DESIGN AND DEVELOPMENT OF COLLABORATIVE ROBOT (COBOT)

Project submitted

in partial fulfilment of requirements

for the award of degree of

Bachelor of Technology

in

Mechanical (Robotics)

by

Tirumala Durga Sai Priyanka (Regd. No: 21131A5334)

Kotamsetti Yaswanth (Regd. No: 22135A5306)

Pottelu Shyam Sai (Regd. No: 21131A5329)

Chinta NSR Shanmukha Teja (Regd. No: 21131A5309)

Under the esteemed guidance of

Dr. Sanjay Krishnarao Darvekar

Associate Professor

COLLEGE OF ENGINEERING
(AUTONOMOUS)

Department of Mechanical Engineering

Gayatri Vidya Parishad College of Engineering, Visakhapatnam

(Affiliated to J.N.T University, Kakinada)

VISAKHAPATNAM – 530 048

March, 2025

CERTIFICATE

This is to certify that the project titled **DESIGN AND DEVELOPMENT OF COLLABORATIVE ROBOT (COBOT)** is a bonafide record of the work done by

Tirumala Durga Sai Priyanka	**(21131A5334)**
Kotamsetti Yaswanth	**(22135A5306)**
Pottelu Shyam Sai	**(21131A5329)**
Chinta NSR Shanmukha Teja	**(21131A5309)**

in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Mechanical (Robotics)** of the Gayatri Vidya Parishad College of Engineering (Autonomous) affiliated to Jawaharlal Nehru Technological University, Kakinada during the year 2024-2025.

Project Guide
Dr. Sanjay Krishnarao Darvekar
Associate Professor
Department of Mechanical Engineering

Head of the Department
Dr. B. Govinda Rao
Professor and Head of the Department
Department of Mechanical Engineering

Project Viva-voce held on___________________

External Examiner

DECLARATION

We hereby declare that this project entitled **"DESIGN AND DEVELOPMENT OF COLLABORATIVE ROBOT (COBOT)"** is a bonafide work done by us and submitted to the Department of Mechanical Engineering, G.V.P. College of Engineering (Autonomous), Visakhapatnam, in partial fulfilment for the award of the degree of B.Tech is of our own and it is not submitted to any other university or has been published any time before.

Tirumala Durga Sai Priyanka	**(21131A5334)**
Kotamsetti Yaswanth	**(22135A5306)**
Pottelu Shyam Sai	**(21131A5329)**
Chinta NSR Shanmukha Teja	**(21131A5309)**

PLACE: VISAKHAPATNAM

DATE:

ACKNOWLEDGEMENTS

We would like to express our deep sense of gratitude to our esteemed institute **Gayatri Vidya Parishad College of Engineering (Autonomous),** which has provided us an opportunity to fulfil our cherished desire.

We express our sincere thanks to **our Dr. A.B. Koteswara Rao, Professor and Principal, Gayatri Vidya Parishad College of Engineering (Autonomous)** for his encouragement to us during this project, giving us a chance to explore and learn new technologies in the form of internship.

We are highly indebted to **Dr. B Govinda Rao, Professor and Head of the Department of Mechanical Engineering, Gayatri Vidya Parishad College of Engineering (Autonomous)**, for giving us an opportunity to do the internship in college.

It is with a sense of great respect and gratitude that we express our sincere thanks to **Dr. Sanjay Krishnarao Darvekar, Associate professor, Department of Mechanical Engineering, Gayatri Vidya Parishad College of Engineering (Autonomous)** for his inspiring guidance, supervision, and encouragement towards the successful completion of our project.

Finally, we would like to express our gratitude to all the faculty members and laboratory technicians of the Mechanical Engineering Department for their valuable insights and support at various stages of this project. Their collective efforts have greatly enriched our learning experience and contributed to the successful completion of this dissertation.

Tirumala Durga Sai Priyanka (21131A5334)

Kotamsetti Yaswanth (22135A5306)

Pottelu Shyam Sai (21131A5329)

Chinta NSR Shanmukha Teja (21131A5309)

ABSTRACT

The transition to Industry 4.0 has highlighted the growing need for collaborative robots (cobots) that can safely and efficiently work alongside humans. Unlike traditional industrial robots, which operate in constrained areas to prevent collisions, cobots enable human-robot collaboration while prioritizing safety. Past incidents of robots harming humans underscore the importance of safer robotic systems. In India, mid and low scale industries face challenges in adopting automation due to the high costs of cobots, as most are imported. These imported robots are often standard models, which may not cater to the specific needs of these industries, further limiting accessibility. To address these challenges, the development of a cost-effective cobot tailored to the requirements of Indian industries.

The project is in collaboration with Dreambots, as the company requires a fully automated kitchen robot with a 3- 4 kg payload capacity, a reach of 700 mm, and medium precision and accuracy. To meet this need, the extensive research on existing cobots and their specifications is conducted. However, due to the evolving nature of cobot technology, available research was limited. As per the industry experts, the most cobots used a dual-encoder system, which ensures compliance and sensor monitoring but significantly increases costs. To make the cobot affordable in India, a single-encoder system is ready to propose in order to reduce its cost by 30% without compromising safety or functionality. The cobot is designed in CATIA V5, achieving a reach of 730 mm and a total height of 961 mm. This design aligns with the requirements of Dreambots and addresses the broader challenge of making cobots more accessible to Indian industries.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

CHAPTER – 1
INTRODUCTION

1.1 What is COBOT?

A cobot (collaborative robot) is a type of robot designed to work alongside humans in a shared workspace. Unlike traditional industrial robots, which operate in isolation for safety reasons, cobots are equipped with sensors, force-limiting mechanisms, and AI to ensure safe interaction with people. They are commonly used in manufacturing, assembly lines, and automation tasks where human-robot collaboration improves efficiency and precision.

Fig. 1. 1 COBOT

1.2 History and Evolution of Cobots

The concept of collaborative robots (cobots) emerged in the mid-1990s as industries sought ways to make automation more flexible and safer for human workers. Traditional industrial robots, which had been in use since the 1960s, were large, powerful, and required safety cages to prevent accidents.

1.2.1 Early Development (1996 - 2000s)

The first cobot was developed in 1996 by J. Edward Colgate and Michael Peshkin, professors at Northwestern University. Their goal was to create robots that could work safely with humans rather than replacing them. These early cobots had no motors and relied on human guidance for movement, acting as intelligent assist devices.

1.2.2 Advancements in Automation (2000s - 2010s)

As sensor technology improved, cobots became more autonomous. Companies like Universal Robots (UR) introduced fully automated cobots with force sensing, which allowed them to stop when encountering obstacles, ensuring human safety. During this period, cobots began appearing in automobile manufacturing, electronics assembly, and packaging industries

1.2.3 Modern Cobots (2010s - Present)

Today's cobots are highly advanced, featuring AI, computer vision, and deep learning capabilities. They can adapt to different tasks, learn from human interactions, and work in various industries, including healthcare, agriculture, and logistics. Unlike traditional robots, modern cobots are affordable, easy to program, and designed for small and medium-sized businesses looking to automate without major infrastructure changes.

1.2.4 Future of Cobots

Cobots are evolving rapidly, with trends focusing on:

- AI-driven decision-making for improved efficiency.
- More advanced human-robot interaction with voice and gesture controls.
- Better mobility with autonomous robotic arms and mobile platforms.
- Increased payload capacities for heavier industrial tasks.

Fig. 1. 2 Evolution of COBOT

1.3 Key features of COBOT

Collaborative robots (cobots) have several key features that make them suitable for working alongside humans safely and efficiently. Here are the main ones:

1.3.1 Safety Features

- Force & Collision Detection – Cobots stop or slow down when they detect unexpected contact.
- Lightweight & Rounded Design– Reduces the risk of injury.
- Speed & Power Limitation– Ensures safe interaction with humans.
- Safe Zone Programming – Restricts movement to predefined areas.

1.3.2 Easy Programming & Deployment

- Drag-and-Drop or Hand-Guided Teaching – Simplifies robot training.
- Intuitive User Interfaces – No complex coding required.
- Quick Setup & Deployment– Faster than traditional robots.

1.3.3 Flexibility & Adaptability

- Multi-Tasking Ability – Can handle various applications (pick & place, welding, assembly, etc.).
- Lightweight & Portable – Easy to move and redeploy.
- Integration with IoT & AI – Enables smarter automation.

1.3.4 Human Collaboration

- Works Alongside Humans – Unlike industrial robots that need cages.
- Assists in Tedious Tasks– Reduces strain on workers.
- Enhances Productivity– Improves efficiency without replacing jobs.

1.3.5 Cost-Effective Automation

- Lower Investment Costs – More affordable than traditional robots.
- Energy Efficient– Consumes less power.
- Minimal Maintenance Required – Designed for long-term usability.

1.4 Applications of COBOT in industry

Cobots are widely used across industries due to their flexibility, safety, and ease of programming:

Assembly & Manufacturing - Cobots assist in assembling products like electronics, automotive parts, and appliances with high precision.

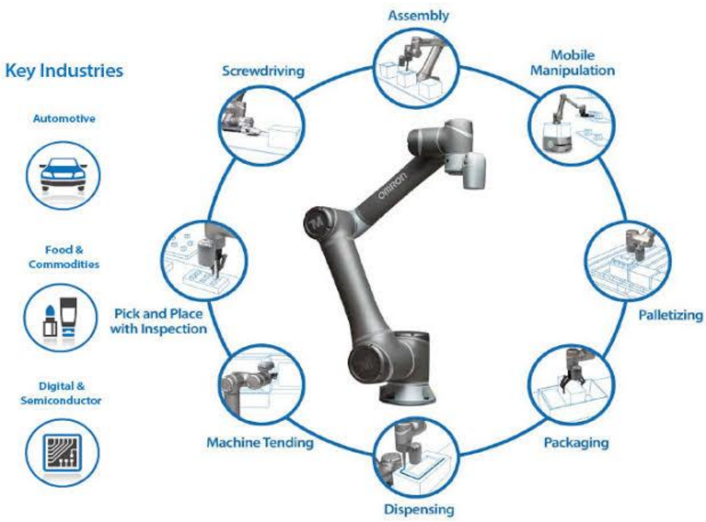

Fig. 1. 3 Applications of COBOT

Pick & Place Operations - Handles repetitive material handling, sorting, and packaging tasks efficiently.

Quality Inspection - Uses cameras and sensors to check for defects in products, improving accuracy and reducing waste.

Packaging & Palletizing - Helps in stacking, packing, and palletizing products, optimizing logistics and supply chains.

Welding & Soldering - Performs precise welding and soldering in industries like automotive, aerospace, and electronics.

Screwdriving & Fastening - Used for assembling products by tightening screws and fastening components consistently.

Gluing & Sealing - Ensures uniform application of adhesives and sealants in manufacturing processes.

Medical & Pharmaceutical Industry - Used for lab automation, handling delicate materials, and even assisting in surgeries.

Agriculture & Food Industry - Automates food packaging, sorting, and handling delicate agricultural produce.

1.5 Advantages & Disadvantages over traditional ROBOT

1.5.1 Advantages of Cobots Over Traditional Robots

Enhanced Safety & User-Friendly Programming

Cobots are designed to work alongside humans with built-in safety features like force detection and collision avoidance, eliminating the need for safety cages. They can be programmed easily through hand-guided teaching or simple drag-and-drop interfaces, making them accessible even for non-experts.

Quick Setup & Deployment

Cobots can be installed and put to work much faster than traditional robots, reducing downtime.

Flexible & Portable

Unlike large industrial robots, cobots are lightweight and can be moved or reprogrammed for different tasks with minimal effort.

Cost-Effective & Space-Saving

They require lower initial investment and have reduced maintenance costs, making automation more affordable for small businesses. Their compact design makes them ideal for small workspaces where large robots wouldn't fit.

Energy-Efficient & Human-Centric Collaboration

Cobots consume less power, helping reduce operational costs. They assist workers instead of replacing them, making jobs safer and reducing fatigue in repetitive tasks.

Fast Return on Investment (ROI) & Easy Integration

Due to their versatility and affordability, businesses see quicker financial benefits from automation. Cobots can be seamlessly integrated into existing production lines and connected with IoT and AI technologies for smarter operations.

1.5.2 Disadvantages of Cobots Over Traditional Robots

Lower Payload Capacity & Slower Speed

Cobots are designed for lightweight tasks and cannot handle very heavy loads like industrial robots. To ensure safety around humans, cobots operate at reduced speeds, which can impact efficiency in high-speed manufacturing.

Less Precision & Not Suitable for Heavy-Duty Applications

While accurate, cobots may not match the extreme precision of high-end industrial robots used in complex manufacturing. They are not designed for tasks requiring high force, extreme temperatures, or harsh industrial conditions.

Higher Cost for Simple Tasks

For very basic automation where safety is not a concern, traditional robots may be a more economical option.

Limited Reach

Cobots usually have a shorter arm length compared to large industrial robots, restricting their range of motion.

Advanced Programming Required for Complex Tasks

While basic operations are easy to set up, complex applications may still require programming expertise.

1.6 Differences Between Cobots and Industrial Robots

Industrial robots have been the backbone of automation for decades. However, their rigid programming, high-speed movements, and safety risks limit their use in environments requiring human collaboration. Cobots, in contrast, offer several key differences:

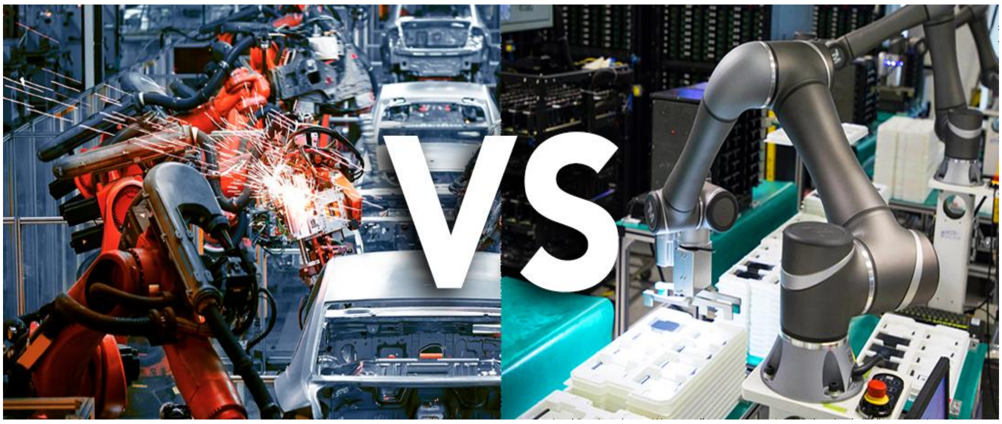

Fig. 1. 4 Comparison of Industrial Robots vs. Cobots

Table 1. 1 Industrial Robots vs Collaborative Robot

Feature	Industrial Robots	Collaborative Robots
Work Environment	Isolated, in safety cages	Works alongside humans
Safety Measures	Requires external safety barriers	Built-in safety sensors and force limiting mechanisms
Flexibility	Fixed automation, limited adaptability	Easily reprogrammable, flexible tasks
Ease of Use	Complex programming, requires experts	User-friendly interfaces, no code/low-code operation
Cost Efficiency	High initial investment, requires safety infrastructure	Lower cost, minimal infrastructure changes

1.7 Human- Robot Collaboration: Benefits & Challenges

Benefits of Human-Cobot Collaboration

Human-cobot collaboration offers numerous advantages, enhancing productivity and safety in the workplace. Cobots are designed to work alongside humans, performing repetitive or physically demanding tasks, which frees up human workers to focus on more complex, creative, or strategic activities. This collaboration enhances efficiency**,** as cobots can handle tasks that require precision and consistency, reducing human error. Additionally, cobots improve safety by taking on hazardous tasks, such as handling toxic substances or working in extreme environments, minimizing the risk of injury for human workers. The flexibility of cobots also means they can be easily adapted to various work environments, creating opportunities for automation in industries such as manufacturing, logistics, and healthcare.

Challenges of Human-Cobot Collaboration

Despite its benefits, human-cobot collaboration comes with its own set of challenges. One of the main obstacles is the need for effective integration between humans and cobots, requiring seamless communication and coordination between both. While cobots are becoming more user-friendly, they still require training and proper programming, which can be a barrier for companies with limited technical expertise. There are also concerns about job displacement**,** as automation could reduce the number of certain manual roles, leading to resistance from workers. Additionally, cobots, though safer than traditional robots, still pose potential safety risks if not properly monitored or programmed, especially in dynamic environments where human actions can be unpredictable. Balancing automation with the need for human oversight and trust in cobots remains an ongoing challenge.

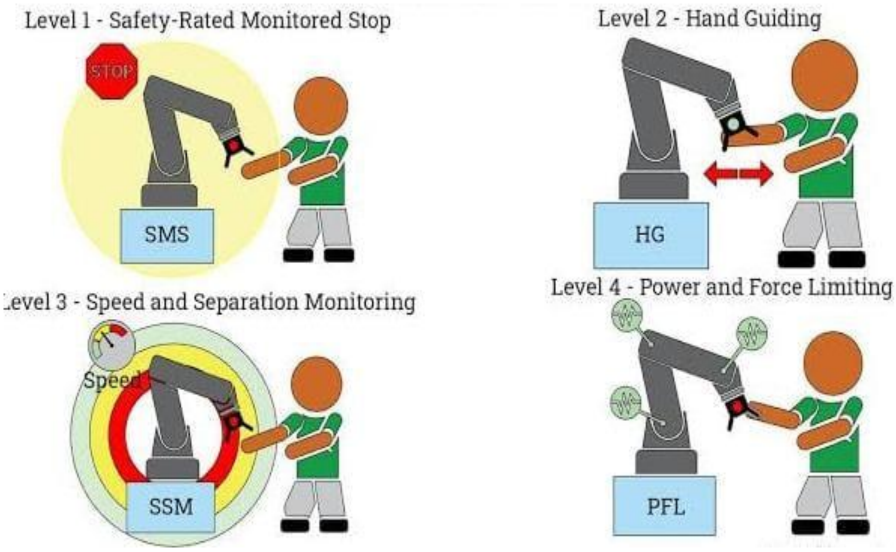

Fig. 1. 5 Human – COBOT Collaboration

1.8 Types of COBOTS

Collaborative Robotic Arms

These are the most typical cobots used in manufacturing. They perform repetitive tasks like assembly, pick-and-place, or machine tending. Their built-in sensors and limited force ensure they can operate in close proximity to humans.

Mobile Cobots

These are also known as autonomous mobile robots (AMRs), these cobots move around factories, warehouses, or hospitals to transport materials or products. They combine navigation algorithms with obstacle detection, allowing them to work seamlessly in dynamic environments.

Wearable Exoskeletons

Rather than replacing tasks, these devices support human workers by augmenting strength and reducing fatigue. Exoskeleton cobots are particularly useful in tasks that require heavy lifting or prolonged physical effort.

Service Cobots

Found in settings such as healthcare, retail, or hospitality, service cobots interact with people. They may help with customer service, deliver items, or provide guidance, combining mobility with human-friendly interfaces.

Hybrid Cobots

These systems blend features of traditional robotic arms and mobile platforms, often enhanced with AI. They adapt to complex tasks by integrating advanced vision, machine learning, and mobility, making them versatile across various applications.

1.9 Future trends in COBOT technology

Cobots are becoming more connected and intelligent. With improved connectivity, they will seamlessly integrate with cloud systems to share data in real time, making them more efficient. Their stronger AI will allow them to quickly learn and adapt to new tasks, improving their performance over time. Better sensors will help cobots detect objects and humans more accurately, ensuring safer and more precise work. They'll also be able to interact with humans more naturally, responding to actions in a way that feels intuitive. Plus, teamwork between multiple cobots will enable them to work together and complete tasks more quickly and effectively.

In the future, programming cobots will be easier than ever, with user-friendly setups that make training simple, even for beginners. Their flexibility will let them move and work across various locations, making them adaptable to different environments. Cobots will also be more energy-efficient, using less power and supporting eco-friendly practices. With customizable solutions designed for specific industries, cobots will meet the unique needs of sectors like healthcare, logistics, and manufacturing. As a result, we can expect wider adoption of cobots across a range of industries, improving productivity and automation everywhere.

1.10 Industry use cases & Real-world examples

Car Manufacturing – Cobots help assemble car parts, tighten screws, and checks for defects.

Electronics Production – Cobots handle delicate tasks like soldering and circuit board assembly.

Medical & Lab Work – Cobots assist in drug handling, lab testing, and even surgeries

Food Processing & Packaging – Cobots sort and pack food items safely

Warehouse & Logistics – Companies like Amazon use cobots to help pick, sort, and move packages efficiently.

Aircraft Manufacturing – Cobots help in precise assembly of airplane parts, similar to Airbus's use of cobots in fuselage assembly.

Retail & Customer Service – Some stores use cobots like SoftBank's Pepper Robot to assist customers and track inventory.

Farming & Agriculture – Cobots help in harvesting, sorting, and monitoring crops

Education & Research – Universities and research centres use cobots for training and experimenting with automation.

Small Business & Custom Manufacturing – Cobots allow small factories to automate without high costs, making production more efficient.

1.11 Challenges & Limitations of COBOTS

- Cobots have limited load capacity, making them suitable only for lightweight tasks and unable to handle heavy-duty industrial work like traditional robots.
- To ensure safety when working alongside humans, cobots operate at slower speeds, which can reduce efficiency in high-speed production environments.
- For basic automation tasks, traditional robots might be a more cost-effective choice compared to cobots.
- Cobots typically have a restricted working range, with shorter arm reach, limiting their ability to handle large or distant objects in big workspaces.
- While cobots are easy to program for simple jobs, complex tasks may still require expert coding and configuration.
- Cobots are designed with force limits to prioritize safety, meaning they lack the strength and force necessary for tasks that require heavy impact or significant power.
- Unlike fully autonomous robots, cobots often need human supervision to ensure smooth operations and make adjustments when necessary.

1.12 Integrating COBOTS into existing workflows

Integrating cobots into workflows requires proper planning for efficiency and safety. The process starts with assessing tasks that can be automated without disrupting operations. A risk assessment ensures compliance with safety regulations. Selecting the right cobot with the appropriate capabilities is essential for smooth integration. Compatibility with existing machinery and software must be ensured. Workstations should be arranged to support human-cobot collaboration safely. Programming should be user-friendly and adaptable to task requirements. Employee training is necessary for effective cobot operation. Regular monitoring and maintenance help maintain performance and prevent breakdowns. Automation should be implemented gradually, starting with simple tasks and expanding over time.

1.13 Market Outlook

The global cobot market is growing rapidly, with a projected CAGR of 30%, driven by increasing automation. SMEs are adopting cobots due to their affordability, flexibility, and ease of use. AI and machine learning advancements are making cobots more intelligent and efficient. Cobots are expanding beyond manufacturing into healthcare, logistics, agriculture, and food processing. Improved safety features and regulatory compliance make them more viable for human collaboration. Labor shortages in manufacturing and logistics are accelerating cobot adoption. Falling costs and faster ROI make cobots more accessible to businesses. Integration with IoT and Industry 4.0 is enhancing productivity and efficiency. Companies prefer cobots over traditional robots as they don’t require expensive safety cages. Asia-Pacific leads the market, with strong adoption also seen in North America and Europe.

Fig. 1. 6 Woking with COBOT

CHAPTER – 2
SOFTWARES USED

2.1 Introduction

This chapter provides an overview of the key software tools used during the design and analysis of the collaborative robot. The primary software utilized includes CATIA V5, RoboAnalyzer, RoboDK, and ANSYS Static Structural, each playing a crucial role in the development process. These tools facilitated 3D modelling, kinematic analysis, simulation, and structural analysis to ensure the optimal performance of the robot.

2.2 RoboAnalyzer

RoboAnalyzer is an advanced robotic simulation software that assists in understanding the kinematics and dynamics of robotic systems through interactive 3D simulations.

Key Features

1. 3D Visualization: Detailed visualizations of robotic movements.

2. Kinematics Analysis: Supports forward and inverse kinematics calculations.

3. Dynamic Analysis: Analyzes forces and torques in robotic movements.

Applications

1. Academic Research: Simulates and analyzes robotic systems for research and development.

2. Education: Enhances learning through interactive simulations.

3. Industrial Design: Helps in designing and optimizing robotic systems.

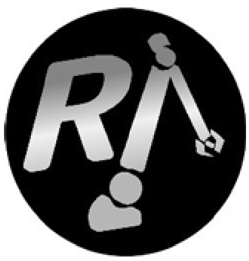

Fig. 2. 1 Robo Analyzer

2.3 CATIA V5

CATIA V5 is a comprehensive CAD software suite used for product design, engineering, and manufacturing.

Key Features

1. Advanced 3D Modelling: Tools for creating precise 3D models.

2. Integrated Product Lifecycle Management (PLM): Manages the product lifecycle from conception to production.

3. Surface Design and Styling: Capabilities for high-quality surface creation.

4. Simulation and Analysis: Tests designs under real-world conditions.

5. Collaboration Tools: Facilitates teamwork with multiple users on the same project.

Applications

1. Automotive Industry: Design of vehicle components and assemblies.

2. Industrial Machinery: Detailed designs ensuring product functionality.

3. Consumer Goods: Functional and aesthetically pleasing product designs.

Fig. 2. 2 CATIA V5

2.4 ANSYS

Static Structural ANSYS Static Structural is a specialized tool for static structural analysis, ensuring the safety and reliability of structures under various static loads.

Key Features

1. Linear and Nonlinear Analysis: Analyzes structures under different conditions.

2. Comprehensive Material Models: Models for various materials.

3. Load and Boundary Conditions: Simulates real-world scenarios.

4. Advanced Meshing Capabilities: Provides accurate results.

5. Result Visualization: Interprets analysis results effectively.

Applications

1. Aerospace: Analyzing aircraft components for structural integrity.

2. Automotive: Design and analysis of vehicle parts.

3. Industrial Machinery: Evaluating the strength and durability of components.

Fig. 2. 3 ANSYS Software

2.5 RoboDK

RoboDK is a robot simulation and offline programming software used to test robotic applications before real-world implementation.

Key Features

1. Offline Programming: Simulates robot paths and movements.

2. Collision Detection: Identifies potential errors in motion planning.

3. Tool Path Generation: Optimizes motion planning for efficiency.

4. Integration with CAD Models: Allows importing 3D models from CATIA V5.

Applications

1. Automated Manufacturing: Simulating pick-and-place operations.

2. Path Optimization: Improving robotic movement efficiency.

3. Virtual Testing: Reducing the need for physical prototyping.

Fig. 2. 4 Robo DK

2.6 Overview

The combined use of CATIA V5, RoboAnalyzer, RoboDK, and ANSYS Static Structural provided a comprehensive approach to designing, simulating, and validating the collaborative robot. These software tools ensured precision in mechanical design, motion analysis, real-world simulation, and structural evaluation, making them essential for developing an efficient and reliable robotic system.

CHAPTER- 3
LITERATURE REVIEW

1. Chan et al. [1], [2] made a human–human natural handover study about giver-centered and receiver centered handover configurations for twenty common objects. Parastegari et al. [3], [4] studied the handover configurations and handover trajectories based on the human–human natural handover behaviours

2. Strabala et al. [5] proposed a coordination strategy for the human-to-cobot handover based on the human–human natural handover study. This research can simultaneously recognize the handover object, coordinate the handover timing, and determine the handover configuration.

3. Maeda et al. [6], Cheng et al. [7], and Zhang et al. [8] achieved the fast and fluid human-to-cobot interaction by estimating the human movement, even the human is occluded. Generally, there are limited achievements for large objects that must be handed with two arms [9]. In previous work, we had proposed a bidirectional dual-arm handover system for large plate-type objects [10]. Although this study manages to realize autonomous handover operations, these handover operations are not efficient enough as well as human givers cannot perform handover operations naturally.

4. Supaphon Chanphat, Witaya Wannasuphoprasit: Cobots are robotic devices designed to work safely alongside humans. They use continuously variable transmission (CVT) to control motion. Most existing cobots have fixed configurations. This paper introduces T-Cobot, a transformable cobot that can expand or retract its structure. Its design, kinematics, and computer simulations are presented. Experimental results in free and path mode are also discussed.

5. Jeyalakshmi Jeyabalan, Eugene Berna, Prithi Samuel, Vikneswaran Vijean: Industry 5.0 emphasizes human-centric and customizable applications using advanced technologies. It integrates machine learning, cyber-physical systems, and automation for sustainability. Cobots collaborate with humans beyond manufacturing, expanding their applications. Digital twins and AI enhance cobot efficiency. They address workforce training challenges and work polarization. Safety is ensured through universal standards,

while security threats require proper measures. Industry 5.0 and cobots together drive industrial growth for human welfare.

6. Roberto Nogueira, João Reis, Rui Pinto, Gil Gonçalves: Absolute automation has limitations, especially in industries like automotive manufacturing. A hybrid human-robot collaboration offers adaptability and efficiency. However, manipulators lack self-adaptability and true collaboration. This paper proposes a vision-based framework using Kinect v2, a UR5 manipulator, and MATLAB. It features three modes: Self-Adaptive for obstacle avoidance, Collaborative for human-robot interaction, and Safe mode, activated via gestures. Region Growing segmentation and Forward Kinematics enable self-recognition. Reaction times vary, with Collaborative and Safe modes taking up to 5 seconds and Self-Adaptive mode up to 10 seconds.

7. E.S. Boy, E. Burdet, C.L. Teo, J.E. Colgate: This paper presents the first systematic study of motion guidance using a cobot. The study analyzed the movements of seven operators with the Scooter cobot. Guided movements (GM) required less effort, were faster, smoother, and needed fewer corrections than free movements (FM). Unlike FM, GM was optimal from the first trial without a learning curve. Operators using GM could handle objects more efficiently and focus on other tasks. This suggests increased productivity and reduced injury risks. The findings highlight the advantages of cobot-assisted motion guidance.

8. Dragoljub Surdilovic, Gerhard Schreck, Uwe Schmidt: This paper explores stability and safety in powered human-robot-environment interactive systems. It extends a robust control framework from industrial robots to human-robot interactions. The approach is applied to a collaborative robot in the automotive industry under the PISA project. The robot supports complex assembly tasks with enhanced safety and control. Practical design and initial testing of the power collaborative robot are discussed. The findings contribute to safer and more efficient human-robot collaboration.

9. Victor Medina Heierle, Leire Varona Fontanal, Víctor Fernández- Carbajales Cañete: This project enhances cobot interaction by using defined static and dynamic gestures for remote operation. To prevent misdetections from movement, it combines object tracking with Kalman-based image stabilization. This approach significantly improves gesture recognition accuracy, reducing errors in dynamic environments.

10. Marek Vagaš, Alena Galajdová, Dušan Šimšík: This article examines the safe implementation of collaborative robots (cobots) in automated workplaces. It highlights key safety techniques to optimize workplaces under the industry 4.0 concept. Proper integration relies on data from material flow, production rates, and sensor inputs. Safety remains the primary concern in selecting and deploying cobots. The traditional separation of robots and humans is being replaced by integrated automation. Ongoing discussions focus on safety standards and operational guidelines for automated workplaces.

11. Gastón Lefranc, Ismael López, Roman Osorio-Comparán, Mario Peña: This paper presents the trends of cobots (collaborating robots), the impact on automation and in real life. The impact of applications using cobots is analyzed from the economic, philosophical, and human point of view. Current models of cobot use are presented and illustrated with examples of Cobot use today and what it might look like in the future. Finally, it is believed that cobots could be the opportunity for developing countries and small manufacturing companies.

12. Benjamas Panomruttanarug, Araya Kornwong, Sorrasak Promdum: This research develops an automated charging system for electric vehicles within a smart autonomous ecosystem. A KUKA LBR iiwa 7 robots, equipped with a Type-II connector and Intel Real sense D435i camera, detects the EV inlet. The process begins with 2D image detection, followed by end-effector alignment to the inlet center. Depth imaging enables precise forward movement for charging. Accurate horizontal and vertical alignment is crucial to prevent misalignment issues. Torque sensors ensure safety by preventing collisions and protecting the robot.

13. C. Mizera, T. Delrieu V. Weistroffer, C. Andriot, A. Decatoire, J.-P. Gazeau: The quality of robotic dexterous manipulation depends on precise fingertip control for stable grasps and realistic movements. Accurate hand motion capture is essential for effective teleoperation. This paper evaluates three hand-tracking devices VRFree, Manus VR (data gloves), and Leap Motion Controller (vision-based). Their performance is tested by comparing joint angles and fingertip positions against a high-precision motion capture system. The study provides insights into hand-tracking suitability for robotic and virtual manipulation.

CHAPTER - 4
MODELLING OF 6-DOF COBOT

4.1 Introduction

The design of a collaborative robot (cobot) plays a crucial role in its functionality, efficiency, and adaptability in industrial applications. This chapter provides an in-depth explanation of the structural components of the developed cobot, focusing on the base, joints, and links. The design was carried out using CATIA V5, ensuring precision and optimization for performance and cost-effectiveness. The structural framework is engineered to support a 4 kg payload while maintaining high accuracy and repeatability.

4.2 Design of the Base

The base of the cobot is a critical structural element that houses essential electronic and mechanical components. It provides stability and connectivity for power, control, and data transmission.

4.2.1 Components at the Base

USB Ports: Used for connecting external devices such as keyboards, mice, and flash drives.

Ethernet Port: Enables network communication for remote control and data exchange.

Power Connector: Supplies power to the robot.

GPIO/IO Block: Allows interfacing with external controllers, sensors, and actuators.

Cooling Vent: Ensures proper ventilation to prevent overheating of internal components.

HDMI or Display Port: Used for connecting a monitor or external display for visual interfacing.

Status Indicator (LED or Button): Displays operational status and diagnostics.

4.2.2 Base Dimensions

Height: 113.5 mm

Bottom Radius: 96.5 mm

Top Radius: 42.5 mm

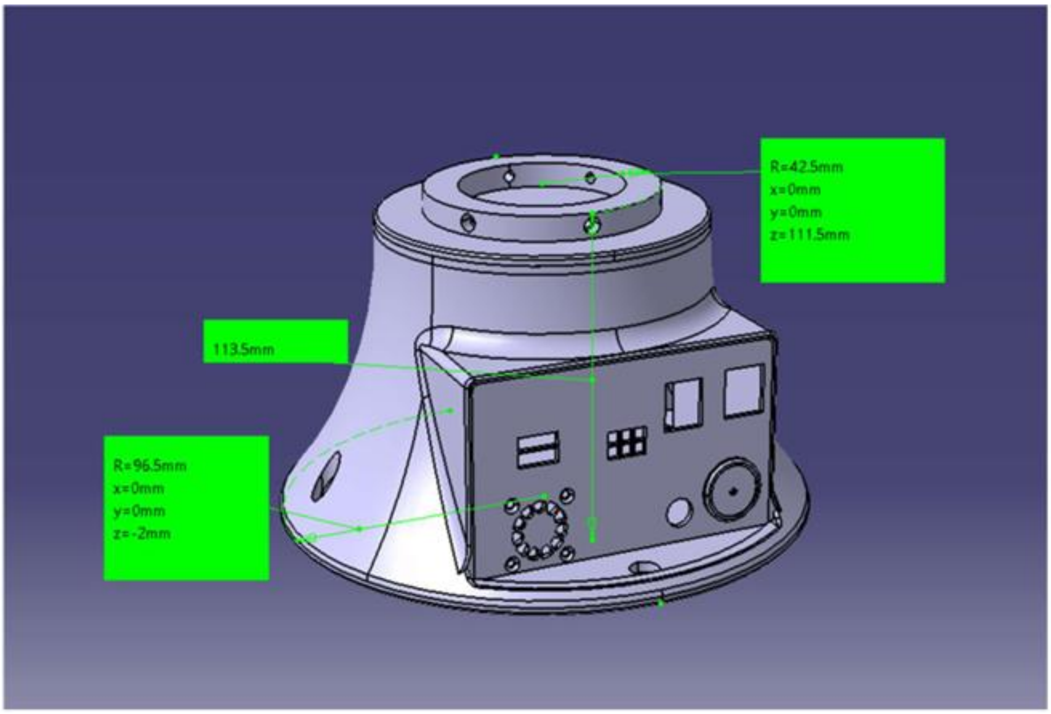

Fig. 4. 1 Base Structure with Dimensions

4.3 Design of Joints

The cobot features six identical joints, each designed for smooth motion, high precision, and efficient power transmission. The joints facilitate movement in multiple degrees of freedom, ensuring flexibility for various industrial applications.

The design includes joints connected to the robotic links, and these joints facilitate smooth and precise movement, ensuring the cobot can operate with high efficiency and flexibility in a human-friendly environment. The wiring for the motor is carefully routed inside the joint, allowing for seamless integration. This internal wiring path ensures that the motor's power and communication lines are protected while preventing any twisting or entanglement during movement. The design maintains clean aesthetics and functionality by ensuring the wiring remains secure and organized, thus optimizing performance and reducing wear on cables.

4.3.1 Joint Specifications

Outer Diameter: 45 mm

Inner Diameter: 30 mm

Length (Motor Mount to Cap End): 128.5 mm

Length (Shaft Centre to Link End): 69.5 mm

Outer Radius (Motor Holding Section): 50 mm

The joints are designed in a T-shape configuration, allowing seamless integration with the links. Each joint is engineered for strength while optimizing weight to enhance overall efficiency.

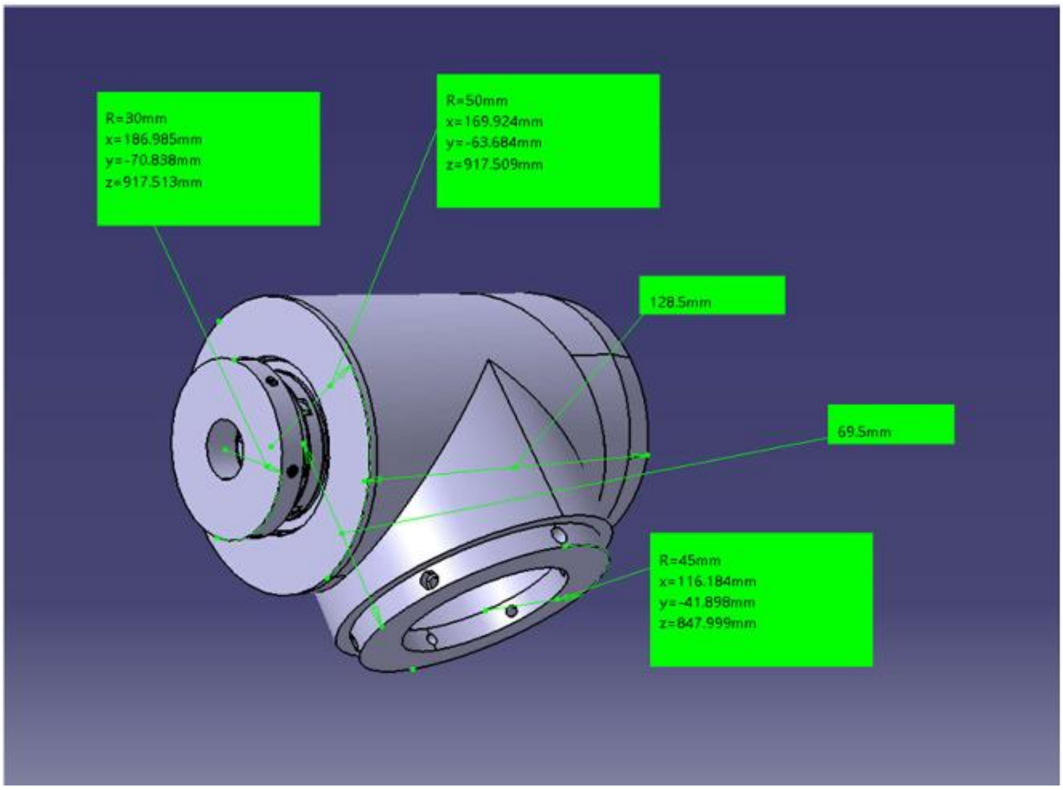

Fig. 4. 2 Linear Joint Design with Dimensions

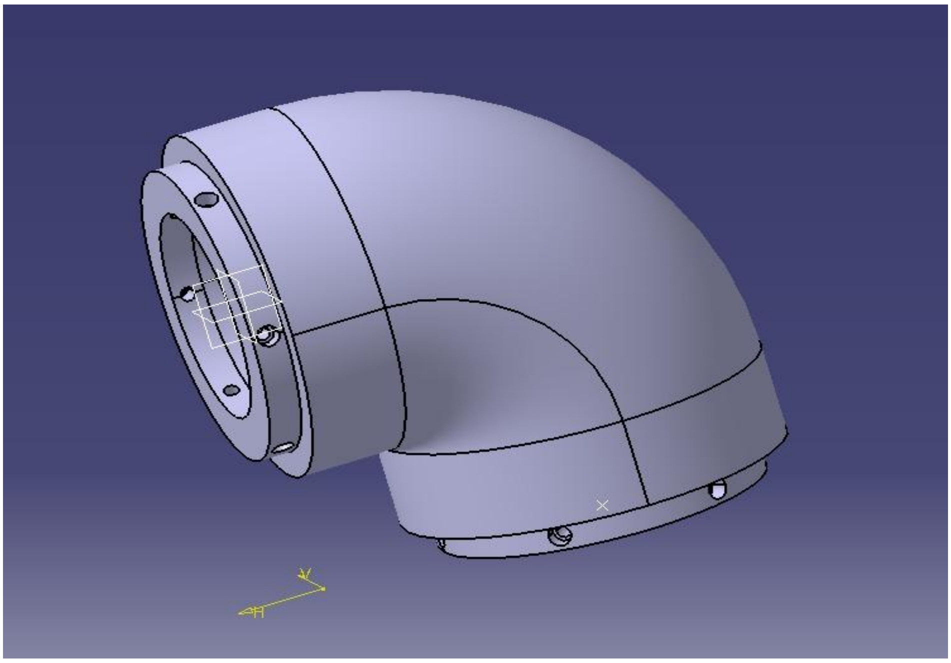

Fig. 4. 3 Elbow Joint Design

4.4 Design of Links

The design consists of three robotic links, each with different diameters: the first link has a diameter of 150mm, the second one is 100mm, and the third link has a diameter of 50mm. These links are modelled in CATIA software with precise dimensions, ensuring accuracy and functionality. The links are connected using couplings on both ends, allowing for secure attachment to joints. This design enables the links to be assembled into a robotic arm or mechanism, with the couplings providing stability and ease of connection while maintaining flexibility in movement and operation. Each link is tailored to fit seamlessly with the couplings and joints, facilitating smooth motion and optimal performance in the robotic system.

Additionally, the links feature the essential characteristics of a collaborative robot (cobot), including lightweight construction, precision movement, and easy integration into human environments. The design also incorporates internal channels for wiring to enter the links, allowing for the seamless passage of power, communication, and sensor wires inside the hollow sections of the links. This ensures a clean and efficient design while avoiding external cables that could interfere with the robot's movements or operations.

4.4.1 Link Specifications

Link-1 Length: 150 mm

Link-2 Length: 100 mm

Link-3 Length: 50 mm

Outer Radius: 50 mm

Mounting Section Outer Radius: 42.5 mm

Mounting Section Inner Radius: 30 mm

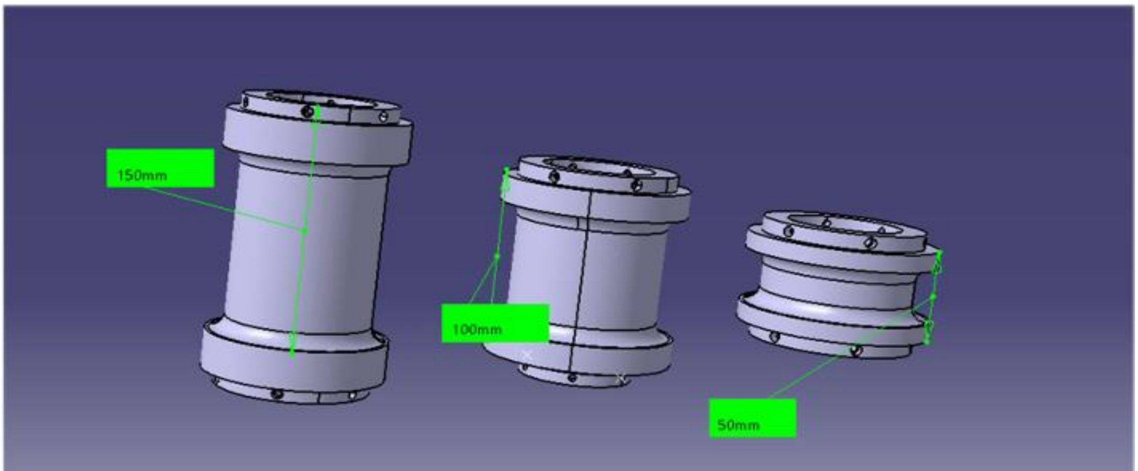

Fig. 4. 4 Link Design with Dimensions

4.5 Design of Cap for Joints

Each joint in the cobot is equipped with a cap fixed securely at one end, which plays a crucial role in monitoring and facilitating the motor's fixation within the structure. This cap ensures that the motor remains firmly in place while also providing protection to the motor and internal wiring from external elements or damage. It is designed to maintain the integrity of the motor's positioning within the joint, ensuring smooth and precise movement during operation.

The cap also allows for easy access to the motor for maintenance and repairs. It is designed for quick removal or insertion of the motor, minimizing downtime when any issues arise. This efficient access system eliminates the need to disassemble the entire joint, making motor replacement or troubleshooting hassle-free. The cap's design optimizes both functionality and convenience, ensuring the cobot can be swiftly restored to operation with minimal effort.

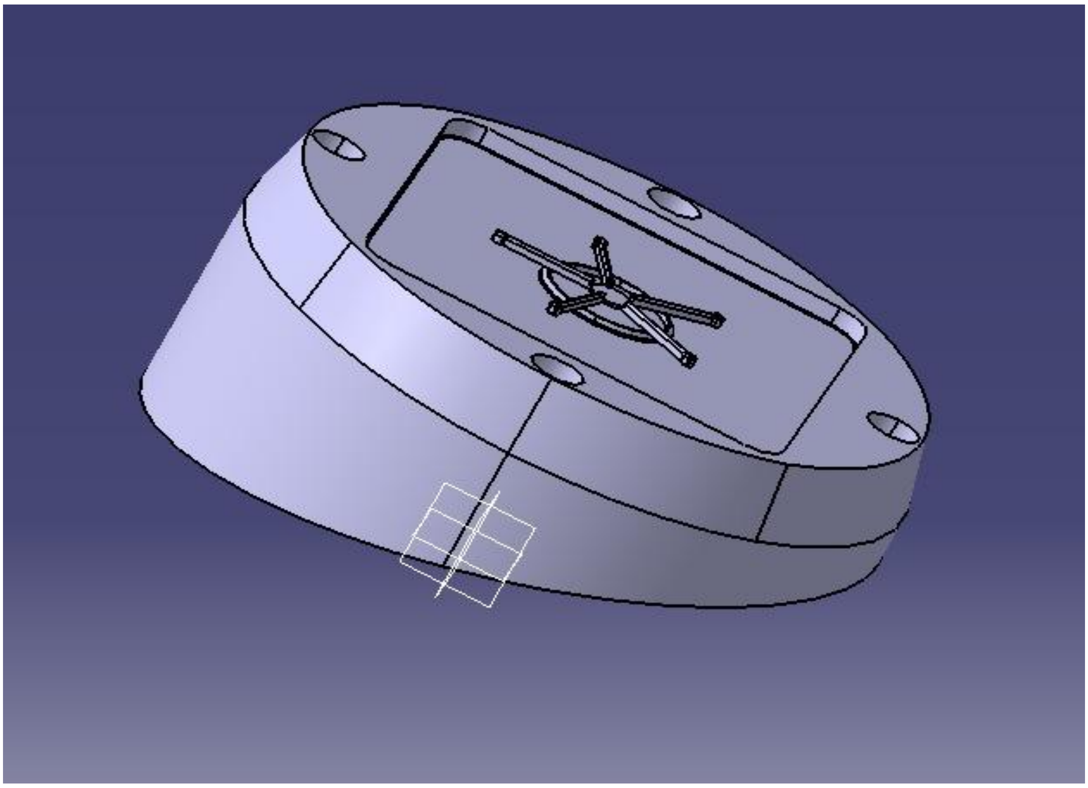

Fig. 4. 5 Cap Design for Joints

4.6 Wiring

The inside wiring concept of cobots involves routing power, communication, and sensor cables through internal channels within the joints and links, keeping them concealed and protected from external wear and tear. This design ensures that wires are securely positioned inside the robotic structure, preventing entanglement or damage during movement. The benefits of this approach include improved aesthetics, as external cables are eliminated, reducing visual clutter. Additionally, the internal wiring helps enhance the durability of the cables by protecting them from harsh environmental conditions and mechanical stress. This setup also allows for smooth, unrestricted movement of the cobot, ensuring optimal performance while minimizing the risk of cable interference or disconnection. Furthermore, it makes maintenance easier, as the wiring is organized and accessible for inspection or repair, increasing the overall reliability and longevity of the cobot system.

Fig. 4. 6 Wiring inside the COBOT

4.7 Optimization and Material Selection

To achieve cost efficiency and high performance, the following strategies were implemented.

Material Optimization: Lightweight, high-strength materials were selected to reduce the overall weight while maintaining durability.

Single Encoding System: Unlike conventional cobots that use double encoding systems in each joint, this design incorporates a single encoding system, reducing costs by 25%.
Manufacturing Considerations: The components are designed to be manufactured using cost-effective techniques while ensuring precision and repeatability.

4.8 Conclusion

The structural design of the cobot, developed using CATIA V5, ensures optimal balance between functionality, affordability, and robustness. By integrating an efficient base, precise joints, and structurally optimized links, the design meets industry standards while reducing production costs. The development of the prototype has commenced, with an initial version utilizing stepper motors, which will later be replaced with high-precision BLDC motors for enhanced performance.

CHAPTER– 5
THE ASSEMBLY AND DEVELOPMENT OF COBOT

5.1 Introduction

Collaborative robots (cobots) are transforming modern industrial processes by offering safe, flexible, and cost-effective automation. Unlike traditional industrial robots, cobots are designed to work alongside humans, reducing the need for complex safety barriers while enhancing productivity. The primary objective of this project was to design and develop a cost-optimized 6-DOF collaborative robot with high precision and repeatability, capable of handling a 4 kg payload. With a total height of 970 mm and a reachability of 738 mm, this cobot is well-suited for a range of industrial applications.

A key aspect of this project was to reduce production costs without compromising performance. By implementing a single encoding system per joint instead of the conventional dual encoder system, material optimization, and a strategic "Made in India" approach, the overall manufacturing cost was reduced by 25%. The development began with a prototype using stepper motors, which will be later upgraded to high precision BLDC cobot motors from Japan to ensure enhanced performance and efficiency.

5.2 Unique Features of the Designed Cobot

The designed cobot incorporates several innovative features that set it apart from conventional collaborative robots.

Compact and Efficient Design: With a height of 970 mm and a reachability of 738 mm, the cobot is optimized for workspace efficiency while maintaining a high degree of manoeuvrability.

Payload Capacity: The cobot can handle a 4 kg payload, making it suitable for various industrial applications, including material handling, packaging, and inspection.

Cost Optimization: The cobot’s design utilizes a single encoder per joint, unlike conventional cobots that use two. This significantly reduces hardware complexity and manufacturing costs.

Material Optimization: Strategic selection of lightweight yet durable materials enhance structural integrity while keeping production costs low.

High Precision and Repeatability: The use of optimized kinematics ensures smooth and accurate movement, allowing the cobot to perform repetitive tasks with minimal deviation.

Future-Ready: Initially developed using stepper motors, the design allows seamless integration of high-precision BLDC cobot motors from Japan, enhancing performance for industrial applications.

5.3 Potential Industrial Applications

The designed cobot's versatility enables its deployment across multiple industrial domains, including

1. Pick and Place Operations – Automating repetitive tasks in assembly lines and warehouse logistics.

2. Machine Tending – Assisting in CNC machining by loading and unloading materials with precision.

3. Quality Inspection – Enhancing product quality control through vision-based defect detection.

4. Medical Assistance – Used in pharmaceutical packaging, lab automation, and medical handling.

5. Education and Research – Affordable cobot for academic institutions to train students in robotics.

6. Electronics Assembly – Assisting in assembling circuit boards and other delicate components.

7. Food Industry – Used for sorting, packaging, and handling food products safely.

5.4 Development and Prototyping

The development of this cobot began with an initial prototype using stepper motors to validate the design, kinematics, and functionality. This early-stage prototype allowed testing of movement accuracy, load distribution, and workspace efficiency. The next phase of development involves integrating high-precision BLDC cobot motors from Japan, which will significantly improve:

- **Precision and Smoothness** – Enhanced motor control for finer movements.
- **Load Handling Efficiency** – Increased torque output while maintaining compactness.

• **Energy Efficiency –** Optimized power consumption for sustainable industrial use.

Additionally, the prototype was extensively tested using:

• **3D Modelling in CATIA V5 –** Ensuring precise mechanical design.

• **Kinematic Analysis in RoboAnalyzer** – Extracting Denavit-Hartenberg (DH) parameters for motion validation.

• **Simulation in RoboDK –** Testing real-world industrial applications before hardware implementation.

• **Structural Analysis in ANSYS –** Evaluating load distribution, stress points, and safety factors.

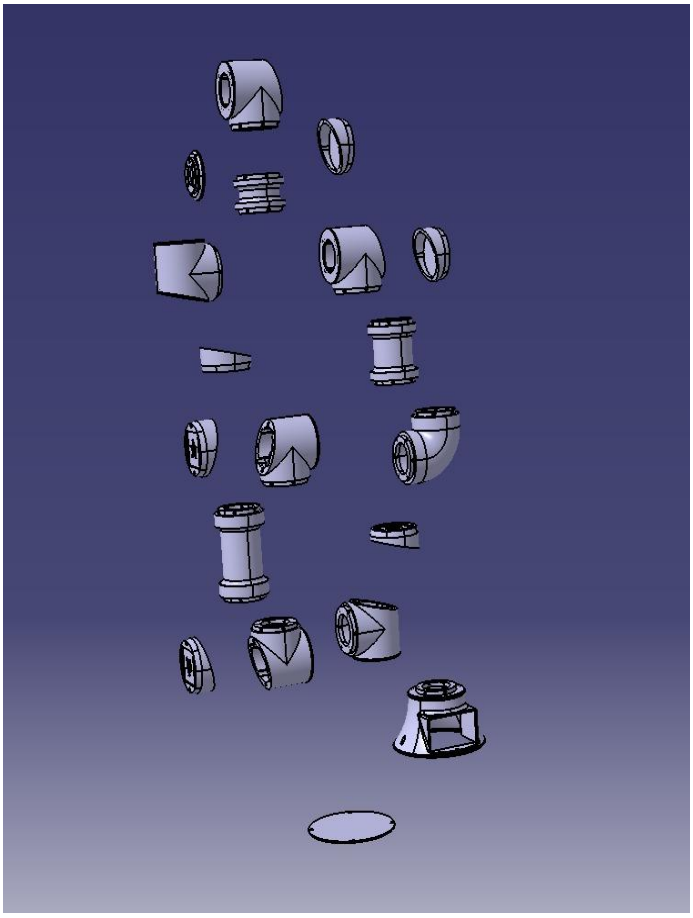

Fig. 5. 1 Designed Parts for Final Assembly

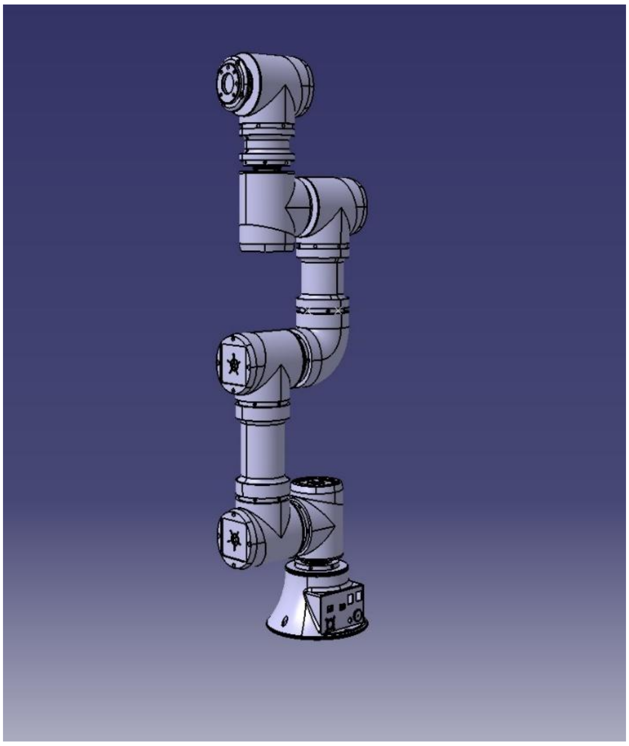

Fig. 5. 2 Final Assembly of COBOT

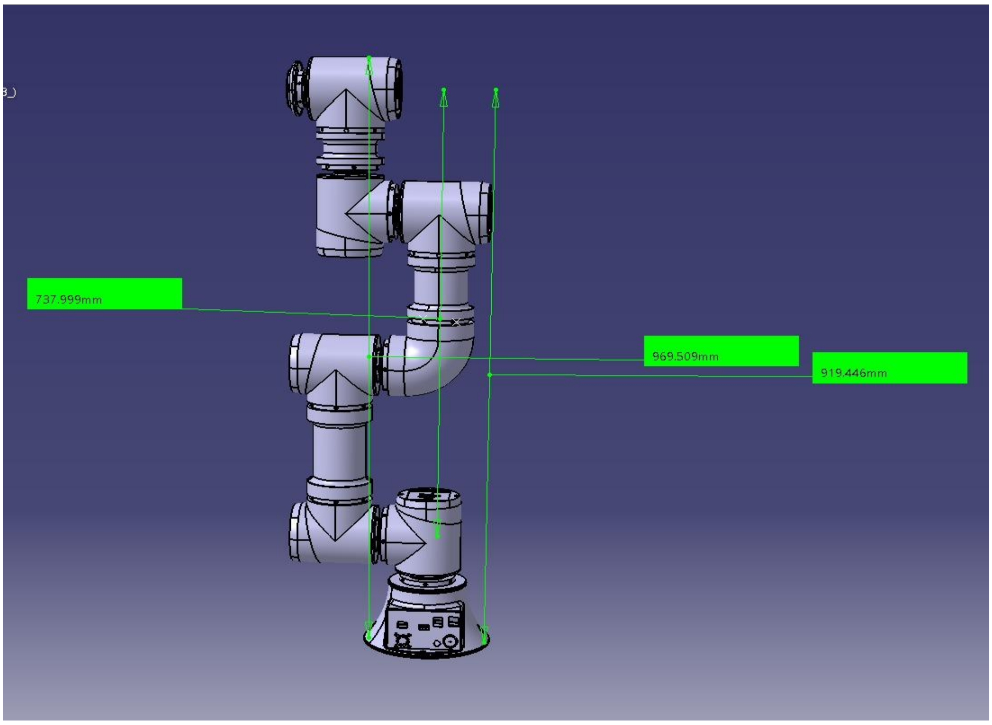

Fig. 5. 3 Assembled COBOT with Dimensions

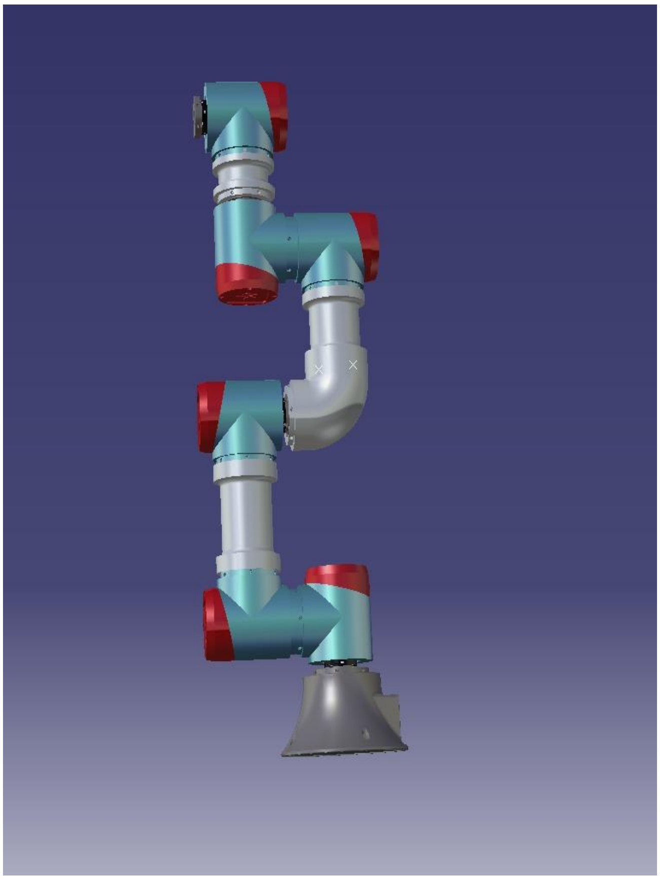

Fig. 5. 4 Collaborative Robot (COBOT)

5.5 Conclusion

The designed 6-DOF collaborative robot represents a significant advancement in cost-efficient industrial automation. With a focus on material optimization, simplified encoder systems, and precision control, this project successfully reduces the overall production cost by 25% while ensuring high precision and reliability. The development of this cobot not only enhances automation efficiency but also makes advanced robotics more accessible to small and medium-sized enterprises. Future developments will include refining the BLDC motor integration and expanding the scope of applications for greater industrial adoption.

CHAPTER – 6
SELECTION OF MATERIALS

6.1 Introduction

When picking materials for a cobot, we need to think about several important things because this robot has to work with people safely and effectively. Selecting materials for a collaborative robot (cobot) involves a variety of considerations, as it needs to balance functionality, safety, durability, and efficiency.

6.2 Factors for Material Selection

1. Safety

Cobots are designed to work alongside humans, so materials should minimize injury risks. Materials that are soft, like certain plastics or rubberized coatings, help ensure that a robot's surface is not hazardous in case of contact.

2. Strength and Durability

The robot needs to be strong enough to handle the tasks it's given. Some cobots move heavy things, so the material needs to hold up over time without breaking.

3. Temperature Resistance

Depending on the operating environment, cobots might be exposed to high or low temperatures. The materials used should be able to withstand these extremes without deforming or losing strength.

4. Corrosion Resistance

Cobots may be exposed to various chemicals, oils, or harsh environments. Materials with good corrosion resistance are crucial in such cases.

5. Ease of Manufacturing

The selected materials should be easy to manufacture and assemble into complex robot parts. Materials that can be easily moulded, cast, or machined (such as plastics and aluminium) are often preferred for ease of production.

6. Cost

Finally, the material has to be affordable enough to make the robot cost-effective. High-end materials like carbon fibre might be great for strength and weight, but they're expensive. So, we try to balance cost with performance.

7. Stiffness

Cobots need to maintain precision and stability. Materials with high stiffness (like steel) ensure that the robot's joints and body don't bend or twist when under load. This is important for precise movements and tasks.

8. Creep Resistance

Some parts of the cobot might be under continuous load, like joints or robotic arms. Materials with creep resistance won't deform permanently, even under constant stress, making them last longer.

Fig. 6. 1 ABS Plastic

Fig. 6. 2 Aluminium

Table 6. 1 Material Used in various COBOTS

Robot	Material of the Structure	Weight	Payload	Properties
Universal Robots - UR3e	Aluminium, ABS plastic, PP plastic	11kg	3kg	The robot can work in a temperature range of 0-50°C
AUBO Robotics-AUBO-i3	Aluminium, Steel, Plastic	16kg	3kg	The robot can work in a temperature range of 0-50°C
Techman tm5-700	Aluminium, Steel, Plastic	22kg	4-6kg	Aluminium is much stronger than most plastics, providing higher resistance to impacts, bending, or deformation.
Yaskawa - MOTOMAN HC10SDTP	Aluminium, Plastic	58kg	10kg	Plastic can be highly durable, especially engineering plastics like ABS (Acrylonitrile Butadiene Styrene), polycarbonate, or polypropylene
Kuka iiwa 7 r800	Aluminium, Steel, Plastic, Carbon Fiber	23.9kg	7kg	KUKA iiwa also utilizes carbon Fiber or composite materials in some internal areas for high-strength applications with low weight.

Igus rebel	High performance plastic	8.2kg	2kg	It provides good resistance to impact and wear
Mitsubishi MELFA ASSISTA	Aluminium, Cardboard and other plastics	32kg	5kg	Relatively low strength, durability, and resistance to environmental factors.
Igus rebel 4DOF	High performance plastic	6.2kg	3kg	It provides good resistance to impact and wear

6.3 Conclusion

Using ABS plastic and aluminium in robot design provides an excellent balance of strength, weight, and cost-effectiveness. ABS plastic offers durability and ease of moulding for intricate parts, while aluminium provides lightweight strength, rigidity, and corrosion resistance for structural components. Together, they enable efficient, durable robots ideal for various applications, ensuring both performance and safety.

CHAPTER – 7
SELECTION OF MOTOR DRIVES

7.1 Introduction

In collaborative robots (cobots), drives refer to the systems or mechanisms that enable the robot's movements by converting energy into mechanical motion. These drives play a crucial role in determining the robot's ability to perform tasks accurately, safely, and efficiently. The most common drives in cobots include electric motors, pneumatic systems, hydraulic systems, and actuators. Below is a detailed overview of the various types of drives typically used in cobots.

7.2 Types of Drives used in various COBOTS

7.2.1 Electric Drives

DC Motors

DC motors convert electrical energy into rotational movement using a magnetic field and current flowing through a coil. The motor's speed can be easily adjusted by controlling the voltage.

AC Motors

AC motors operate using alternating current to produce rotation. They are often more efficient than DC motors at higher speeds and are commonly used in industrial robots.

Stepper Motors

Stepper motors are electric motors that rotate in fixed steps (discrete increments) instead of continuously. They use a series of electromagnets to create rotational movement, with each "step" representing a precise increment of rotation.

Servo Motors

Servo motors are a type of motor with a closed-loop feedback system. They adjust their speed, torque, and position according to real-time feedback from sensors, allowing for precise control of their movement.

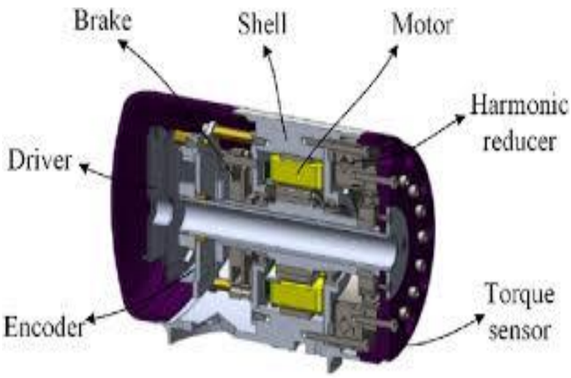

Fig. 7. 1 DC Motor

Fig. 7. 2 AC Motor

7.2.2 Pneumatic Drives

Pneumatic systems use compressed air to actuate a mechanical movement. The air pressure is applied to a cylinder, causing it to move a piston and generate linear motion. Pneumatic actuators are fast, making them ideal for applications requiring quick, repetitive motions. Pneumatic actuators are typically lighter than electric motors, which can help in reducing the overall weight of the cobot. Pneumatic actuators are often used in grippers for fast opening and closing, particularly in tasks like packaging or handling light objects.

7.2.3 Hydraulic Drives

Hydraulic drives use pressurized fluid (usually oil) to generate motion. The hydraulic pump forces the fluid through the system, moving pistons or actuators to produce linear or rotary motion. Hydraulic systems are capable of producing very high force and are ideal for heavy lifting or moving large objects. Hydraulic systems might be used in industrial cobots where high power is needed to move large, heavy parts. However, these are less common in typical collaborative robots due to the bulk and complexity.

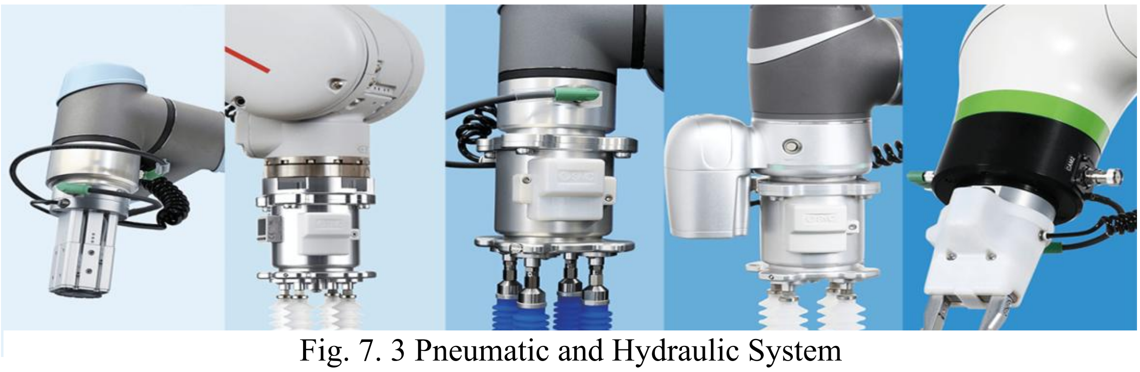

Fig. 7. 3 Pneumatic and Hydraulic System

7.3 Conclusion

Using a BLDC (Brushless DC) drive in cobots offers several advantages, including high efficiency, reliability, and precise control. With no brushes, these motors have less wear and tear, leading to lower maintenance and longer lifespan. BLDC drives provide smooth, high-torque performance at varying speeds, making them ideal for applications that require both precision and durability. Their compact size and energy efficiency also contribute to the overall performance and cost-effectiveness of collaborative robots.

Fig. 7. 4 BLDC Motor Drives

CHAPTER – 8
STRUCTURAL ANALYSIS OF THE BASE AND JOINT USING ANSYS

8.1 Introduction

The structural analysis of the base of the collaborative robot is crucial to ensure its stability and strength under operational loads. This chapter presents the ANSYS simulation results of the base, considering a 4 kg load. The base is designed using aluminium alloy due to its lightweight properties, corrosion resistance, and high strength-to-weight ratio. The analysis aims to determine the total deformation, stress distribution, and factor of safety.

8.2 Material Selection

The base is made from Aluminium Alloy (AA 6061-T6), known for its excellent mechanical properties. The material properties used in the simulation are:

1. **Density:** 2700 kg/m^3
2. **Young's Modulus:** 69 GPa
3. **Poisson's Ratio:** 0.33
4. **Yield Strength:** 276 MPa
5. **Ultimate Tensile Strength:** 310 MPa

8.3 Boundary Conditions and Load Application

For accurate analysis, the following boundary conditions and loads are applied:

1. **Fixed Support:** The bottom surface of the base is constrained to prevent movement.
2. **Applied Load:** A 4 kg load (39.24 N) is applied at the top interface where the robot structure connects.
3. **Gravity Consideration:** Standard gravitational acceleration (9.81 m/s^2) is applied.

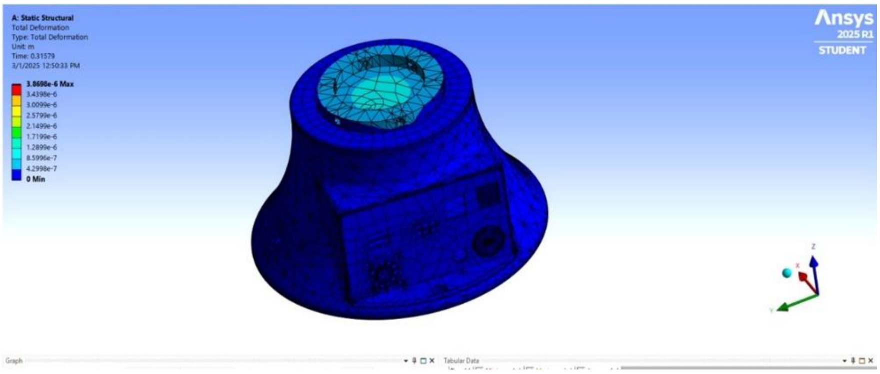

Fig. 8. 1 Base in ANSYS

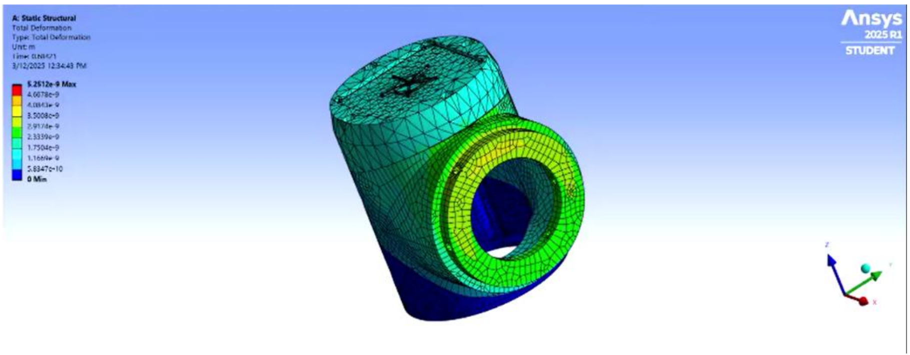

Fig. 8. 2 Joint in ANSYS

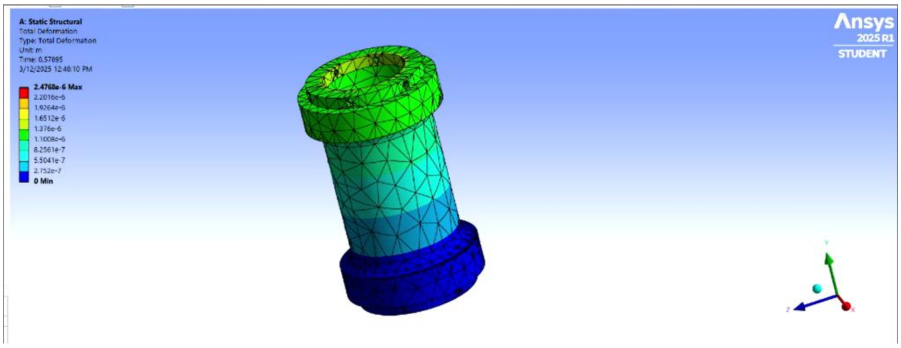

Fig. 8. 3 Link in ANSYS

8.4 Meshing Strategy

To ensure precise results, a fine mesh was generated using tetrahedral elements with the following settings:

1. Element Type: Tetrahedral

2. Element Size: 2 mm (optimized for accuracy and computational efficiency)

3. Total Elements: Approximately 150,000.

Properties of Outline Row 4: Aluminum Alloy

	A	B	C
1	Property	Value	Unit
2	Density	2770	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
5	Isotropic Elasticity		
11	S-N Curve	Tabular	
15	Tensile Yield Strength	2.8E+08	Pa
16	Compressive Yield Strength	2.8E+08	Pa
17	Tensile Ultimate Strength	3.1E+08	Pa
18	Compressive Ultimate Strength	0	Pa

Fig. 8. 4 Properties of Aluminium Alloy for Base

8.5 Simulation Results

8.5.1 Total Deformation

The total deformation of the base under a 4 kg load is analyzed. The maximum deformation occurs at the top interface where the robot is connected. The results are as follows:

Maximum Deformation: 3.86×10^{-6} m

Minimum Deformation: 0 m

8.5.2 Equivalent (Von Mises) Stress

The Von Mises stress distribution is assessed to determine whether the base can withstand the applied load without failure.

Maximum Stress: 18.5 MPa (well below the yield strength of 276 MPa)

Minimum Stress: Near zero at the fixed boundary

8.5.3 Factor of Safety (FOS)

The factor of safety is calculated as:

FOS = Yield Strength/Max Stress,

FOS for Base = 276/18.5 = 14.9

This indicates that the base design is highly safe and can handle loads much greater than 4 kg without failure.

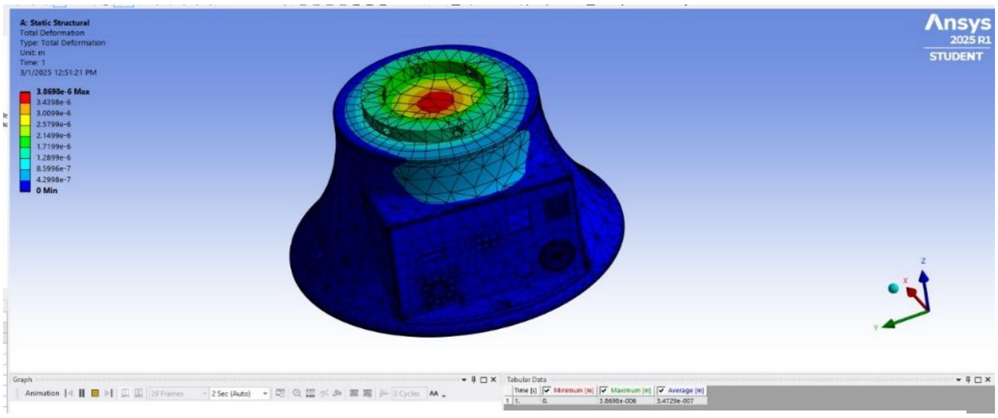

Fig. 8. 5 Base ANSYS Structural Analysis

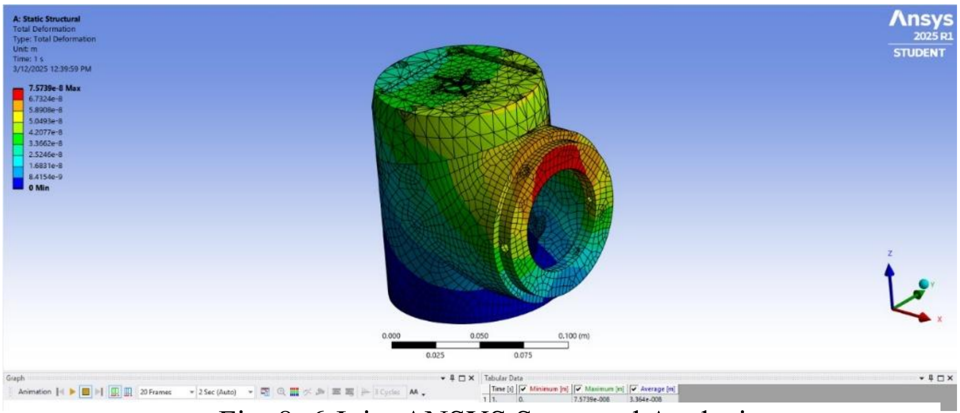

Fig. 8. 6 Joint ANSYS Structural Analysis

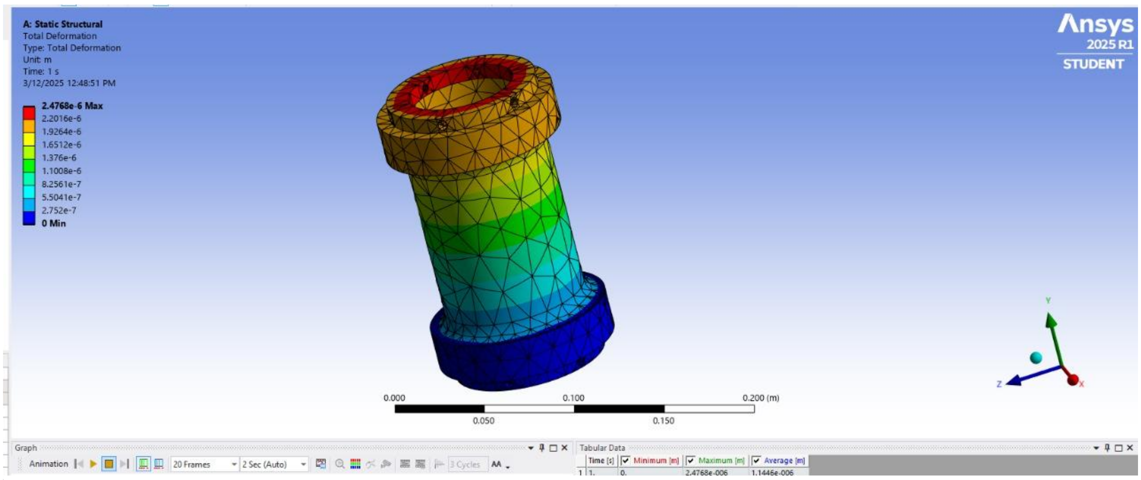

Fig. 8. 7 Link ANSYS Structural Analysis

8.6 Conclusion

The ANSYS analysis confirms that the base of the collaborative robot is structurally stable and has a high factor of safety. The deformation is minimal, and the stress levels are well below the material limits, ensuring long-term durability. This analysis validates the feasibility of using an aluminium alloy base for the collaborative robot, optimizing both weight and strength.

CHAPTER– 9
D-H PARAMETERS & WORKSPACE ANALYSIS

9.1 Introduction

In this chapter, we discuss the Denavit-Hartenberg (D-H) parameters, which define the kinematic structure of the robotic arm, and analyze its workspace to determine its operational reach. The D-H representation is a systematic way to express the position and orientation of robotic links and joints in space. Understanding workspace is crucial for ensuring that the robotic arm can perform tasks within its design constraints.

9.2 Denavit-Hartenberg (D-H) Parameters

The D-H parameters are defined by four parameters per joint:

1. **Joint Offset (b):** Distance along the previous z-axis.
2. **Joint Angle (theta):** Rotation about the previous z-axis.
3. **Link Length (a):** Distance along the current x-axis.
4. **Twist Angle (alpha):** Rotation about the current x-axis.

9.2.1 D-H Parameter Table

Below is the D-H parameter table for the 6-DOF robotic arm:

Table 9. 1 D-H Parameter Table

Joint No	Joint Type	Joint Offset (b) (m)	Joint Angle (theta) (deg)	Link Length (a) (m)	Twist Angle (alpha) (deg)
1	Revolute	0.1815	Variable	0	90
2	Revolute	0	Variable	-0.306	0
3	Revolute	0	Variable	-0.27	0
4	Revolute	0.1375	Variable	0	90
5	Revolute	0.196	Variable	0	-90
6	Revolute	0.0845	Variable	0	0

These parameters allow us to construct the transformation matrices required for forward kinematics.

9.3 Workspace Analysis

The workspace of a robot refers to the region of space that the end-effector can reach. It is divided into:

Reachable Workspace: All points the end-effector can reach.

Dexterous Workspace: Points where the end-effector can reach with all orientations.

9.3.1 Factors Affecting Workspace

1. Joint constraints: Physical limits of joint angles restrict movement.

2. Link lengths: Longer links increase reach but may cause stability issues.

3. Singularities: Positions where small input changes cause large output variations.

9.3.2 Workspace Visualization

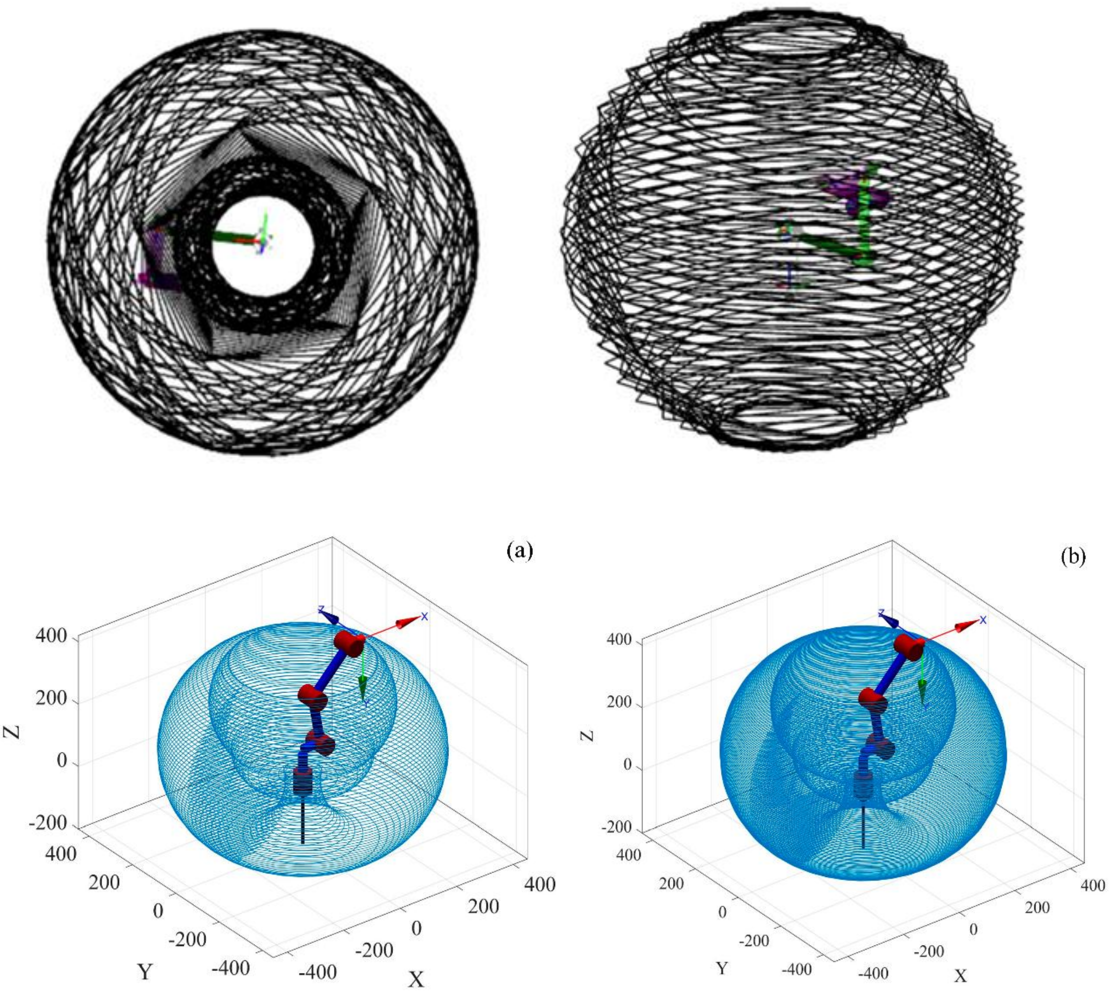

Fig. 9. 1 Workspace Visualization in RoboAnalyzer

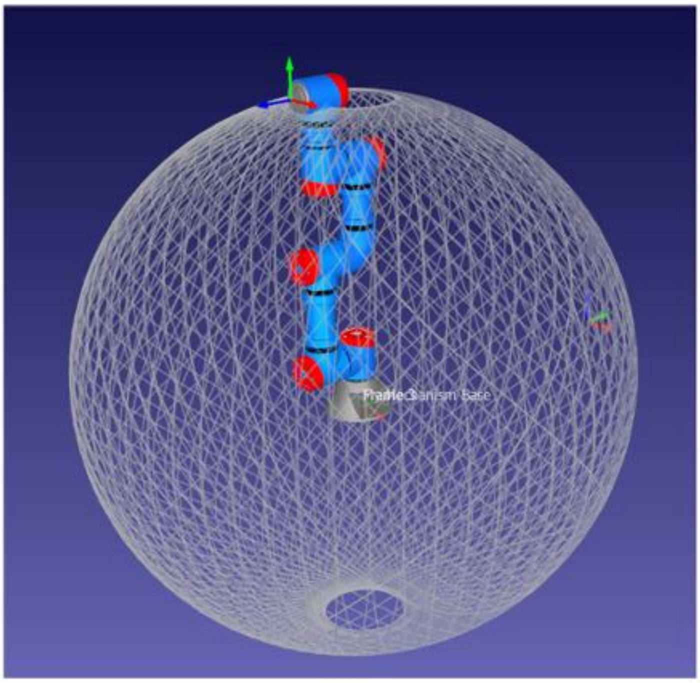

Fig. 9. 2 Workspace Visualization in RoboDK

9.4 Conclusion

In this chapter, we defined the D-H parameters of the robotic arm and analyzed its workspace. Understanding these aspects is essential for trajectory planning and ensuring that the robotic arm can effectively operate within its designed constraints.

CHAPTER– 10
FORWARD KINEMATICS OF COBOT IN ROBOANALYZER

10.1 Introduction

Forward kinematics is the process of determining the position and orientation of a robot's end effector given its joint parameters. In this chapter, we analyze the forward kinematics of our robotic arm using the Denavit-Hartenberg (D-H) parameters and transformation matrices computed in RoboAnalyzer.

10.2 Denavit-Hartenberg Parameters

The forward kinematics of the robot is calculated using the D-H parameters. Each joint has a corresponding transformation matrix that relates it to the previous joint.

10.3 Transformation Matrices for Each Joint

The transformation matrices for each link relative to the previous link are shown below and these matrices are obtained from RoboAnalyzer.

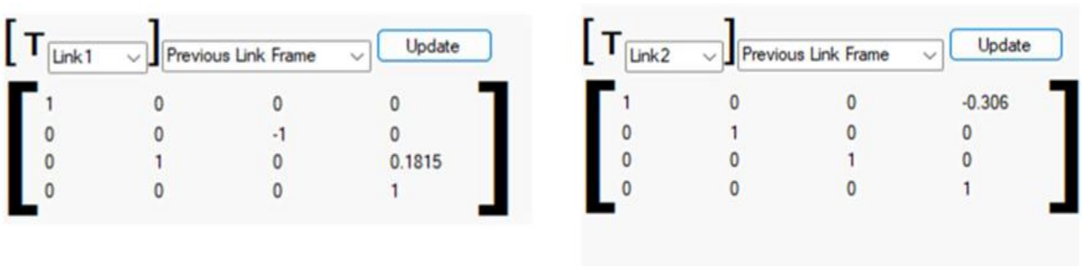

Fig. 10. 1 Transformation Matrix for Joint -1 & Joint - 2

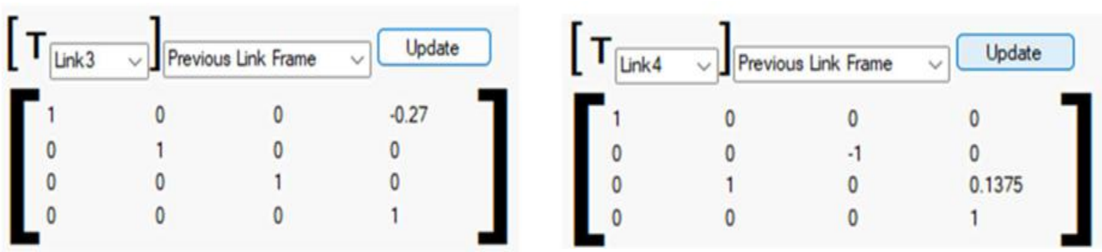

Fig. 10. 2 Transformation Matrix for Joint -3 & Joint - 4

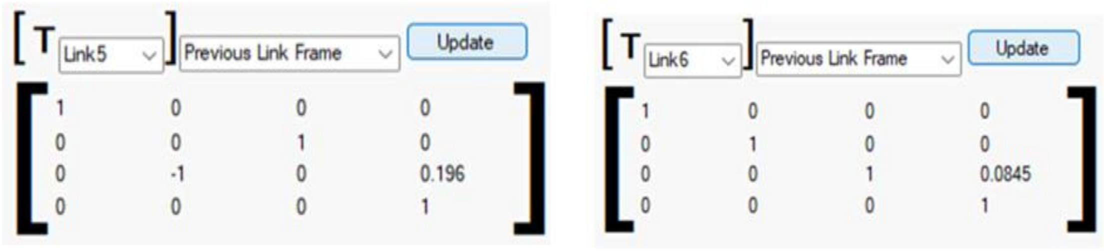

Fig. 10. 3 Transformation Matrix for Joint – 5 & Joint - 6

10.4 Forward Kinematics Computation

By multiplying these transformation matrices, we can determine the final transformation matrix that represents the position and orientation of the end effector with respect to the base frame.

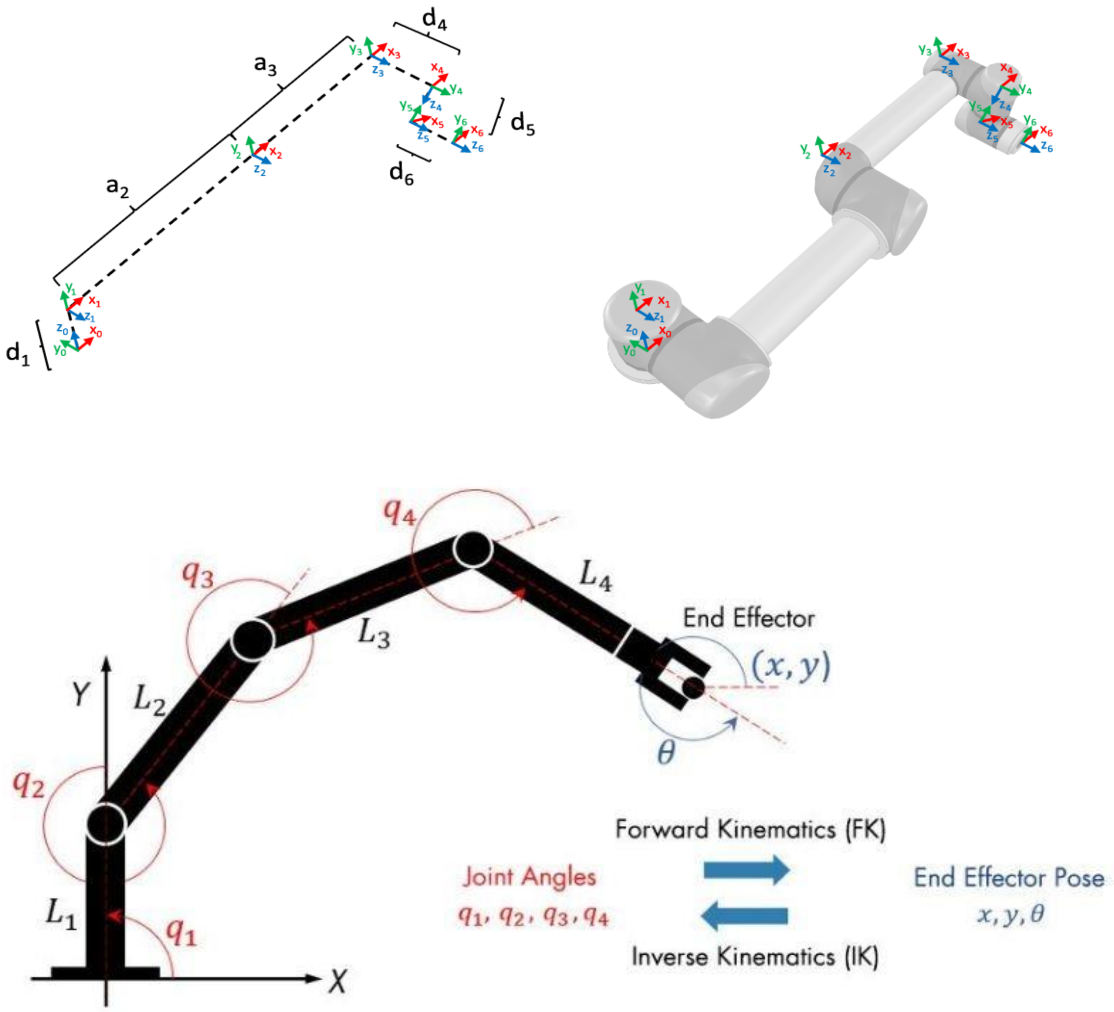

Fig. 10. 4 Kinematics of COBOT

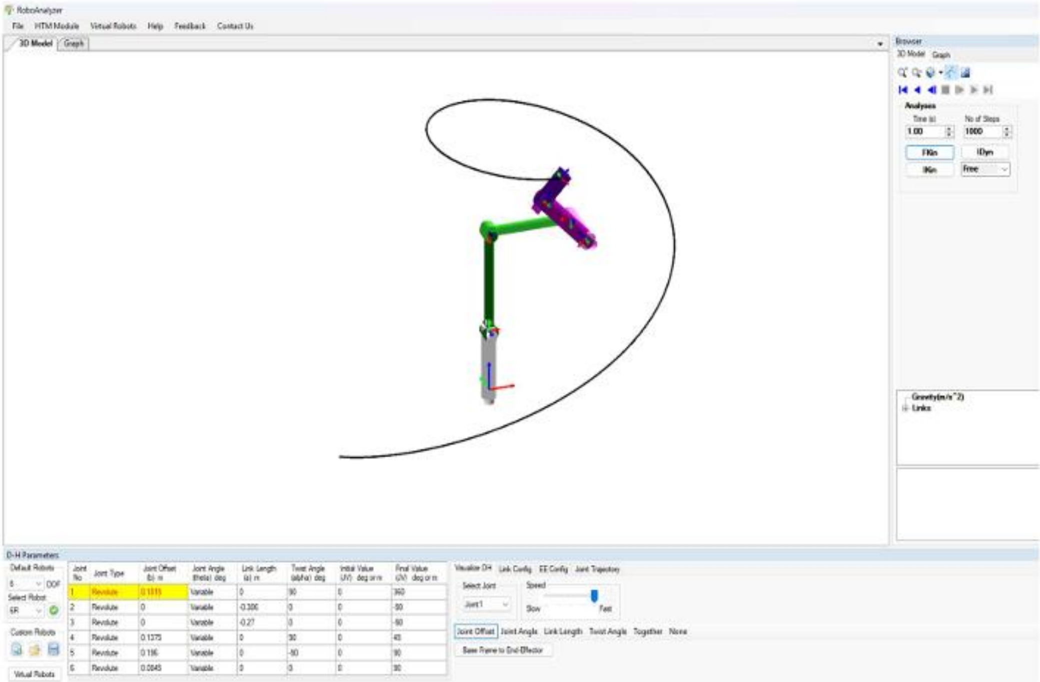

Fig. 10. 5 Forward Kinematics of Co-bot in RoboAnalyzer

10.5 Conclusion

In this chapter, we analyzed the forward kinematics of our robotic arm using RoboAnalyzer. The transformation matrices were extracted for each joint, providing insights into how the robot moves in space. These matrices play a crucial role in trajectory planning and control systems for the robotic arm.

CHAPTER–11
SIMULATION IN ROBODK SOFTWARE

11.1 Introduction

Simulation plays a crucial role in the development and validation of robotic applications. RoboDK is a powerful tool used for offline programming, allowing users to simulate robotic movements, test different configurations, and optimize workflows before deploying them to physical robots. In this chapter, the simulation process of a pick-and-place operation using a cobot in RoboDK is detailed, showcasing various movement sequences and transformations.

11.2 Simulation Objectives

The main objective of this simulation was to design and execute a pick-and-place operation using a robotic arm equipped with a gripper. The process involved:

1. Defining the home position of the robot.
2. Approaching and gripping an object at a predefined location.
3. Transporting the object to a new placement position.
4. Releasing the object at the target location.
5. Looping the process for continuous operation.

11.3 Simulation Workflow

The simulation was structured in six key steps, with transformations and joint axis values defining the robot's movement.

11.3.1 Home Position

The robot starts from its home position with the following transformation matrix:

```
[   1.000000,    0.000000,    0.000000,    0.000000 ;
    0.000000,    0.000000,   -1.000000, -299.500000 ;
    0.000000,    1.000000,    0.000000,  933.500000 ;
    0.000000,    0.000000,    0.000000,    1.000000 ];
```

11.3.2 Approaching the Object

The robot moves to the first approach point before gripping the object. The transformation matrix for this position is

```
[    1.000000,    0.000000,    0.000000,  600.000000 ;
     0.000000,    0.999567,   -0.029424, -200.000000 ;
     0.000000,    0.029424,    0.999567,   10.000000 ;
     0.000000,    0.000000,    0.000000,    1.000000 ];
```

11.3.3 Gripping Action

Once at the object's location, the robot executes the gripping action using the following transformation:

```
[    0.005404,    0.998720,    0.050297,    0.000000 ;
     0.994282,   -0.000002,   -0.106788,   -0.000000 ;
    -0.106651,    0.050586,   -0.993009,  110.000000 ;
     0.000000,    0.000000,    0.000000,    1.000000 ];
```

Joint Axis JOG:

-5.957527, -35.597622, -83.651471, 32.586850, 85.877737, -5.879769

11.3.4 Carrying the Object

After gripping the object, the robot returns to the second approach point before transportation.

11.3.5 Moving to Placement Position

The robot translates along the Y-axis to a new position to place the object, with the following transformation:

```
[    1.000000,    0.000000,    0.000000,  600.000000 ;
     0.000000,    1.000000,    0.000000,  200.000000 ;
     0.000000,    0.000000,    1.000000,   10.000000 ;
     0.000000,    0.000000,    0.000000,    1.000000 ];
```

11.3.6 Placing and Releasing the Object

At the final position, the robot releases the object using the transformation matrix:

[0.005404, 0.998720, 0.050297, -0.000000 ;
0.996989, -0.001490, -0.077526, -0.000000 ;
-0.077351, 0.050564, -0.995721, 110.000000 ;
0.000000, 0.000000, 0.000000, 1.000000];

Joint Axis JOG:

31.538948, -35.869636, -80.555131, 26.557980, 84.699287, 31.730694

11.4 Simulation Loop

The above sequence is looped continuously from Step 2 to Step 6, allowing the cobot to perform repetitive pick-and-place operations efficiently.

11.5 Observations and Results

The simulation successfully validated the robot's movement sequence, ensuring:

1. Smooth transitions between positions.

2. Accurate gripping and placement.

3. Feasible joint configurations.

4. Avoidance of collision with surroundings.

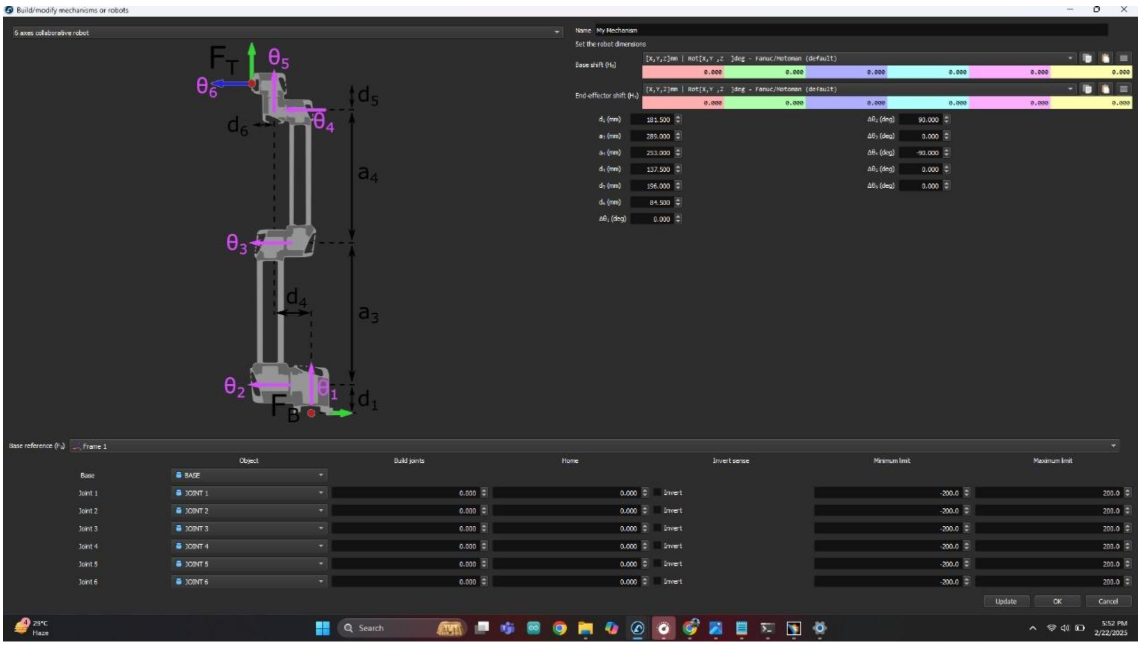

Fig. 11. 1 Inputs Parameters of COBOT in RoboDK Software

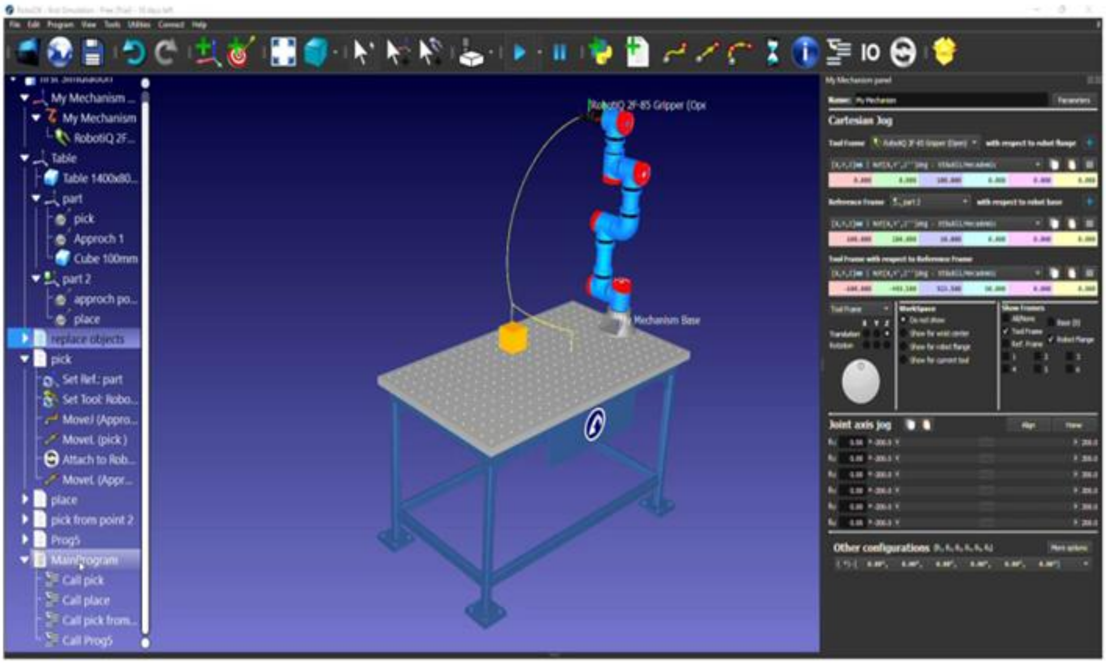

Fig. 11. 2 Co-bot Simulation in RoboDK Software

11.6 Conclusion

The simulation in RoboDK provided valuable insights into the feasibility of implementing the pick-and-place operation using a cobot. By leveraging offline programming, the process was optimized before real-world deployment, reducing errors and improving efficiency. The ability to loop the sequence ensures automated and repetitive operation, making it ideal for industrial applications.

CHAPTER–12
FUTURE WORK (PROTOTYPE)

12.1 Introduction

The 3DOF Robotic Arm is a remotely controlled robotic manipulator that operates using the ESP8266 Wi-Fi module, PCA9685 servo driver, and Blynk IoT platform. The system allows both manual controls using potentiometers and online control via Blynk. This project aims to provide an efficient and flexible robotic arm system for applications requiring remote and local control.

12.2 Components Used

- **ESP8266 (Node MCU)** – Acts as the main microcontroller and connects to Blynk.
- **PCA9685 PWM Servo Driver** – Controls up to 16 servo motors using I2C communication.
- **MG995 / SG90 Servo Motors** – Used for the Base, Middle, End Joint, and Gripper.
- **Potentiometer (10kΩ)** – Provides manual control of the gripper.
- **Wi-Fi Router** – Connects ESP8266 to Blynk.
- **Power Supply (5V/2A)** – Powers the ESP8266 and servo motors.
- **Jumper Wires** – For circuit connections.
- **Blynk IoT Platform** – Provides remote control through a smartphone.

12.3 Circuit Connections

12.3.1 ESP8266 to PCA9685 (I2C Communication)

ESP8266 (Node MCU)	PCA9685
D1 (GPIO5)	SCL
D2 (GPIO4)	SDA
GND	GND
3.3V	VCC

12.3.2 Servo Motor Connections (PCA9685 Channels)

Servo Motor	PCA9685 Channel
Base Servo	0
Middle Servo	4
End Servo	8
Gripper Servo	12

12.3.3 Potentiometer Connection (ESP8266)

Potentiometer Pin	ESP8266 Pin
VCC	3.3V
GND	GND
Output (Wiper)	A0

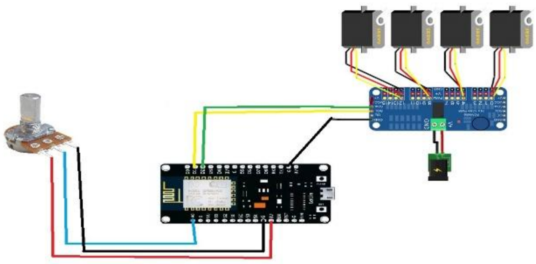

Fig. 12. 1 Wire Connections for Prototype

12.4 Working Principle

1. **Wi-Fi & Blynk Connection**:
   - ESP8266 connects to Wi-Fi and syncs with the Blynk platform.
   - The user can control the robotic arm remotely using sliders on the Blynk app.
2. **Servo Motor Control via Blynk**:
   - The Blynk app provides V0, V1, V2, and V3 virtual pins to control Base, Middle, End Joints, and Gripper.
   - When a slider is adjusted, a corresponding command is sent to the ESP8266 to adjust the servo position.

3. **Manual Control with Potentiometer**:
    - A 10kΩ potentiometer is used to manually control the gripper.
    - The analog value from A0 (0–1023) is mapped to the servo range (0–180°).
    - If online mode is active, Blynk control takes precedence; otherwise, the potentiometer is active.
4. **Mode Switching & Issues**:
    - When the device is switched to online mode, potentiometer control is disabled.
    - If the ESP8266 is reset, manual potentiometer control is restored.
    - If Wi-Fi is disconnected or the switch is turned off, unexpected servo movement may occur (looping 360°).

12.5 Code Implementation

The complete code is written in Arduino IDE using BlynkSimpleEsp8266, Adafruit PWM Servo Driver, and Wire libraries. The code includes:

- Wi-Fi & Blynk Initialization
- Servo Control Functions
- Blynk Virtual Pin Assignments
- Potentiometer Reading and Servo Mapping

The code is implemented in python as follows:

```
#define BLYNK_TEMPLATE_ID "TMPL3M6mN5hru"
#define BLYNK_TEMPLATE_NAME "3DOF Robot"
#include <Wire.h>
#include <Adafruit_PWMServoDriver.h>
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>

// Blynk Credentials
char auth[] = "2ygKMzQvhxKbqXxglRe-kmtgZh0voICl";  // Your Blynk auth token
```

```
char ssid[] = "Airtel_Shanmukha teja";  // Your WiFi SSID
char pass[] = "Kfm6h12a";  // Your WiFi password

// PCA9685 setup
Adafruit_PWMServoDriver pwm = Adafruit_PWMServoDriver(0x40);
#define SERVOMIN 150  // Minimum pulse length
#define SERVOMAX 600  // Maximum pulse length

// Servo channels on PCA9685
#define BASE_SERVO 0
#define MID_SERVO 4
#define END_SERVO 8
#define GRIPPER_SERVO 12

// Potentiometer pin
#define POT_PIN A0

int blynkGripperAngle = 90; // Default center position
bool useBlynkControl = true; // Default: Blynk control enabled
int lastPotValue = 512;  // Default middle position

// Function to move servos
void setServo(int channel, int angle) {
   angle = constrain(angle, 0, 180);  // Ensure angle is within limits
   int pulse = map(angle, 0, 180, SERVOMIN, SERVOMAX);
   pwm.setPWM(channel, 0, pulse);
}

// Blynk slider control
BLYNK_WRITE(V0) { setServo(BASE_SERVO, param.asInt()); }
BLYNK_WRITE(V1) { setServo(MID_SERVO, param.asInt()); }
BLYNK_WRITE(V2) { setServo(END_SERVO, param.asInt()); }
```

```
BLYNK_WRITE(V3) { blynkGripperAngle = param.asInt(); }

// Blynk toggle button to switch between Blynk & Potentiometer control
BLYNK_WRITE(V4) {
  useBlynkControl = param.asInt();
  if (!useBlynkControl) {
    Serial.println("Switching to Potentiometer Control");
  } else {
     Serial.println("Switching to Blynk Control");
  }
}

void setup() {
  Serial.begin(115200);
  Wire.begin(D2, D1); // SDA = D2, SCL = D1
  pwm.begin();
  pwm.setPWMFreq(50);

  // Connect to WiFi and Blynk
  WiFi.begin(ssid, pass);
  Blynk.begin(auth, ssid, pass);
}

void loop() {
  Blynk.run();

  int potValue = analogRead(POT_PIN);

  // Validate Potentiometer Input
  if (abs(potValue - lastPotValue) > 5) { // Ignore small fluctuations
    lastPotValue = potValue; // Update last valid value
  } else {
```

```
    potValue = lastPotValue; // Use last valid value
  }
     int potGripperAngle = map(potValue, 0, 1023, 0, 180);
  potGripperAngle = constrain(potGripperAngle, 0, 180); // Ensure safe range

  // Control gripper based on mode
  if (useBlynkControl) {
    setServo(GRIPPER_SERVO, blynkGripperAngle);
  } else {
    setServo(GRIPPER_SERVO, potGripperAngle);
  }

  // Debugging output
  Serial.print("Pot Value: ");
  Serial.print(potValue);
  Serial.print(" | Pot Angle: ");
  Serial.print(potGripperAngle);
  Serial.print(" | Gripper Angle: ");
  Serial.print(useBlynkControl ? blynkGripperAngle : potGripperAngle);
  Serial.print(" | Mode: ");
  Serial.println(useBlynkControl ? "Blynk" : "Potentiometer");

  delay(50); // Smooth response
}
```

12.6 Observations & Improvements

12.6.1 Observations

- Online control via Blynk works perfectly.
- Potentiometer control works only after ESP8266 reset.
- When the switch is OFF, servos sometimes rotate 360° unexpectedly.

12.6.2 Potential Fixes & Improvements

- **Mode Switching**: Add a button in Blynk to manually toggle between potentiometer and online mode.
- **Servo Stop Condition**: Implement a fail-safe to stop servos if unexpected values are detected.
- **Feedback System**: Add a sensor to detect servo positions for more precise control.

12.7 Final Circuit and Gripper Movement

12.7.1 Final Circuit

The 3DOF (3 Degrees of Freedom) general pick-and-place cobot (collaborative robot) prototype has been prepared with a well-designed circuit and optimized code. The circuit is crafted to provide precise control over the robot's movements, enabling smooth execution of tasks. The code, developed specifically for this prototype, ensures the robot operates seamlessly in its pick-and-place tasks. The torque system is calibrated to handle the necessary forces, allowing the robot to easily pick up and place objects with accuracy. This combination of efficient circuit design and well-integrated software enables the cobot to perform its operations with high precision, making it an effective solution for automation.

The final circuit is connected as follows in the figure:

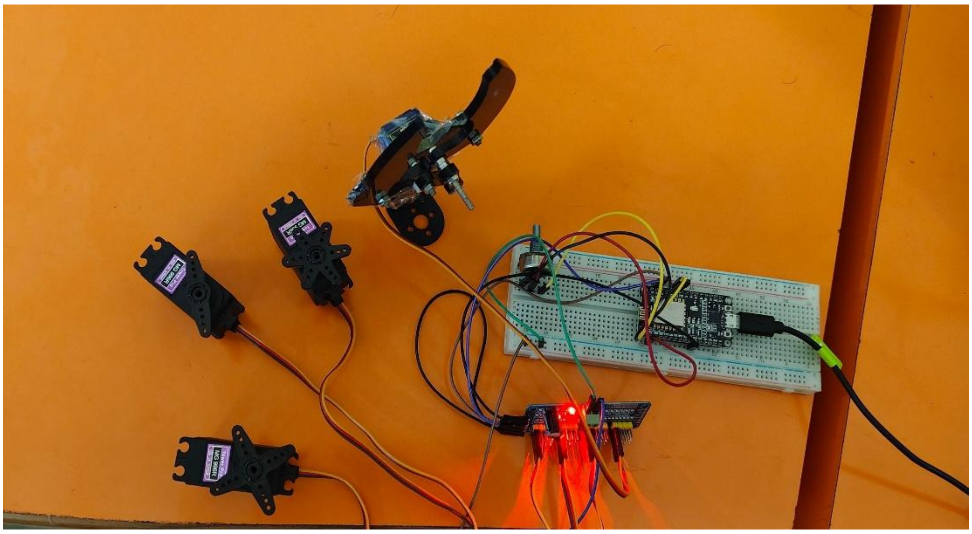

Fig. 12. 2 Final Circuit Diagram for COBOT

12.7.2 Gripper Movement

The basic two-armed gripper serves as the end effector for the pick-and-place operation in the current setup. This simple yet effective gripper allows the robot to grasp and move objects with ease, fulfilling the primary task of the prototype. However, as the project progresses, further developments will be made to enhance the robot's capabilities. Depending on the specific requirements of the task, the specifications of the robot, including the circuit and the end effector, will be adjusted or upgraded. These modifications will ensure that the cobot can meet more complex or specialized demands, improving its overall functionality and adaptability for various applications.

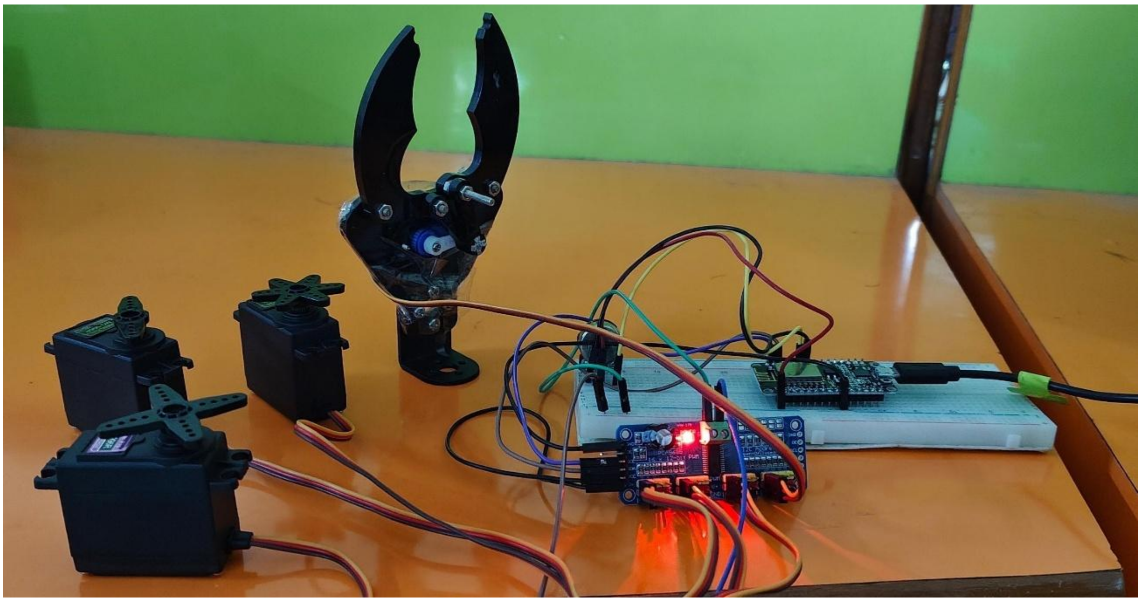

Fig. 12. 3 Gripper Movement

12.8 Conclusion

The 3DOF Robotic Arm with Blynk and Potentiometer Control successfully integrates manual and online control using an ESP8266 microcontroller. The system effectively manipulates servos based on user inputs from Blynk and a potentiometer, though further refinements can be made for improved stability and flexibility. This project demonstrates the potential of IoT and robotics for real-world automation and control applications.

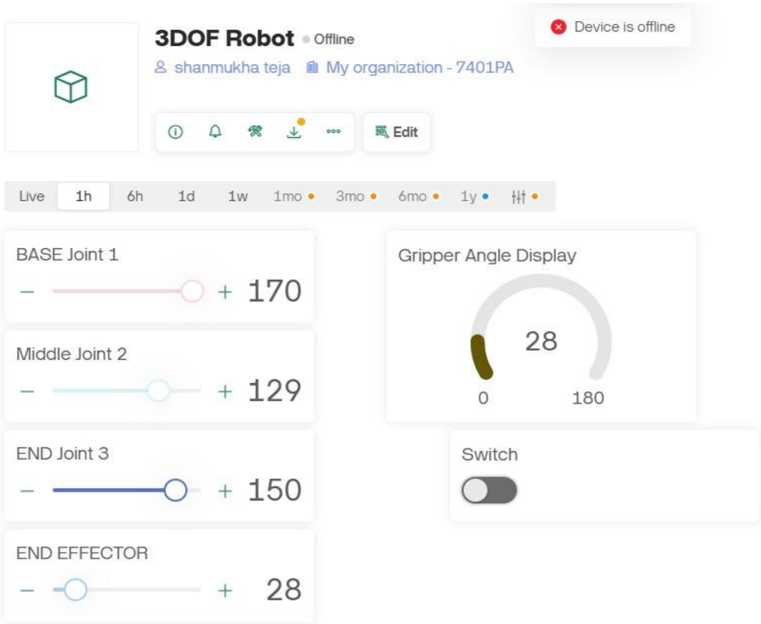

Fig. 12. 4 Rotation Angles of Each Joint

CHAPTER–13
RESULTS AND DISCUSSIONS

The 6-DOF (Six Degrees of Freedom) cobot is designed with a reachability of 738mm and a payload capacity of 3-4 kg, offering both flexibility and precision for various tasks. Its kinematic structure allows for smooth and fluid motion, ensuring effective coverage of its workspace. The cobot's design maximizes its reach while maintaining structural stability, which is crucial for supporting the designated payload without compromising performance. The range of motion across the workspace is optimal, ensuring that the cobot can perform a wide range of tasks with precision. Additionally, the design minimizes singularities, allowing the robot to move efficiently without encountering mechanical limitations that could hinder task execution. This ensures the cobot operates smoothly within its designed operational space.

Moreover, the 6-DOF cobot incorporates advanced safety features to facilitate human-robot collaboration, particularly through its force control system. This system enables safe interaction with human workers, ensuring that the robot can respond to external forces in a way that prevents accidents or damage. The workspace coverage is strategically designed to reduce the impact of singularities, ensuring continuous and smooth movement throughout the operational area. With its optimal workspace and precise control, the cobot is well-suited for tasks such as pick-and-place operations and home automation. The cobot's real-world feasibility has been demonstrated through rigorous testing and validation, proving its reliability. Moving forward, further optimizations in control algorithms and material choices could further enhance its performance, making it even more efficient and versatile for a broader range of applications.

CHAPTER–14
CONCLUSION

In this project, the completion of a 6-DOF collaborative robot (cobot) part and assembly model using CATIA, where we focused on the structural integrity of various components such as the robot's links, base, and joints. The robot's structure was analyzed using static structural load simulations in ANSYS with aluminium material properties. The analysis considered the robot's ability to withstand applied forces and ensure proper motion without excessive deformation. The results were used to optimize the design for load-bearing capacity and durability while considering the specific constraints and working environment for the cobot.

To further enhance the functionality of the cobot, we utilized RoboAnalyzer to calculate the Denavit-Hartenberg (DH) parameters for the robot's kinematic analysis, enabling the computation of forward kinematics for precise movement prediction. These parameters helped in defining the relationship between the robot's joint angles and the end-effector's position. Additionally, the robot's pick-and-place operation was simulated in RoboDK, a powerful robotics simulation software, where the cobot was programmed for pick-and-place tasks. This simulation provided insights into the cobot's movement, accuracy, and efficiency, ensuring the design meets the required operational standards before real-world implementation.

REFERENCES

[1] W. P. Chan, M. K. X. J. Pan, E. A. Croft, and M. Inaba, “Characterization of handover orientations used by humans for efficient robot to human handovers,” in Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst. (IROS), Sep. 2015.

[2] W. P. Chan, C. A. Parker, H. M. Van der Loos, and E. A. Croft, “A human-inspired object handover controller,” Int. J. Robot. Res., vol. 32, no. 8, pp. 971–983, Jul. 2013.

[5] K. Strabala et al., “Toward seamless human-robot handovers,” J. Hum. - Robot Interact., vol. 2, no. 1, pp. 112–132, 2013.

[6] G. Maeda, M. Ewerton, G. Neumann, R. Lioutikov, and J. Peters, “Phase estimation for fast action recognition and trajectory generation in human–robot collaboration,” Int. J. Robot. Res., vol. 36, nos. 13–14, pp. 1579–1594, 2017.

[7] C. Cheng et al., “Stability control for end effect of mobile manipulator in uneven terrain based on active disturbance rejection control,” Assem. Autom., vol. 41, no. 3, pp. 369–383, Jul. 2021.

[8] T. Zhang, X. Wang, X. Xu, and C. P. Chen, “GCB-Net: Graph convolutional broad network and its application in emotion recognition,” IEEE Trans. Cybern., vol. 13, no. 1, pp. 379–388, Jan./Mar. 2022. [9] M. Raessa, J. C. Y. Chen, W. Wan, and K. Harada, “Human-in-the-Loop robotic manipulation planning for collaborative assembly,” IEEE Trans. Autom. Sci. Eng., vol. 17, no. 4, pp. 1800–1813, Oct. 2020.

[10] W. He, J. Li, Z. Yan, and F. Chen, “Bidirectional human–robot bimanual handover of big planar object with vertical posture,” IEEE Trans. Automat. Sci. Eng., vol. 19, no. 2, pp. 1180–1191, Apr. 2022.

[11] https://revistas.udes.edu.co/aibi/article/view/4538

[12] https://ieeexplore.ieee.org/document/9202398/

[13] Https://ieeexplore.ieee.org/iel7/10011453/10011454/10011601

[14] https://ieeexplore.ieee.org/document/8869848

[15] https://ieeexplore.ieee.org/document/10805106/

[16] https://ieeexplore.ieee.org/document/9202398/

[17] https://ieeexplore.ieee.org/iel7/10011453/10011454/10011601

[18] https://ieeexplore.ieee.org/document/8869848

[19] https://ieeexplore.ieee.org/document/10805106/

[20] https://ieeexplore.ieee.org/document/10006164/

[21] https://ieeexplore.ieee.org/document/9257277/

[22] https://ieeexplore.ieee.org/document/10090067/

[23] https://ieeexplore.ieee.org/document/5756781/

[24] https://ieeexplore.ieee.org/document/1191232/

[25] https://ieeexplore.ieee.org/document/8869165/

[26] https://ieeexplore.ieee.org/document/10705149/

[27] https://ieeexplore.ieee.org/document/4018805/