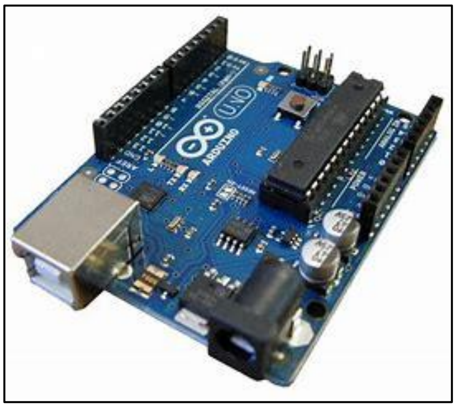


Fig.7 Arduino UNO

The robot's joints are likely actuated by servo motors. Arduino offers libraries specifically designed for servo motor control, enabling the sending of precise control signals based on the calculated joint positions. The robot's vision system, potentially a Raspberry Pi camera as mentioned in the methodology section, can communicate with the Arduino using serial communication protocols. This allows the Arduino to receive object location data and adjust movement accordingly. If the octopus tentacle-shaped end effector utilizes controllable suction or variable tentacle configurations, Arduino can be programmed to receive commands from the main control unit and translate them into control signals for the end effector's actuation mechanisms.Arduino enables real-time adjustments to the robot's movement based on sensor feedback, enhancing accuracy and precision during operation. Arduino's open-source nature and readily available libraries make it a cost-effective and user-friendly solution for real-time control. The Arduino platform can be easily adapted to accommodate future modifications or upgrades to the robot's functionalities.

B. Servos

The proposed pick-and-place robot relies on precise joint movements to achieve accurate manipulation of objects. Servo motors provide a crucial actuation mechanism for realizing this precise control. Unlike conventional DC motors, servo motors incorporate a control loop mechanism. This loop integrates a position sensor (e.g., potentiometer) and a motor driver circuit. The position sensor continuously feeds back information about the current joint angle to the control circuit. This circuit compares the desired angle (received from the control program) with the actual angle and sends corrective signals to the motor driver. The motor driver then adjusts the motor's power and direction to minimize the difference between the desired and actual positions.

Fig.8 Servo motor

Servo motors ensure the robot's joints reach and maintain the planned angular positions with high accuracy, crucial for grasping and placing objects securely. Consistent and repeatable movements are essential for reliable operation in a warehouse environment. Servo motor's closed-loop control promotes consistent positioning across multiple pick-and-place cycles. Servo motors allow for controlled variation in joint speeds during movement. This enables the robot to handle delicate objects carefully while maintaining efficiency for sturdier items.The torque requirement depends on the weight and size of objects the robot needs to manipulate. The servo motor's torque rating should comfortably exceed the maximum anticipated load for each joint. The desired speed of each joint movement should be considered. While faster speeds can improve overall task execution time, slower speeds might be necessary for delicate grasping or precise positioning. The robot's design dictates the required range of motion for each joint. Servo motors come with varying rotation ranges and selecting motors that meet or slightly exceed the needed range is recommended.

C. Motors

The discussion around actuation in the pick-and-place robot has focused on servo motors due to their precise control capabilities. However, it's worth mentioning DC motors as a potential alternative, particularly for applications with less stringent positioning requirements or for cost-centric designs. Unlike servo motors, DC motors offer a simpler and more cost-effective actuation solution. They consist of a rotating shaft and windings that generate torque when supplied with DC voltage. The speed of the motor is primarily dictated by the voltage applied.While DC motors provide a basic actuation mechanism, their inherent limitations make them less suitable for the proposed robot's core functionalities. DC motors lack a built-in feedback mechanism. The control system cannot directly determine the exact joint position, leading to potential inaccuracies and inconsistencies in movement. While the voltage can influence speed to some extent, precise speed control becomes challenging with DC motors, potentially hindering smooth and controlled object handling.

Fig.9 DC motors

Despite their limitations, DC motors could be considered for specific scenarios within the robot's design. For functionalities where, precise positioning is not critical, such as operating fans or gripper actuation mechanisms with simple on/off control, DC motors might be a viable option due to their lower cost. During initial development and prototyping stages, DC motors could be used for basic movement testing before integrating servo motors for final implementation. If DC motors are used, a more sophisticated control system would be necessary to compensate for the lack of precise position feedback. This control system might involve. Adding encoders to the motor shafts would provide some level of position feedback. The control system could then utilize this feedback to implement basic closed-loop control strategies, although achieving the same level of precision as servo motors would remain challenging. Monitoring the motor current can offer indirect insights into the motor's load and potentially aid in regulating speed to a certain extent.

VI. RESULTS

Fig.10 Side view of pick and place robot

pick-and-place robot prototype, which is run by an 11-volt battery and an Arduino controller, has demonstrated encouraging performance. It efficiently carries out the task of choosing and positioning objects at a designated location under the direction of a servo motor. However, higher lifting strength, more precise calibration, and setup are required for real-world applications to be handled effectively. To enhance traffic, future iterations will concentrate on independent direction. Although the core idea is reflected in this prototype, further work is required to ensure precise and effective resource usage as well as maximize its utility for warehouse operations.

Fig.11 Isometric view of Pick and place robot

A. MATLAB

Matlab Code: Joint Angles And Velocities

```
clear all;
close all;
L1 = 1.5; L2 = 16; m1 = 1; m2 = 1; g = 9.81;
theta1 = 0.1; theta2 = 0.2; theta1_dot = 0; theta2_dot = 0; dt = 0.01;
accelerations = @(theta1, theta2, theta1_dot, theta2_dot) ...
    [(-m2*L2*theta2_dot^2*sin(theta1 - theta2) - (m1 + m2)*g*sin(theta1)) / ...
    (m1*L1+m2*L1*L1-m2*L1*L2*cos(theta1- theta2));
    (m1*L1*(theta1_dot^2*sin(theta1 - theta2) - g*sin(theta2)) + ...
    m2*L2*theta2_dot^2*sin(theta1 - theta2)) / ...
    (m1*L1 + m2*L1*L1 - m2*L1*L2*cos(theta1 - theta2))];
t = 0:dt:10;
theta1_vals = zeros(size(t));
theta2_vals = zeros(size(t));
theta1_dot_vals = zeros(size(t));
theta2_dot_vals = zeros(size(t));
for i = 1:length(t)
    theta1_vals(i) = theta1;
    theta2_vals(i) = theta2;
    theta1_dot_vals(i) = theta1_dot;
    theta2_dot_vals(i) = theta2_dot;
    accelerations_val = accelerations(theta1, theta2, theta1_dot, theta2_dot);
    theta1_dot = theta1_dot + accelerations_val(1) * dt;
    theta2_dot = theta2_dot + accelerations_val(2) * dt;
    theta1 = theta1 + theta1_dot * dt;
    theta2 = theta2 + theta2_dot * dt;
end
Plot joint angles and velocities
Figure(1)
subplot(2,1,2);
```

In pick-and-place activities, correct camera calibration is critical since mislocalization can have a detrimental impact on job performance. The work reported proposes and develops a marker-less hand-eye calibration approach particularly intended for the pick-and-place task utilizing nonlinear iterative optimization techniques. The vision system employed is a Raspberry Pi camera attached to the robot, which gives the necessary data for further processing[18].

The use of an arm mounted to an inventory pod for carrying orders implies the need for precise control to avoid collision between the racks[40]. To achieve this, it is essential to use more precise sensors and software integrated with artificial Intelligence (AI) that can accurately detect and plan its trajectories. The arm integrated with AI vision camera can scan the QR's specified for different orders to recognize the place and weight of it. In addition, the octopus tentacle-shaped end effector intelligently adapts to the type and weight of the order and adjusts its tentacle shape and suction capacity for precise and safe handling. It uses a separate control system that constantly communicates with the main control unit of the vehicle and intelligently adjusts its shape and ability according to the commands and data from the sensory units.

B. Mathematical Optimization

To solve the problem, we used MATLAB which used the length, weight, and angle at rest position to analyze the arms feasibility and precision. During the tasks, the robot's workspace must be considered.

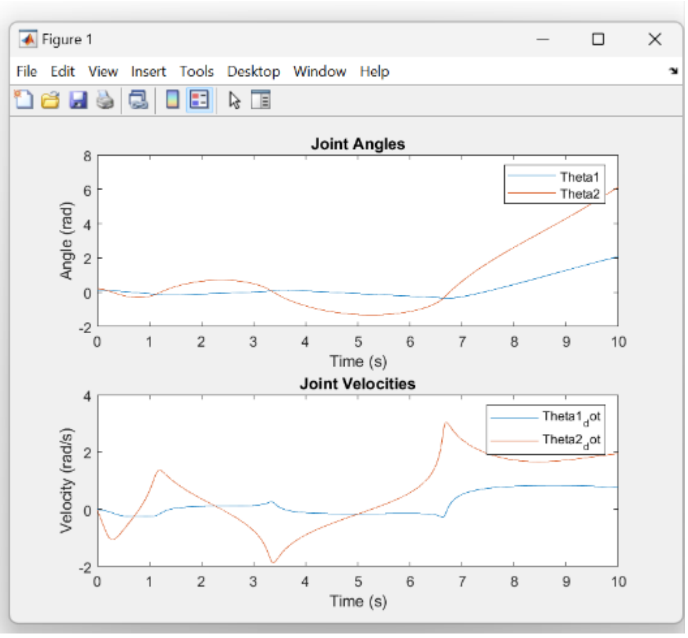


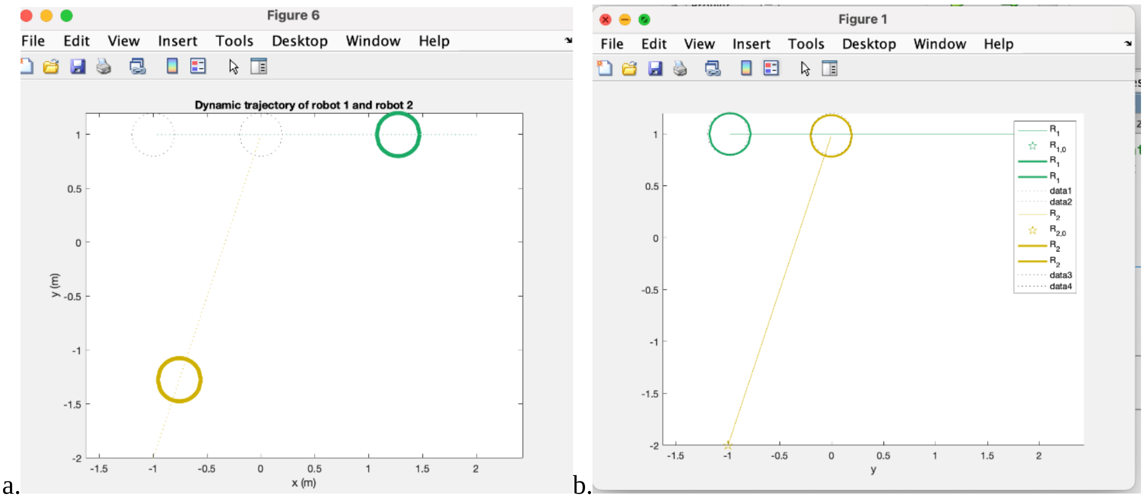
Fig.12 angular velocity of the joint's variation

C. Path Planning Using PSO-Adaptive Intelligence

Particle Swarm Optimization (PSO) has emerged as an effective optimization technique for path planning in mobile robots, especially in complex environments like warehouses. Inspired by the social behavior of birds flocking and fish schooling, PSO operates through a swarm of particles, each representing a potential solution to the path planning problem. These particles explore the solution space, adjusting their positions based on their individual best positions and the global best position discovered by the swarm. The main advantage of PSO lies in its ability to balance exploration and exploitation, leading to the discovery of optimal or near-optimal paths for robot navigation. In warehouse environments, mobile robots are tasked with moving efficiently from a starting point to a target while avoiding obstacles and navigating dynamic layouts. PSO facilitates this by initializing a population of particles that represent potential paths for the robot. Each particle's position corresponds to a point in the warehouse environment, and the fitness of each path is evaluated based on the Euclidean distance to the target. The algorithm uses two key components to update the particles' positions: the cognitive component, which guides particles toward their own best-known position, and the social component, which directs particles towards the best solution found by the swarm. These components are weighted by factors such as cognitive coefficient (\(c1\)) and social coefficient (\(c2\)), allowing the swarm to efficiently explore the search space. Through iterative updates, the particles adjust their velocities and positions to converge toward the most efficient path. The process continues until convergence, where the particles collectively find a solution that minimizes path length, travel time, or other relevant criteria, depending on the specific warehouse robot's goals. The integration of PSO with robot motion planning allows for real-time adaptation to changes in the warehouse layout or dynamic obstacles, making it highly suitable for environments where conditions can change rapidly. PSo's application in warehouse robotics offers several advantages, including adaptability to changes in the environment, efficiency in pathfinding, and the ability to handle multiple objectives simultaneously, such as minimizing travel distance and avoiding collisions. Its parallel exploration nature allows for a diverse set of potential solutions, increasing the likelihood of finding a globally optimal path. Additionally, PSO's flexibility allows it to account for various operational constraints, such as robot size, speed, and battery life, ensuring that the generated paths are not only efficient but also feasible.

Algorithm 1: Particle Swarm Optimization For Mobile Robot

```
Procedure (p,s,c,s,g,l)
Initialize PSO parameters
Initialize best positions and values
For each in i
    cognitive_component = c1 * rand(num_particles, dimensions) .* (best_positions - positions);
    social_component = c2 * rand(num_particles, dimensions) .* (repmat(min(best_values), num_particles, 1) - positions);
    velocity = w * velocity + cognitive_component + social_component; then
    positions = positions + velocity;
    current_values = evaluate_fitness(positions, start_points, target_points);then
end
    best_positions(current_values<best_values) = positions(current_values<best_values);
    best_values = min(current_values, best_values);
function fitness = evaluate_fitness(positions, start_points, target_points)
    distances = sqrt(sum((positions - repmat(target_points, size(positions, 1), 1)).^2, 2));
    fitness = distances;
end
Parameters (Area, dt,k_size, robots)
if x=n
    Add parameters for alpha,v, diff_vel; do and robots with colour [];
end
figure(1)
figure(2) %graph
end procedure
```



a. b.

Fig.13 a.intial point of robot yellow color and green is an obstacle, b. Final positions of robot and obstacle

D. *Interpretation of the Results:*

The plot in Figure 5 showcases the variation in angular velocity of each joint over time. The specific values and variations depend on the planned trajectories and the robot's arm geometry. Here's a general interpretation of possible observations:

i. Peak Values: The peaks in the curves represent the points where the joints experience maximum rotational speed during the movement.
ii. Direction of Motion: The positive values of ω(t) indicate counterclockwise (CCW) rotation, while negative values indicate clockwise (CW) rotation for the corresponding joint.
iii. Joint Coordination: The interplay between the individual joint movements depicted by the curves is crucial for achieving the desired end-effector motion for grasping and placing objects.

E. *Comparison*

Feature	Traditional Pick and Place	Proposed Pick and place
Design of Arm	Typically, 4-DoF for basic movement and cost optimization	6-DoF collaborative arm for enhanced flexibility and adaptability
End Effector	Rigid grippers or suction cups, limited adaptability	Octopus tentacle-inspired flexible end effector for diverse object handling
Item Handling	Limited to specific item shapes and sizes; may damage fragile items	Handles various sizes and weights without damage; adaptable to different shapes
Object Identification	Basic object detection with limited adaptability	Ultrasonic Sensors
Collision Avoidance	Limited collision detection capabilities	Real-time collision avoidance system for dynamic environments
Control System	Static programming, limited real-time adaptability	Continuous communication with control center for dynamic adjustments

CONCLUSION

This work presents an adaptive pick-and-place robot suited for dynamic warehouse situations by stressing the pragmatic design of a 6-DoF robotic arm with a flexible, octopus tentacle-inspired end effector. Because of its modular end effector, which lets the robot escape the constraints of conventional grippers, it can readily handle a broad range of object sizes and shapes without damage. The PSO algorithm optimizes arm trajectories, ensuring accurate, efficient movement within workspace constraints, while ultrasonic sensors provide essential real-time feedback for object detection and safe navigation. This improves operating safety and handling precision. Recent developments in fields such enhanced motion planning, instantaneous collision avoidance, and object recognition utilizing artificial intelligence-driven vision systems provide a strong automation alternative. The robot may instantly change its form and suction to satisfy the needs of any task thanks to its fluid connection with the control center. Through reduced processing times for orders and operating expenses, this ground-breaking concept has the potential to significantly enhance warehouse automation. Future research may focus on enhancing the control algorithms of the tentacle-shaped end effector and extending AI capabilities to enable difficult judgments in more sophisticated warehouse situations. Successful use of this technology marks a major stride forward in the evolution of smarter, more flexible robotic systems for utilization in warehouses and beyond.

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The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression, "One of us (R.B.G.) thanks . . ." Instead, try "R.B.G. thanks". Put applicable sponsor acknowledgments here; DO NOT place them on the first page of your paper or as a footnote.

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