# Autonomous Robotic Arm for Pick & Place Application

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K E Y W O R D S

Pick and Place Robotic Arm
Computer Vision
Image Processing
Efficient Automation Solution
Control Algorithms

A B S T R A C T

The pick and place robotic arm stands as a versatile and efficient automation solution, widely adopted in manufacturing and industrial settings. This abstract delves into the design, control, and automation aspects of a robotic arm system capable of autonomously picking and placing objects by discerning their characteristics. Utilizing advanced sensors, actuators, and control algorithms, the system achieves precise manipulation of objects with diverse shapes, sizes, and weights. Challenges associated with the mechanical structure of the arm, intelligent control strategies, and the integration of computer vision for object recognition are explored. The arm finds applications in various industries such as assembly, packaging, and logistics, enhancing productivity, reducing human intervention, and improving operational efficiency. The incorporation of computer vision expands the robot's potential scope by enabling it to cover a designated area, picking objects from a trolley, and automatically placing them using a vacuum gripper. Additionally, robotic arms play a crucial role in minimizing human errors and enhancing efficiency, productivity, and precision in industrial operations, especially in harsh conditions where human intervention is risky. Being a part of Flexible Automation, robotic arms can be easily updated and modified, facilitating continual improvement in performance. Drawing insights from existing research papers, we leverage this knowledge to design an autonomous robotic arm prototype. This prototype is equipped to detect objects, recognize optimal placement positions, and execute tasks autonomously. Utilizing 3D printing technology, control systems, and advanced computer vision concepts, the prototype serves as a practical demonstration of the theoretical concepts explored in this research paper.

## 1 Introduction

The application of robotics field is broadly used in the laboratory based on work, industrial work to automate process and reduce the human errors. In the field of robotics the beginner can contribute many functional operations in the world. The robotic arm can solve many human's limitations. Many people cannot move from one place to another place from their limitation. When they use this type of robot they can solve their problem easily without help other person for its easy operational system. For an example, when a person is working in a wearhouse and that person needes to carry an object/some packages from one place and place to another place can use these autonomous robots. These robot can recognize the object autonomously using capturing images by camera. It will captures the images as per the programmed algorithms and sends to the controller. It will send actions to the respective actuators like motors etc. And it will perform a task accordingly. So, we need to design of mechanical structure of a robotic arm. This robotic arm is often indicated to move an object from one place to another place. It will prefere the industrial area where need to move a weighable object like packages or any boxes in the wearhouse . The advantage of automated process results is faster completion time with lowest errors. The productivity also increases with using this automatic robotic system. This system operated totally automated. The main objective of project is implementing the technology is to increase the quality of human life and decrease the physical as well as mental strain. It is an interdisciplinary approach of dealing with the mechanical applications of mechanical mechanisms for the kinematic motions of the robotic arm, electronics engineering for automate the system and computer science algorithms which is used to guide the path of arm and to locate accurately location of object by using computer vision concept. These all aspects has been used in this project to increasing requirement of automation. This system reduces the human efforts, increase productivity, increase efficiency of system, increase accuracy of operation and make the process more streamline.

Problem Statement: With e-commerce companies using complex automation systems to scale for customer demand, there are still multiple areas that require human intervention. Sortation is a huge problem statement for all e-commerce companies. To ensure packages reach over 19,000 pin codes in India, massive automation systems are employed by all companies. However, one area that still faces challenges is essentially the act of "Automated Singulation". Picking up a parcel from a bulk of shipments and putting it in the drop zone.

### 1.1. Features of Autonomous Robotic Arm

This Autonomous Robotic Arm system typically comes with several features to perform its tasks efficiently.

**Autonomous:** The robotic arm is capable of operating independently without involving human intervention. It can perform tasks based on pre-programmed instructions or by using sensors to perceive and adapt to its environment.

**Vacuum Gripper:** The vacuum gripper is a specialized tool attached to the end of the robotic arm. It uses suction to securely grasp and lift objects of various shapes, sizes, and weights.

**Sensors:** The robotic arm is equipped with various sensors such as cameras, proximity sensors. These sensors help the arm perceive its surroundings, detect objects, and determine the best approach for gripping and manipulating them.

**Collision Detection:** Advanced robotic arms have built-in collision detection systems to prevent accidents or damage to objects and equipment in their near area . These systems can automatically adjust the arm's trajectory or stop its movement if it detects an obstacle.

**Positioning Accuracy:** Precise control over the arm's movements ensures accurate positioning of the gripper relative to the target object. This enables the robotic arm to pick up and place objects with high precision.

**Adaptive Gripping:** The vacuum gripper may have adjustable settings to accommodate different types of objects or surfaces. It can adapt its gripping force, suction level, or gripper configuration based on the characteristics of the object being handled.

### 1.2. Advantages & Limitations

❖ **Advantages -**

- It performs task faster than human to increase productivity thus it also reduce labor cost.
- As it made to do work automatically, it is quite useful for repetitive task.
- Due to its high accuracy and precision it reduces or may not contain any human error.
- To increase versatility, robotic arm can be programmed to perform complex task.
- Robotic arm help to save time and improves accuracy and precision which results high quality output, thus leads to higher efficiency.

❖ **Limitations –**

- As per market requirement automatic equipment are in more demand therefore robotic arm leads to high initial cost for purchasing.
- Robotic arm is designed for specific task and it requires programming for different application hence it has limited flexibility.
- It is not suitable where decision making is needed or any human interaction.
- Requires skilled programming and by a skilled programming to ensure its optimal performance.
- To make sure it's efficient working, regular maintenance and upgrades is necessary.

### 1.3. Challenges faced by the industries on inventory management:

1. Inaccurate Object Recognition
2. Complex Environment
3. Variable Object Orientation
4. Speed and Efficiency
5. Adaptability to Different Packages
6. Environmental Factors
7. Safety Concerns
8. Maintenance and Downtime
9. Cost Considerations
10. Above factors are involved in inventory packaging and drop zone management in industries. There are several objects having different shapes and sizes with their variety of weights. It is very necessary to segregate the packages as per their category. but traditional methods relying on human labor can be inefficient, costly, and require skilled workers. To reduce the cost and increase the productivity of the operation the automatic system is needed.

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## 2. Methodology

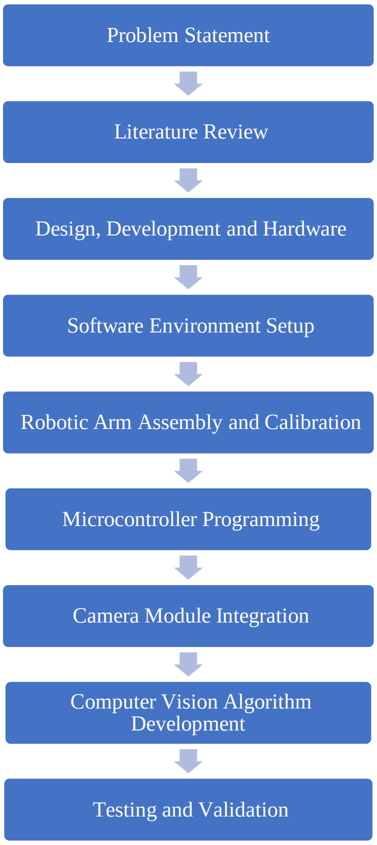



Fig. Methodology of Problem Solving

### 2.1. Design and Manufacturing

The Purpose of designing 3D printed robotic arm for pick and place purpose is to increase the efficiency of warehouse. As it is made to do automatically it is quite useful for repetitive task, so we have designed this robotic arm as a cobot of humans so that the process of sorting goods and packages can be carried out for 24 hrs. The overall manufacturing of robotic arm is done by additive manufacturing technique to minimize the cost and waste which contribute to reduce overall carbon footprint from manufacturing processes. The design involves creating several parts including joints, arms, and grippers. These parts are connected together to form a flexible arm that can move in different directions. We made sure the arm is lightweight yet strong enough to carry objects. We also designed it to be precise so it can pick up items accurately. The advantage of using 3D printing is that it allows us to customize the design easily and quickly. Plus, it's cost-effective compared to traditional manufacturing methods.

Overall, our robotic arm design using 3D printing technology is efficient, customizable, and suitable for various pick and place tasks and overall working area of our robotic arm if 2*2 feet in which arm will scan the barcodes and sort the packages.

❖ Conceptual Drawing-

As per the problem statement, the first task is to create a conceptual design that clarifies the basic structure of the robotic arm. The robotic arm is designed based on standardized configurations such as Cartesian, Cylindrical, SCARA, Articulated, Spherical, etc. The specific configuration is selected according to the application's requirements. For our application, we are choosing the articulated configuration, which will provide the required degrees of freedom, kinematics, and the correct space-occupying structure within the constraints.

Fig.2: Articulated configuration for Robotic Arm

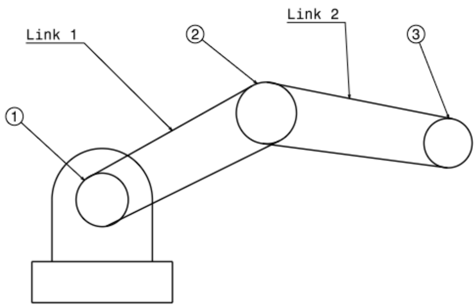
Benefits of articulated configuration:

- Articulated arms typically have multiple joints, providing greater flexibility in reaching various points within the workspace from different angles and orientations.

- The multiple degrees of freedom (DOF) in articulated arms allow for intricate and complex motions, enabling them to perform a wide range of tasks with precision

- With articulated joints, the robotic arm can extend, retract, and pivot its segments to cover a larger workspace efficiently, maximizing its operational range without compromising accuracy or speed.

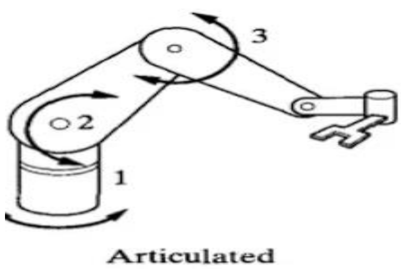
- Articulated robotic arms can be scaled up or down to meet the specific requirements of different applications. Whether it's a small-scale assembly line or a large-scale manufacturing facility, articulated arms can be customized to fit the size and scope of the operation, providing scalability and flexibility in deployment.




Above figures show about the conceptual drawing of robotic arm. Having 4- Joints, 2- Links, 1-End effector.

Based on the problem statement, the working space area is approximately 0.5 meters by 0.5 meters. Therefore, we need to design a robot that operates within this specific area. The length of the robotic arm should cover the entire workspace area and perform tasks smoothly. If the length of the robotic arm is 1 meter, it will cover the entire workspace area and execute the specific tasks within the constraints.

Fig.1: Conceptual Drawing of Robotic Arm

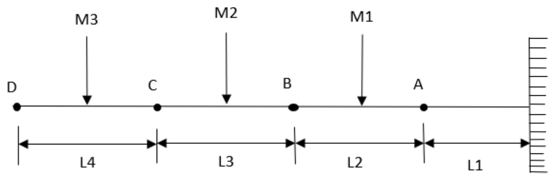


### 2.2. Design Calculations

To calculate output required torque to lift a load on a particular point:

For calculating required output torque, we are using some mechanics theory of beam. In which by considering applying forces or loads on particular points we are calculating the moments which result gives a torque. Due to this, we can observe the theoretical calculations such as moments, forces of a particular sections on which basis we can decide the components selection.

Torque Calclusions:




- **Given Data:**

L1 = 45.73 cm, L2 = 45.72 cm,

L3 = 45.72 cm, L4 = 30.48 cm,

M1 = 1.5 kg, M2 = 1.5 kg, M3 = 1 kg

- **Solution:**

**1.** Moments about point A:

A= [(B×L2) - (M1×L2/2)] - [C×(L3+L2)] - [M2×(L3/2+L2)] - [D×(L4+L3+L2)] - [M3×(L4/2)+L3+L2]

A= (0.363x45.72) - (1.5x 45.78/2) - [(0.290 x (45.73 +45.72) × (1 x 45.72/2+45.72)] - [0.290x (45.72+45.72+30.98)] - [1x (30.48\2 + 45.72 +45.72)]

| A= 252.79 kg.cm = 30.98 N.m.~35 N.m. |
|---|

2. Moment about Point B:

B = (M2×L3/2) - (C3×L3) - (M3×(L4/2+L3)-D×(L3+L4)

B = (1×45.72/2) - (0.290×45.72) -(1×30.48/2+45.72) - (0.290×30.48+45.72)

| B = 763.43 kg.cm = 7.20 N.m.~10 N.m. |
|---|

3. Moment about Point C:

C =(M3×L4/2) - (D×L3)

| C =1.9812 kg cm = 1.299 N.m.~2 N.m. |
|---|

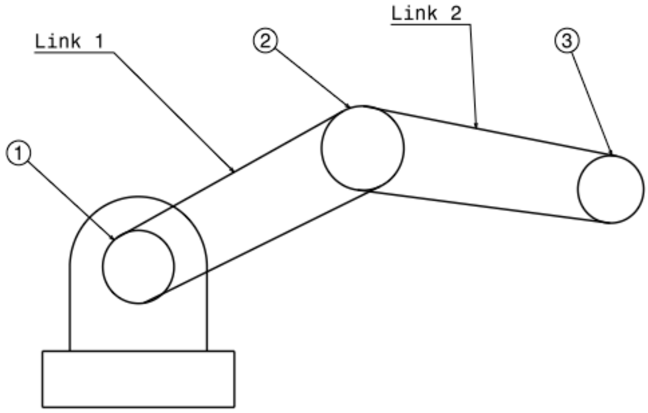
On the basis of theoretical calculations, the required output torque is calculated at a particular point which is considered as the points of the robotic arm at which the torque is required to lift the load. The required torques are as follows:

At point A: Torque at base to lift or rotate a robotic arm = 35 N.M.

At point B (1): Torque to lift a shoulder = 21 N.M.

At point C (2): Torque to lift forearm = 8 N.M.

At point D (3): Torque required is 1 N.M.




### 2.3. Gearbox calculations for reduction to get required output:

On the basis of torque calculations, the motors are selected as per the specifications which gives a required output torque such as:

Planetary Gear Motor (12V DC 2NM torque)

Stepper Motor 1 (NEMA 23 23 KG-CM torque)

Stepper Motor 2 (NEMA 17 8 KG-CM torque)

Servo Motor MG995 (180 deg rotation) & (360 deg rotation)

For base, we are using Planetary gearmotor having 2 NM torque and 435 rpm. but for base required torque is about 35 NM. So, we required gear reduction box to increase torque and decrease the rpm of motor for archiving the required output torque.

Similarly, for shoulder we are using stepper motor neema-23 having 2.3 NM torque and we required for 21 NM torque. So here is also requirement for the reduction of gears box system.

Gear Reduction Clculations:

1. For base gearbox calculations:

- Given data:

Required Torque = 35Nm,

RPM of motor, N1= 435rpm,

Torque of Motor = 2Nm

- Solution:

a) To calculate gear ratio:

Gear Ratio = (Required Torque/Torque of motor) = (35/2) = 17.5Nm~18

Therefore, the required gear ratio for the base is 18.

b) For calculate the no. of teeth on gears:

Pinion gear, Z1 = 10 teeth's

Gear, Z2 = 180 teeth's

So, by calculating the gear ratio from this,

Gear ratio = Output gear teeth/ Input gear teeth = 180/10 = 18

c) For calculate the rpm of output gear:

G = N1/N2

N2 =435/18

N2 = 24.16 ~ 25rpm

Therefore, when gear having 180 teeth's it will generate 36 NM torque with 25 rpm.

d) Calculate the diameter of gears:

For Pinion:

Module = diameter of pinion/number of teeth of pinion

M=d1/Z1

2=d1/10

d1=20mm

Pinion having 20mm diameter with 10 teeth on it.

For gear:

Module = diameter of pinion/number of teeth of pinion

M=d1/Z1

2=d2/Z2

D2= 360mm

Gear having 360mm diameter with teeth on it.

2. For Shoulder gearbox:

- Given data:

Required Torque: 21Nm,

Motor rpm N1: 400rpm

Torque of motor: 2.3Nm

- Solutions:

a) To calculate gear ratio:

(Required Torque/Torque of motor) = (21/2.3) = 9.13Nm~11-(Gear ratio) Therefore, the required gear ratio for the base is 11.

Standard Gear ratio of gear box available for motor =1:10

b) For calculate the rpm for output shaft:

G = N1/N2

N2=400/5

N2= 80 rpm

For calculating gear ratio of 3d printed gears

Pinion: 10 teeth's

Gear: 60 teeth's

So, by calculating the gear ratio from this,

Gear ratio = Output gear teeth/ Input gear teeth = 60/10 = 6

For calculate the rpm of output gear:

G = N1/N2

N2=80/6

N2= 13.33 ~ 14 rpm

Therefore, when gear having 60 teeth's it will generate 21 NM torque with 14 rpm.

Calculate the diameter of gears:

a) For Pinion:

Module = diameter of pinion / number of teeth of pinion

M=d1/Z1 2=d1/10 d1=20mm

Pinion having 20mm diameter with 10 teeth on it.

b) For gear:

Module = diameter of gear /number of teeth of gears

M=d1/Z1

2=d2/60

D2= 120mm

Gear having 120mm diameter with 60 teeth on it.

3.. Elbow Torque calculations:

- Given data:

Required Torque = 5 Nm,

RPM of motor, N1= 400 rpm,

Torque of Motor = 0.8Nm

- Solution:

To calculate gear ratio:

Gear Ratio = (Required Torque/Torque of motor) = (5/0.8) = 6.25 ~7
Therefore, the required gear ratio for the Elbow is 7.

Standard Gear ratio of gear box available for motor =1:10

For calculate the rpm of output gear:

G = N1/N2

N2 =400/10

N2 = 40rpm

Therefore, it will generate 8NM torque with 40 rpm.

Fig: Pinion Gear

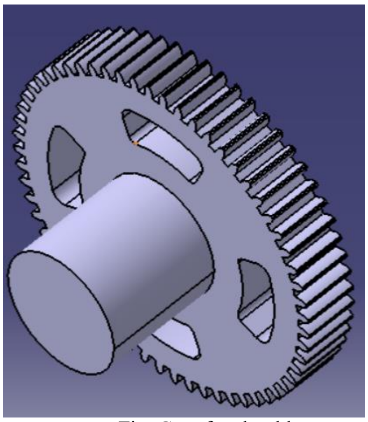


Fig. Gear for shoulder

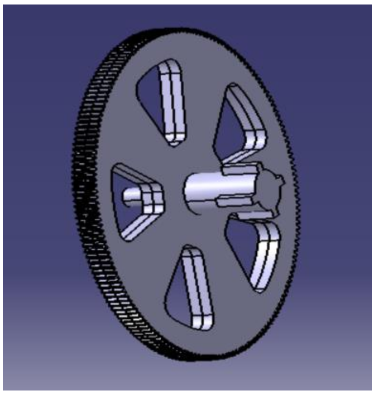


Fig Base Gear

2.3. Manufacturing

Manufacturing is the process of transforming raw material into finished functional products. It includes designing, planning, and assembling using various methods and technologies. The aim is to create durable, efficient, and functional robotic arm to perform specific task in different industry applications. In manufacturing, robotic arms can greatly enhance efficiency, precision, and consistency. It can handle repetitive tasks around the clock without fatigue, reducing the risk of errors and increasing production rates. The robotic arm for pick and place system includes the robotic arm itself, sensors for object detection and positioning, a control system to manage operations, and end effector such as suction grippers to the specific objects being handled. Overall, integrating robotic arms into manufacturing processes for pick and place tasks can lead to improved productivity, cost savings, and a safer working environment.

For our project we used two types of manufacturing processes such as in additive manufacturing process (3D Printing) and in subtractive manufacturing process (Cutting, Drilling, Press Fitting, Surface Polishing etc.)

**Additive Manufacturing Process (3D Printing):** 3D printing, also known as additive manufacturing, is a transformative technology that creates three-dimensional objects by layering materials based on digital designs. This innovative approach enables faster prototyping, customized production, and optimized designs previously impossible with traditional manufacturing methods.

Parameters used in 3D printing technology for manufacturing process during project:

- Layer Height: 0.2
- Printing Speed:
- Bed Temperature: 60 Deg
- Extruder Temperature: 210 Deg
- Infill Density:
- Shell Thickness:
- Supports: Automatically developed by software
- Raw Material used: PLA Filament
- Nozzle Diameter: 0.6
- Filamet Diameter: 1.75

**Subtractive Manufacturing Processes:**

Cutting Process: The cutting process is a subtractive manufacturing technique used to shape materials by removing unwanted sections. We used cutting process for cutting PVC pipes as per the requirement of the length of the pipe and cutting unwanted part from the 3d printed components as well.

Drilling Process: The drilling process is employed in subtractive manufacturing. We used this process to create holes in the 3d printed parts. Drilling process used for making holes in 3d component to joined two similar components by using nut bolts.

Press fitting is a method used to assemble parts by pressing them together with a force. press fitting can be used to secure bearings into 3D components. This ensures that the bearings are firmly attached and can handle the loads and movements associated with the robotic arm's operation. Proper press fitting techniques are essential to ensure accuracy, alignment, and the longevity of the robotic arm's components.

Surface Polishing: This method used to polish the 3d printed parts which are manufactured having poor surface finishing over the parts. So, to remove that impurities polish paper are used.

| Software | Hardware | Material |
|---|---|---|
| Catia – For 3D modelling | Ardunio | PLA for 3D printing parts |
| ROS (Robot Operating System) | Planetary Motor (12V DC, 2Nm Torque) | Stainless steel bearings |
| MATLAB - For Making URDF model | Stepper motor (Neema-23, 60kgcm torque) | Wooden block |
| Arduino UNO - Controlling motor | Stepper motor (Neema-17, 45kgcm torque) | |
| Ansys - For Analysis of mechanical components | Servo motor MG99 (180 deg rotation) | |
| | Stepper motor driver | |
| | BTS7960 motor driver and rotary encoder | |
| | Suction motor, pipe and suction cup | |
| | Reduction of 1:10 for stepper motor | |
| | Ball Bearings | |

Table: Specifications Required

## 3. Final Design

Summary of Project Assembly

The assembly of the autonomous robotic arm for pick and place is structured around a combination of innovative components with their materials to achieve functional robotic arm and efficient work output. The assembly of our autonomous robotic arm combines PVC pipes as links for structural support with 3D-printed components joints for precision. The supportive base is a made by wooden box, that box provides support to the entire arm fixes at a particular location and there is also placement for reduction of gearbox to rotate the arm from the base as well. While the arm segments (Shoulder Joint, Elbow Joint 1&2, wrist) are crafted using 3D printing technology for optimized design and accuracy. The end effector is equipped with a suction gripper featuring suction cups for efficient object handling. To enhance torque and lifting capabilities, gear reduction mechanisms are integrated into the base and shoulder segments. This assembly design results in a robust robotic arm optimized for reliable pick and place operations. . This setup enhances the arm's capacity to handle heavier loads while maintaining smooth movements. Overall, the assembly combines robust construction with advanced features, resulting in a versatile robotic arm.

- Supporting Box (Base)
- Shoulder Link
- Shoulder Joint
- Bicep Link
- Elbow Joint-1
- Elbow Joint-2
- Forearm Link
- Suction Gripper
- Above Components are designed and manufactured based upon the requirement and calculations. The detailed drawings of the components are given below with their 3D view.

### 4. Algorithms

Classification and recognition algorithms play a crucial role in the automation of pick and place tasks in warehouses and industrial settings. In the context of package handling, these algorithms are used to identify and categorize objects, enabling robotic systems to autonomously locate, grasp, and move packages with precision and efficiency. Here's a brief description of how classification and recognition algorithms are applied in this scenario:

- Object Detection: Object detection algorithms are used to locate and identify packages within the warehouse environment. These algorithms analyze images or sensor data to detect the presence of packages and determine their positions within the workspace. Common techniques for object detection include convolutional neural networks (CNNs), which can learn to recognize objects based on their visual features.
- Object Classification: Once packages are detected, classification algorithms are employed to classify them into different categories or types. This is essential for sorting and organizing packages based on various criteria such as size, shape, weight, or content. Classification algorithms utilize machine learning models trained on labeled datasets to assign labels or categories to detected objects accurately.
- Instance Segmentation: In scenarios where multiple packages may overlap or occlude each other, instance segmentation algorithms are utilized to separate individual instances of objects within the scene. These algorithms not only detect objects but also delineate their boundaries, enabling precise localization and manipulation by robotic systems.
- Pose Estimation: Pose estimation algorithms determine the spatial orientation or pose of packages within the environment, providing information about their position, orientation, and alignment. This information is crucial for robotic arms to plan and execute grasping and manipulation tasks effectively. Pose estimation algorithms may employ geometric methods, feature-based approaches, or deep learning techniques to estimate object poses accurately.
- Object Recognition: Object recognition algorithms identify specific objects or patterns within the detected packages, enabling the system to make informed decisions based on object attributes or characteristics. For example, barcode or QR code recognition algorithms can read and interpret information encoded on package labels, facilitating inventory management, tracking, and sorting processes.

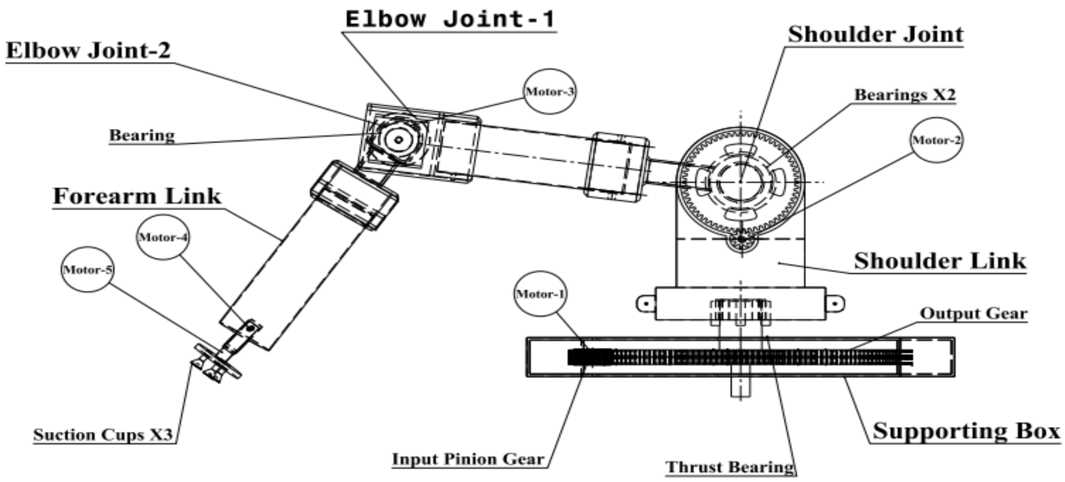



Fig. Robotic Arm Structure

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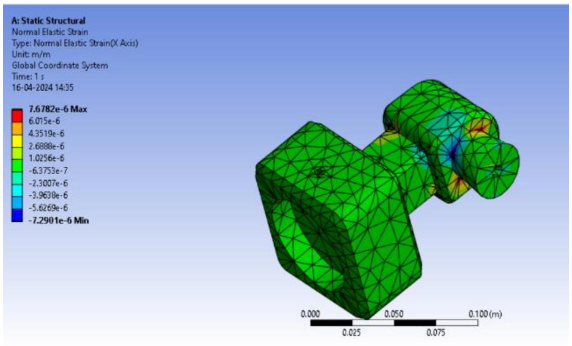
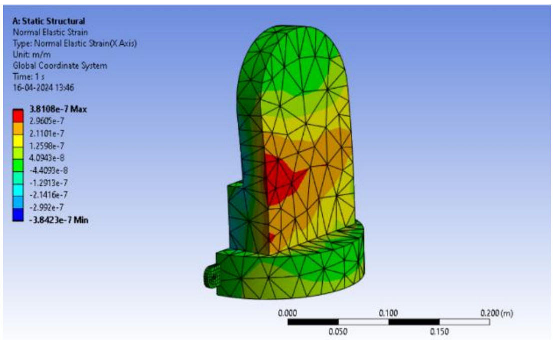
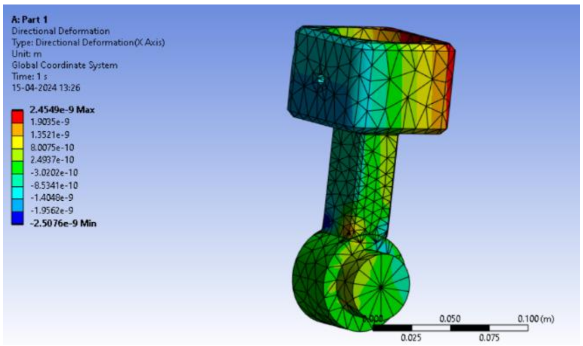
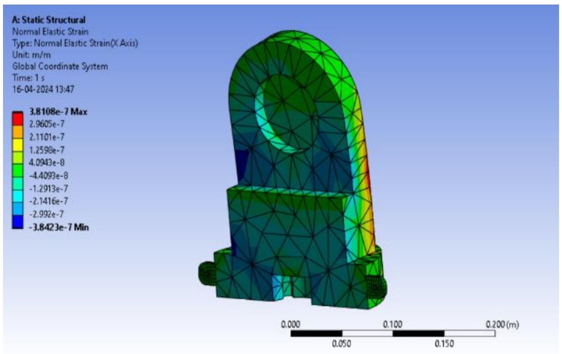
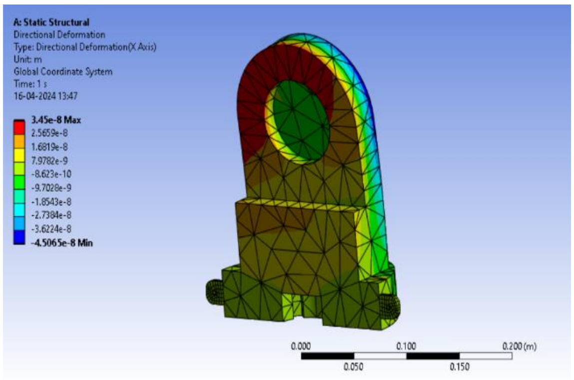
## 5. Analysis



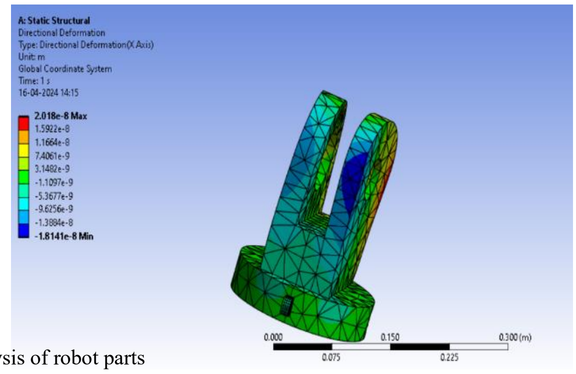




Fig. Analysis of robot parts

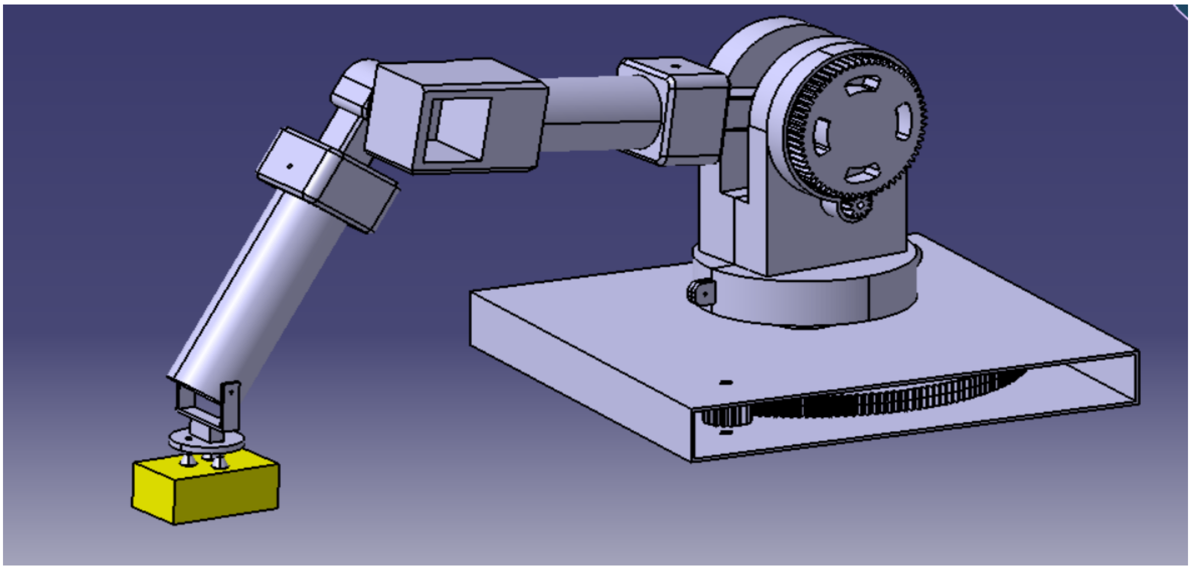


Fig. Final Designed Model of Robotic Arm

## 6. CONCLUSION

The development and implementation of an autonomous robotic arm for pick-and-place application in a warehouse, where it separates packages from a trolley using computer vision for object detection and accurately places them at the correct location in a drop zone. The robotic system automates the process of segregation of packages from the bulk of boxes or packages in the trolley. The computer vision is the advanced technology which is used to recognize the robot to detect the object which should be pick up from one place and place to the drop zone. This system is replicable to the human beings and will increase the work productivity. The use of an autonomous robotic arm with computer vision for package separation and placement in a warehouse environment represents a significant advancement in warehouse automation. It improves efficiency, accuracy, and safety while also offering scalability for growing operations. However, it requires careful planning, investment, and ongoing maintenance to ensure its continued success and adaptability in a dynamic warehouse setting.

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