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ROBOSORT: A SYSTEM FOR AUTOMATED SINGULATION AND SORTING OF PARCELS

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Abstract: The rapid growth of e-commerce and online shopping has significantly increased the demand for efficient parcel sorting solutions in logistics and distribution centres. Traditional manual sorting methods are often time-consuming, labour-intensive, and prone to errors. **"RoboSort: A System for Automated Singulation and Sorting of Parcels."** Addresses these challenges by leveraging advanced robotics, computer vision, and machine learning technologies to automate the parcel handling process. RoboSort is designed to streamline and enhance the efficiency of parcel sorting through its integrated components: robotic arms for handling parcel, computer vision systems for parcel identification and Singulation, and machine learning algorithms for accurate classification and destination sorting. The machine learning models within RoboSort analyze the collected data to determine optimal sorting paths; ensuring parcels are accurately directed to their designated outputs. This process significantly reduces manual intervention, increases throughout, and enhances sorting accuracy. Additionally, RoboSort includes robust quality control mechanism to detect and address damaged or misrouted parcels, thereby maintain high operational standards. Designed for scalability and adaptability, RoboSort can efficiently handle varying parcel volumes and evolving logistics requirements. This project demonstrates how automation and intelligent system can revolutionize the logistics industry, offering a solution that meets the growing demands of modern distribution networks. Through comprehensive testing and real-world application, RoboSort has proven its potential to optimize parcel sorting operation, leading to significant improvements in operational efficiency and cost-effectiveness.

Keywords: *Robotic arm, Singulation Robot, Barcode identification, Automated sorting system, Machine Learning, Optimization, Computer Vision, Real time Data, Iot Integration,*

Introduction: The problem of "Automated Singulation" is a major challenge for e-commerce companies, as it requires a lot of manual labour and can be time-consuming. By automating this process, companies can save time and money, increase productivity, and reduce the risk of injuries. Our robotic system can help solve this problem by using machine vision algorithms to detect individual packages from a group of packages, and a robotic arm with a gripper to pick up the package and drop it in the Drop Zone. The main scientific contribution of this article lies in evaluating an AI-based robot solution for automating the parcel-handling process. The proposed architecture tackles the challenges posed by diverse parcel characteristics, ensuring adaptability, efficiency, and reliability in parcel-sorting centers. The developed system and both the design choices and implementation in the physical setup are shown and described in detail. Various crucial aspects for implementing similar systems are discussed and possible shortcomings are identified. This concept of a pick-up-place robot can be used in an assembly line, E-commerce, supply chain, and distribution center. It is the development and modification of the type of robot that uses peripheral interface (PLC) Programmable logic control as the robot brain to control all the robotic movement. The results show that the system throughput capacity is significantly affected by robot congestion in the single-tier layout with the detour path topology, but it is only slightly affected in the other systems. A square layout fits the shortest path and a rectangular layout fits the detour path. Both the random assignment rule and the shortest queue assignment rule are superior for a large number of robots. In contrast, the dedicated assignment rule is superior for a small number of robots.

Literature Review:

"Automated Parcel Sorting System"

This paper discusses the use of a QR code scanner to read the QR code on packages and distinguish them from other parcels according to their portions. The system's output is 100 percent trustworthy and can be employed with large functioning systems in the future. Automated singulation and sorting of parcels is a common problem statement in the e-commerce industry. The most advanced automation today combines 3D machine vision, AI algorithms, and compatibility with major robot brands. However, the act of "Automated Singulation" still faces challenges. To address this issue, we need to build a robotic arm that can perform the act of "Automated Singulation" by picking up a parcel from a bulk of shipments and putting it on the conveyor belt. Our approach to solving this problem is unique because we are building a robotic arm that can detect and pick up individual packages from a bulk of shipments. We use computer vision techniques to detect the packages and use a robotic arm with a gripper to pick them up. Once the package is picked up, we use a barcode scanner to read the shipment barcode and ensure it is on top when dropped in the Drop Zone. We can use a combination of sensors and actuators to ensure that the package is dropped in the correct location.

Here are some research papers that can refer to Automated singulation and sorting of parcels Robotic Arm:

"Singulation and sorting of parcels can benefit from AI-powered robots" from Robot-report.com: This article discusses the challenges of manual singulation of parcels and how automation of this process can increase productivity, save costs and time, and reduce injuries. The article also discusses the use of AI-powered robots for singulation and sorting of parcels.

This paper discusses the use of infrared bar code detection based on radio frequency identification (RFID) technology for the delivery of information. The paper also discusses the use of a semi-automatic sorting machine based on machine learning algorithms.

There has been a lot of research on "Automated Singulation" and similar topics in recent years. Machine vision algorithms and robotics are being utilized by many companies to automate the sorting process, which has resulted in significant improvements in productivity and efficiency. Some of the key research papers in this area include. "Singulation and Sorting of Parcels Can Benefit from AI-powered Robots", which discusses how AI-powered robots can help automate the singulation and sorting process, and "Parcel and Packet Sorting System Automated by AI", which describes a robotic singulation and sorting system powered by artificial intelligence.

Singulation and sorting of parcels is a complex problem that has been the subject of extensive research in recent years. Machine vision algorithms and robotics are being utilized by many companies to automate the sorting process, which has resulted in significant improvements in productivity and efficiency. In addition to machine vision algorithms, many other technologies can be used for automated singulation and sorting of parcels. For example, some companies are using tilt-tray sorters, cross-belt sorters, sliding shoe sorters, or Activated Roller BeltTM (ARB) sortation equipment to automate the sorting process. These technologies can help ensure that parcels are sorted accurately and efficiently. Robotic systems in such environments have several prerequisites that are frequently not feasible to comply with due to different limitations of the manufacturing plant. A typical limitation is the availability of space to divide and position objects on one level, which is also the case for the problem addressed in this article. In the post office parcel-handling context, the sorting process can be fully automated; however, it requires a substantially large space in the factory or even redesigning the whole process, where an industrial robot system, if used at all, could then be deployed with a rather simple 2D vision system.

Several object manipulation systems, applicable to post office automation, have been developed in the past. A system for package handling automation employing a robot arm with a vacuum gripper is described in Mail piece singulation, i.e., removing items one by one from a moving conveyor was described in. They considered a bin-picking task, where a mix of objects with different shapes and weights should be grasped and removed, and designed a system comprising a range imaging camera, sparse data range imaging algorithm, grasp target selection algorithm, and a vacuum gripper.

Methodology:

1] Design and Drafting:

1.1) CAD System Design:

This design is been carried out in Solidwork with various dimension involved, the model has 2 robotic arm with suction gripper as per shown in Fig 1.1 and other model specify with 1 robotic arm with 1 degree of freedom suction gripper as per shown in Fig 1.2 .

The other part of the model are been designed. The basic idea for the robot mechanism was taken from this design. After the selection of the motors the necessary link lengths were decided and created using aluminum box bars. During the assembly of the robot the design changed considerably, the final design of the robot is as below.

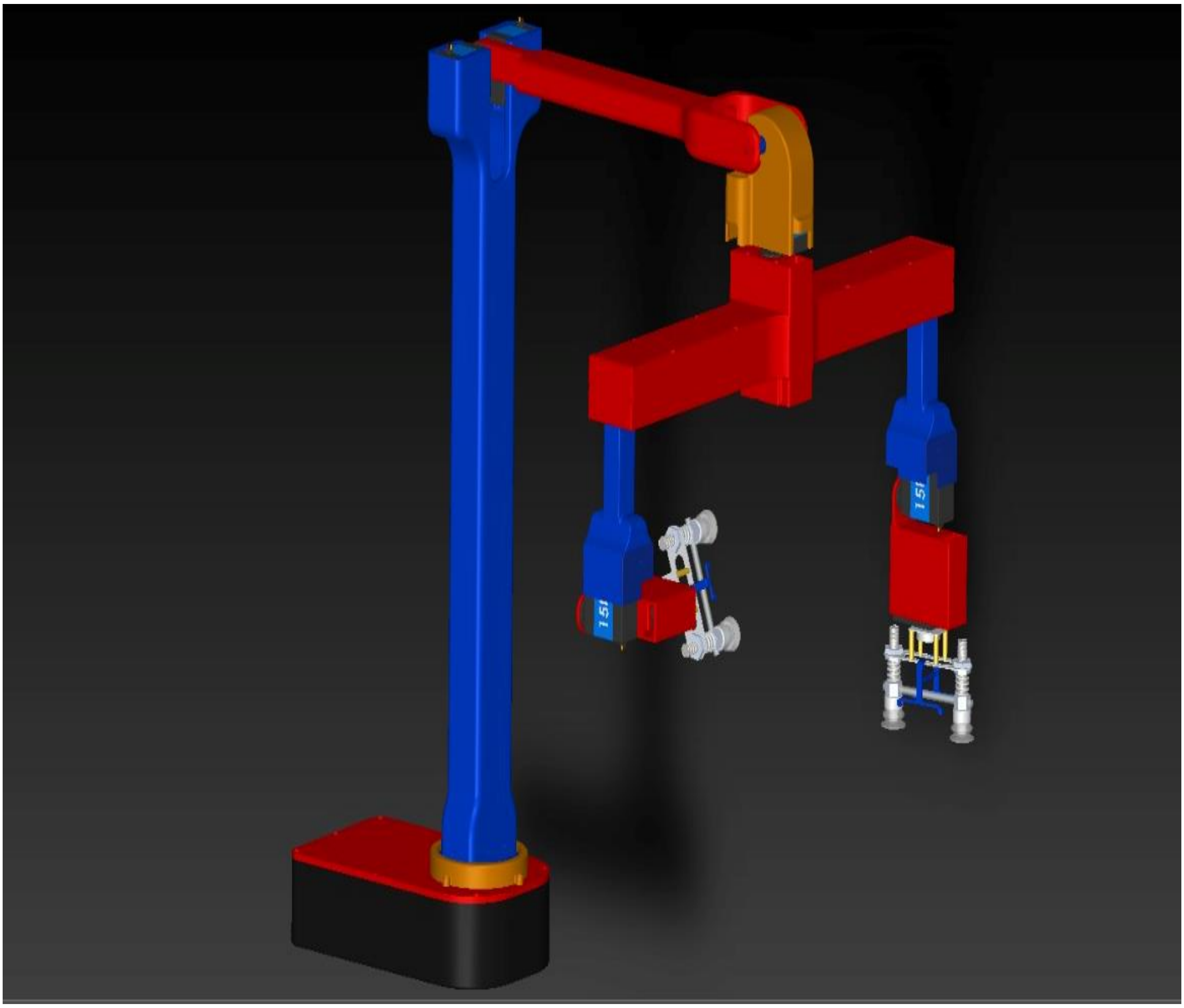

Fig.1.1 System with 2 robotic arm CAD Design

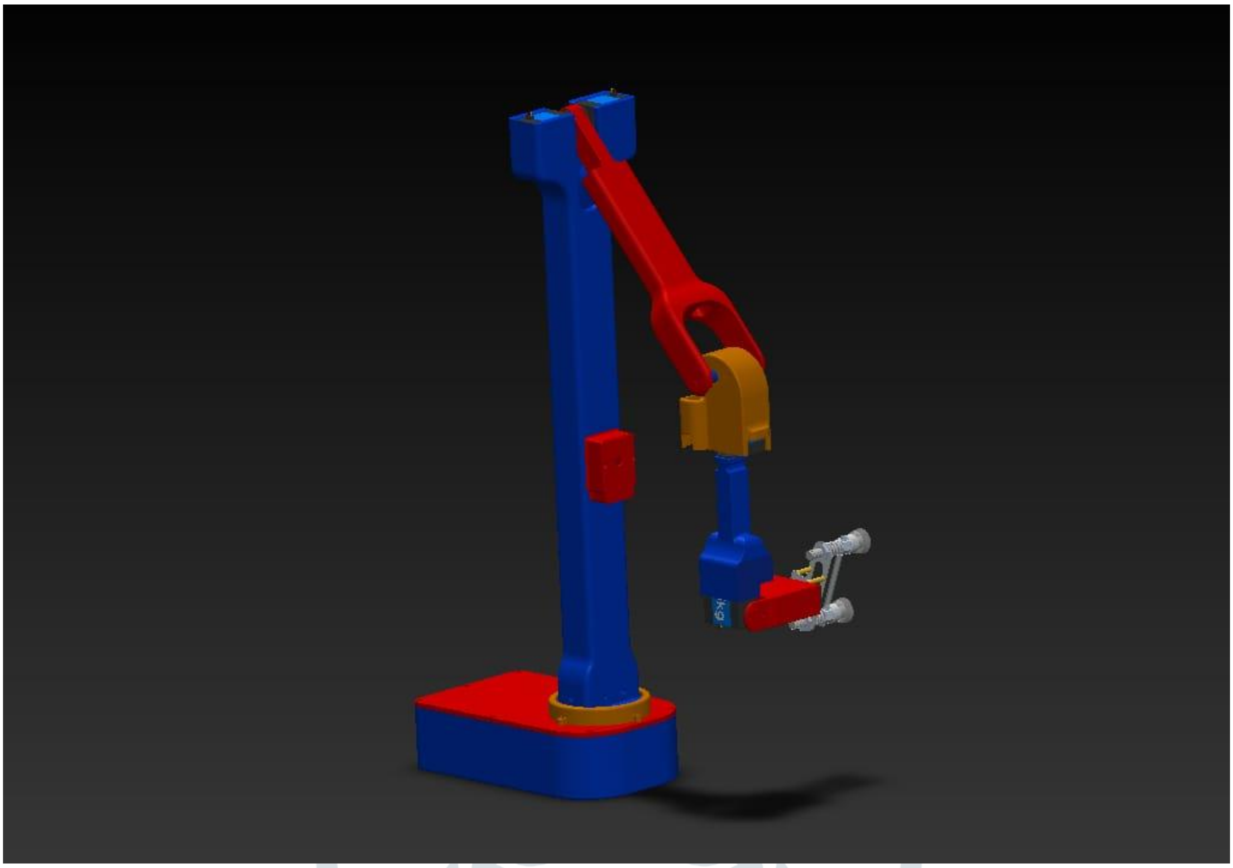

Fig.1.2 System with 1 robotic arm CAD Design

1.2 System Part CAD Model

1.2.1 Suction Gripper

The end – effectors of the robotic system vacuum grippers are a type of end effectors that uses suction to lift and manipulate objects. . They are widely used for robotic palletizing, which is the process of stacking and arranging products on pallets for transportation or storage

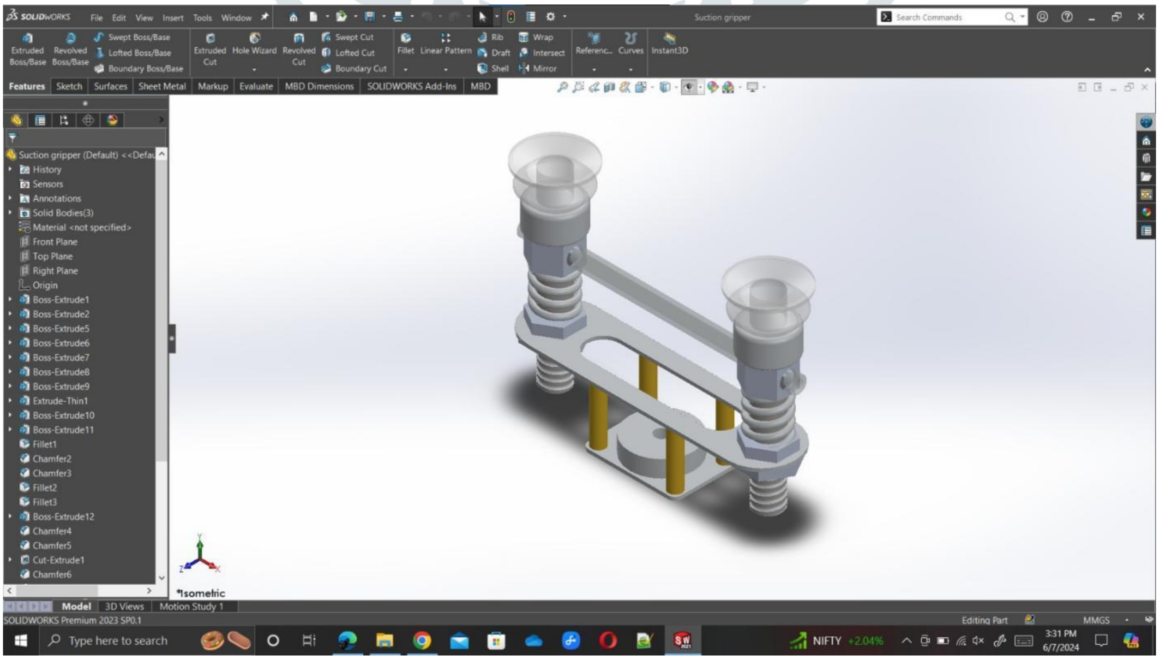

Fig 1.4 CAD Model of Suction Gripper

1.2.2 Torso

Creating an effective robotic torso mechanism is essential for achieving human-like mobility in robots. Past research has spotlighted the LARMbot humanoid's torso as a viable option. This paper introduces an innovative design, depicted in Figure 1.5, which represents a significant advancement over existing framework.

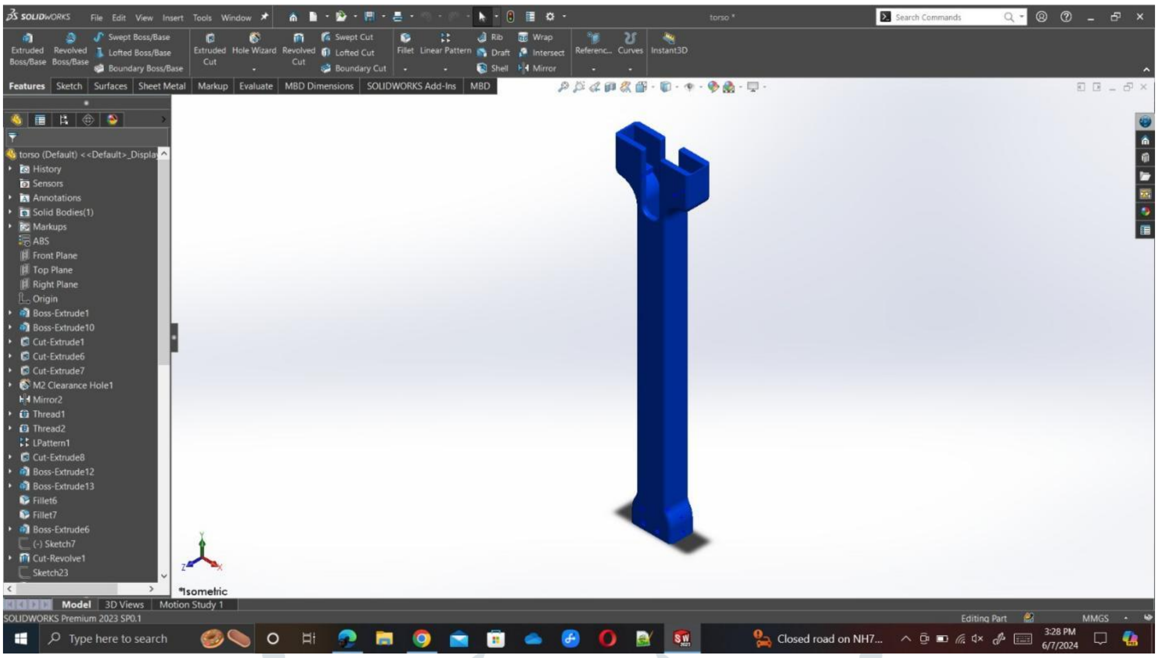

Fig 1.5 CAD Model of Torso

1.2.3 Shoulder Arm

The shoulder arm integrates with the rotating shaft to impart verticle motion to the robot. This component plays the very important role to the working of robot, as depicted in Fig. 1.6. It serves as the conduit for transmitting rotational force from the power source to the upper body of the robot which is a shoulder arm, enabling verticle reach and movement.

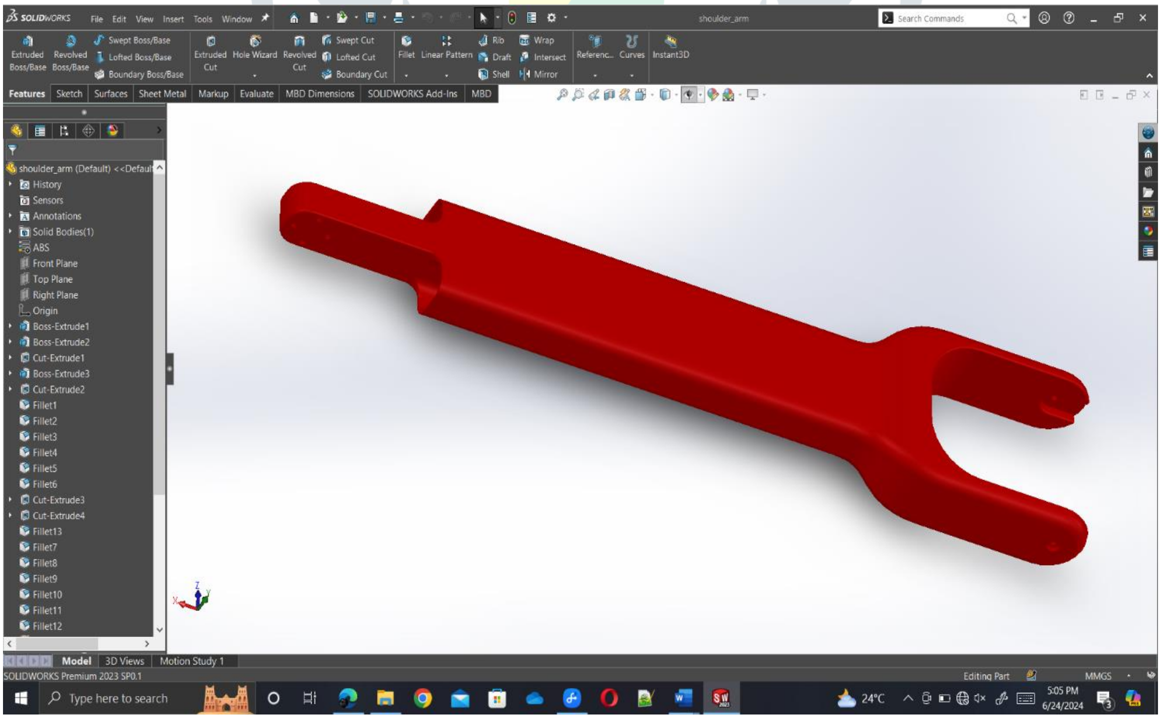

Fig 1.6 CAD Model of Shoulder arm

1.2.4 Shoulder Arm shaft

The shoulder integrates with the rotating shaft to impart rotational motion to the robotic arm. This component features a shaft-key combination connected at the base, as depicted in Fig. 1.7. It serves as the conduit for transmitting rotational force from the power source to the upper body of the robot arm, enabling horizontal reach and movement.

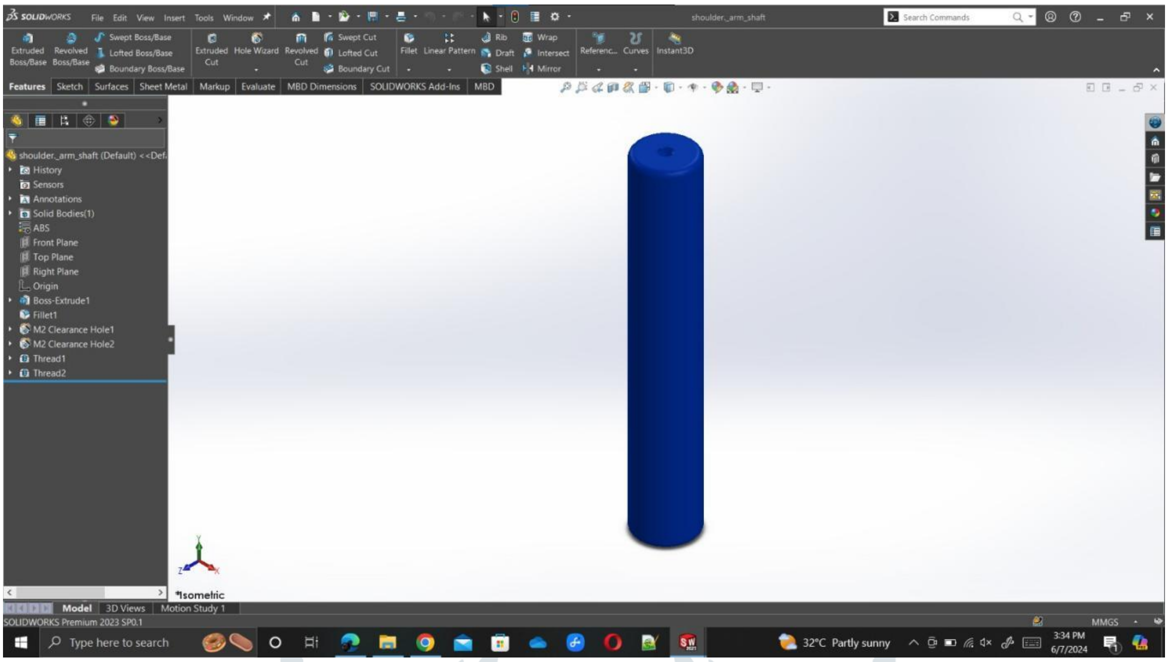

Fig 1.7 CAD Model of Shoulder arm shaft

1.2.5 Neck Joint

In robotics, the "neck" typically refers to a mechanical structure or joint that connects the robot's torso or body to its head or sensor array. This component allows the robot to move its shoulder in circular directions, enabling it to perceive its surroundings and interact with the environment more effectively.

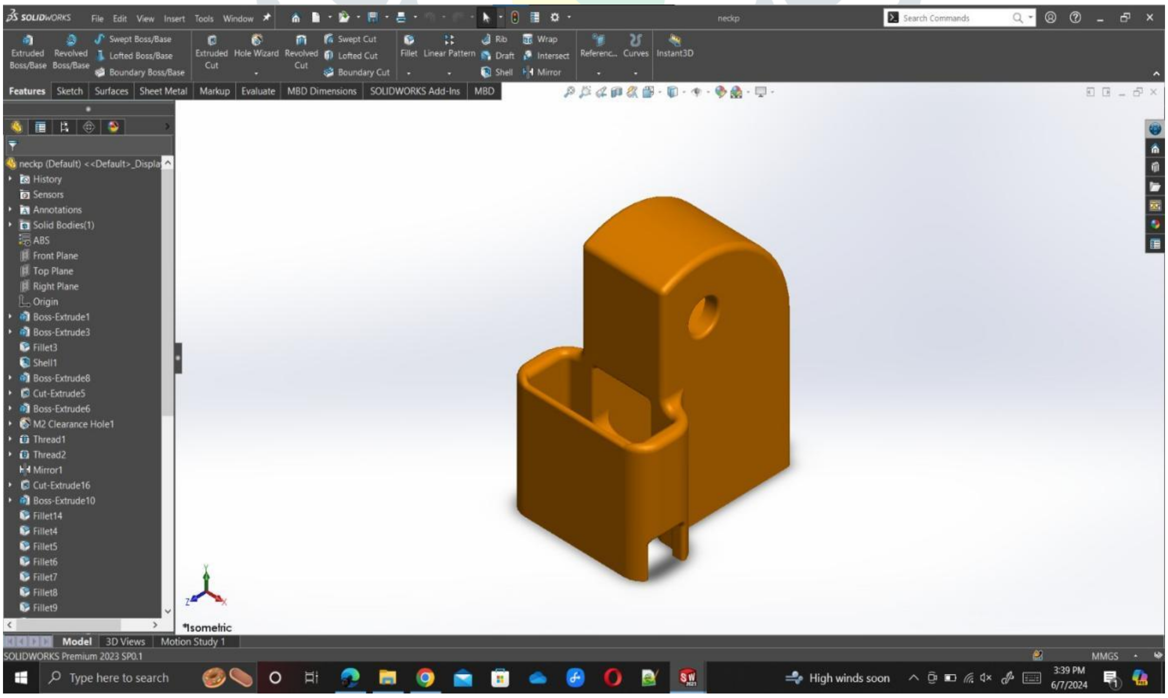

Fig 1.8 CAD Model of Neck Joint

1.2.6 Shoulder

The shoulder integrates with the rotating shaft of servo motor to impart rotational motion to the robotic arm. Meanwhile, the elbow joint connects the upper and lower arm segments. It facilitates bending motions that enable the arm to achieve circular motion and extend its reach.

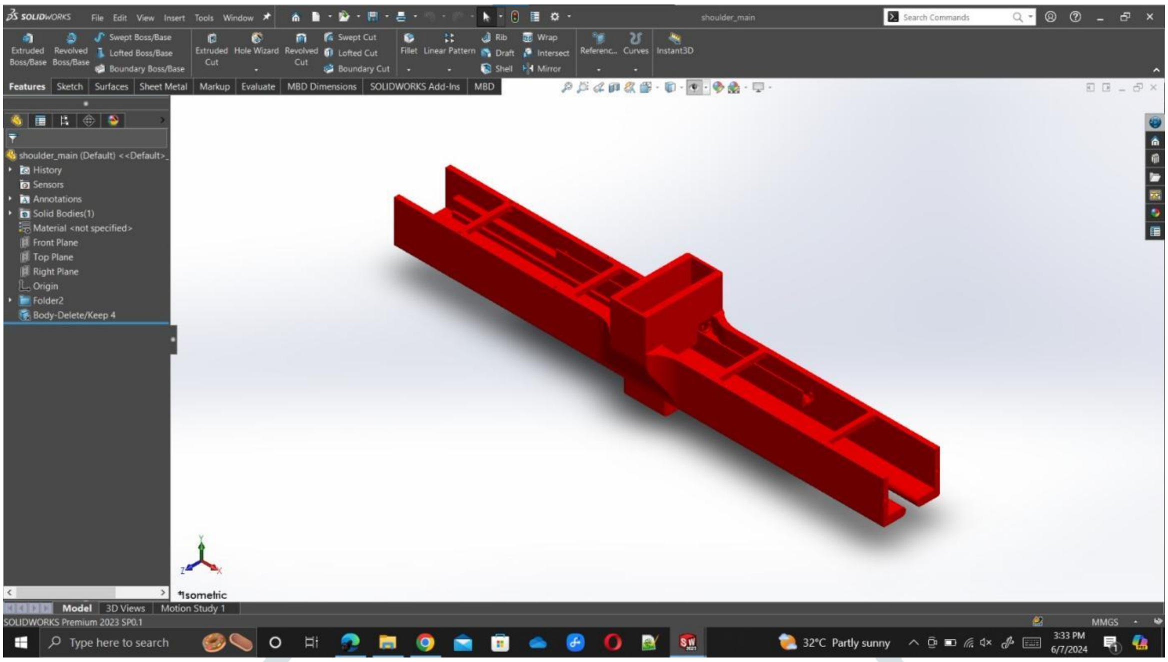

Fig 1.9 CAD Model of Shoulder

1.2.7 Right Bicep and Left Bicep

In robotics, the term "right bicep" generally refers to a component or joint within the robot's arm structure that mirrors the anatomical region known as the bicep in humans. This terminology is commonly used in humanoid robots or those engineered to replicate human movements.These robotic arms are typically segmented similarly to human arms, allowing for flexibility and dexterity in executing various tasks. The "right bicep" specifically denotes a part of the arm mechanism that corresponds to the bicep muscle, contributing to the robot's ability to perform movements akin to those of a human arm.

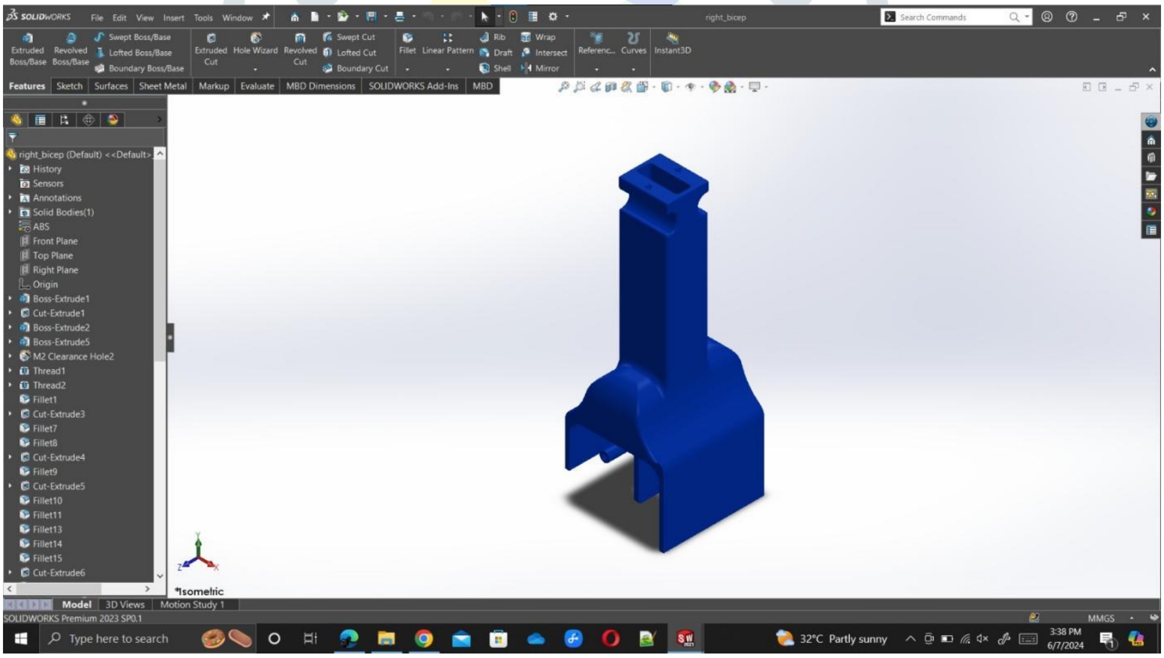

Fig 1.10 CAD Model of Right Bicep

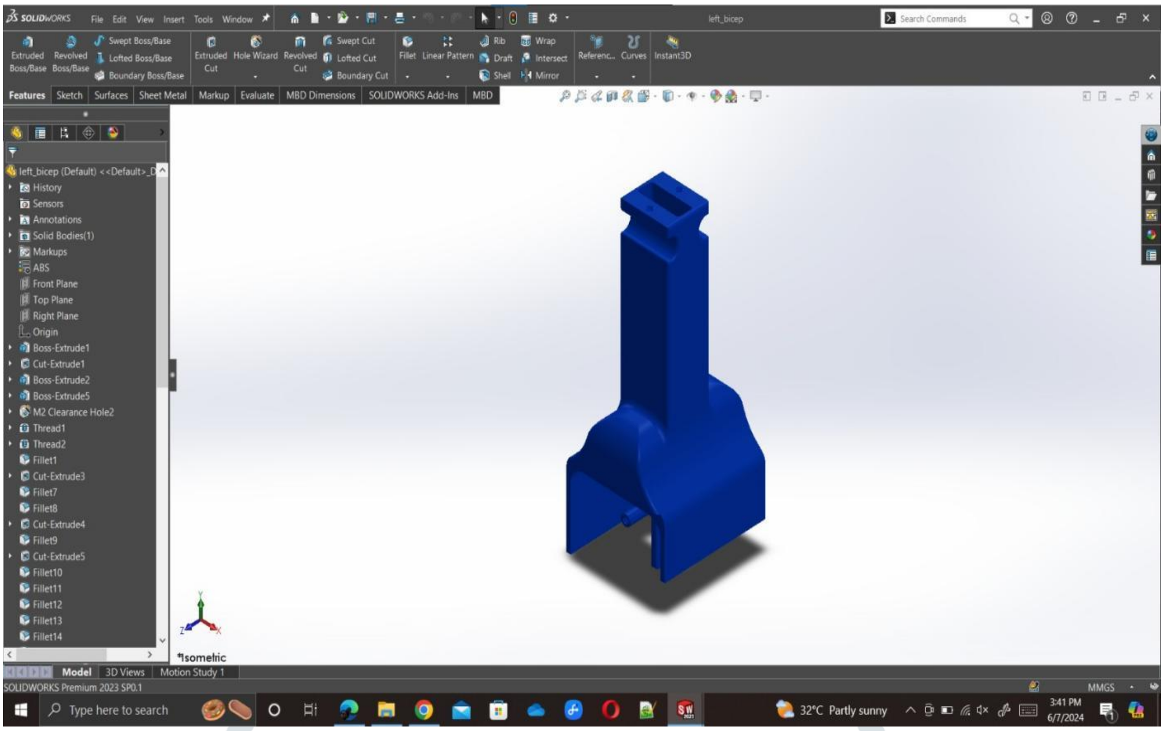

Fig 1.11 CAD Model of Left Bicep

1.2.8 Rack and Pinion

A rack and pinion is a type of mechanical linear actuator that converts rotational motion into linear motion. It consists of a gear (the pinion) and a linear toothed bar (the rack). The pinion, which is a small gear, meshes with the teeth of the rack

. When the pinion rotates, it engages with the rack, causing the rack to move linearly.Rack and pinion systems are commonly used in various applications where linear motion is required, such as in steering systems of automobiles, CNC machines, robotics, and other mechanisms requiring precise linear movement as shown in Fig 1.12

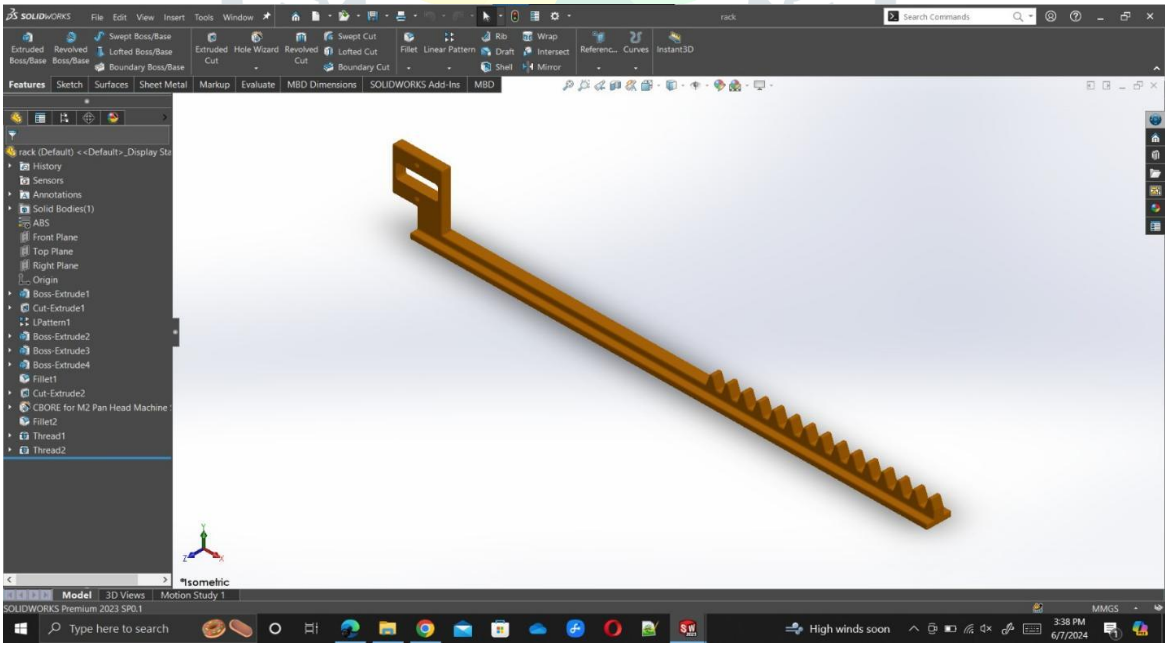

Fig 1.12 CAD Model of Rack

The advantages of rack and pinion systems include their simplicity, efficiency, and ability to provide precise linear motion. They are often preferred in applications where high accuracy and reliability are essential. However, they may not be suitable for applications requiring long travel distances, as the length of the rack is typically limited.

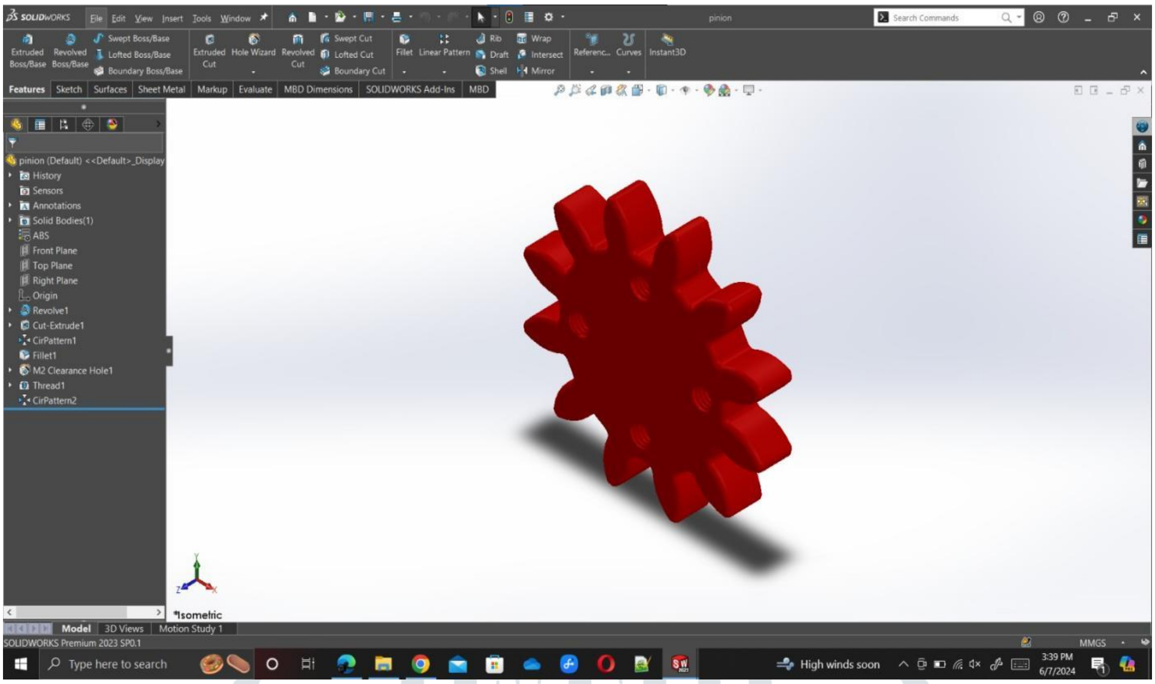

Fig 1.13 CAD Model of Pinion

1.2.9 Torso Bottom Disc

the torso has also a Yaw joint and the figure 6 shows the capability for the torso to combine both motions. To throw the canister, the robot moves its shoulder to the left and rotates its torso to any requested range of angle

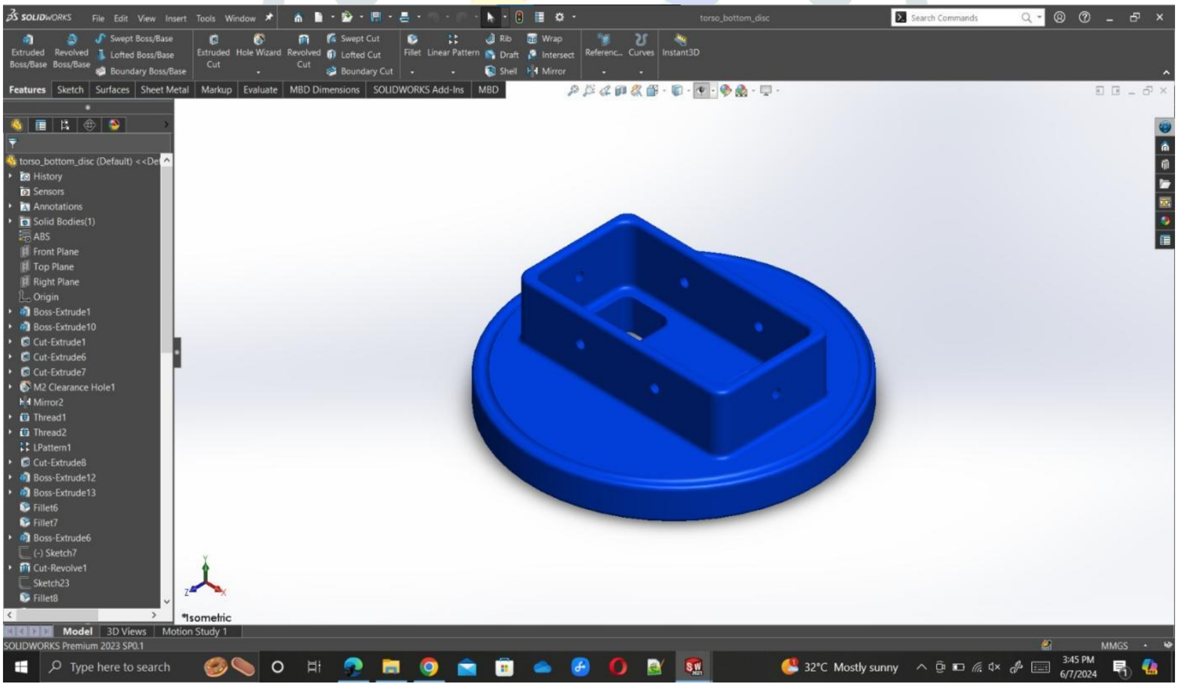

Fig 1.14 CAD Model of Torso Bottom Disc

1.2.10 Base

The "base" in robotics typically refers to the lowermost structural component of a robot on which other parts are mounted. It serves as the foundation upon which the entire robot is built and provides stability and support for the robot's movement and operation.

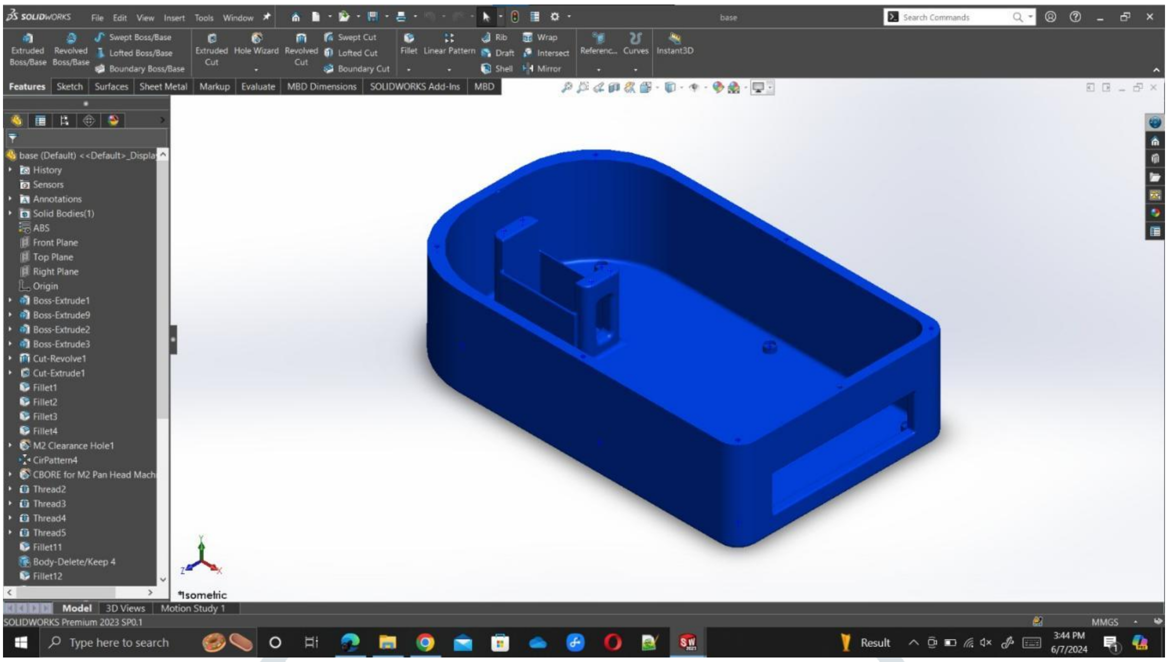

Fig 1.15 CAD Model of Base

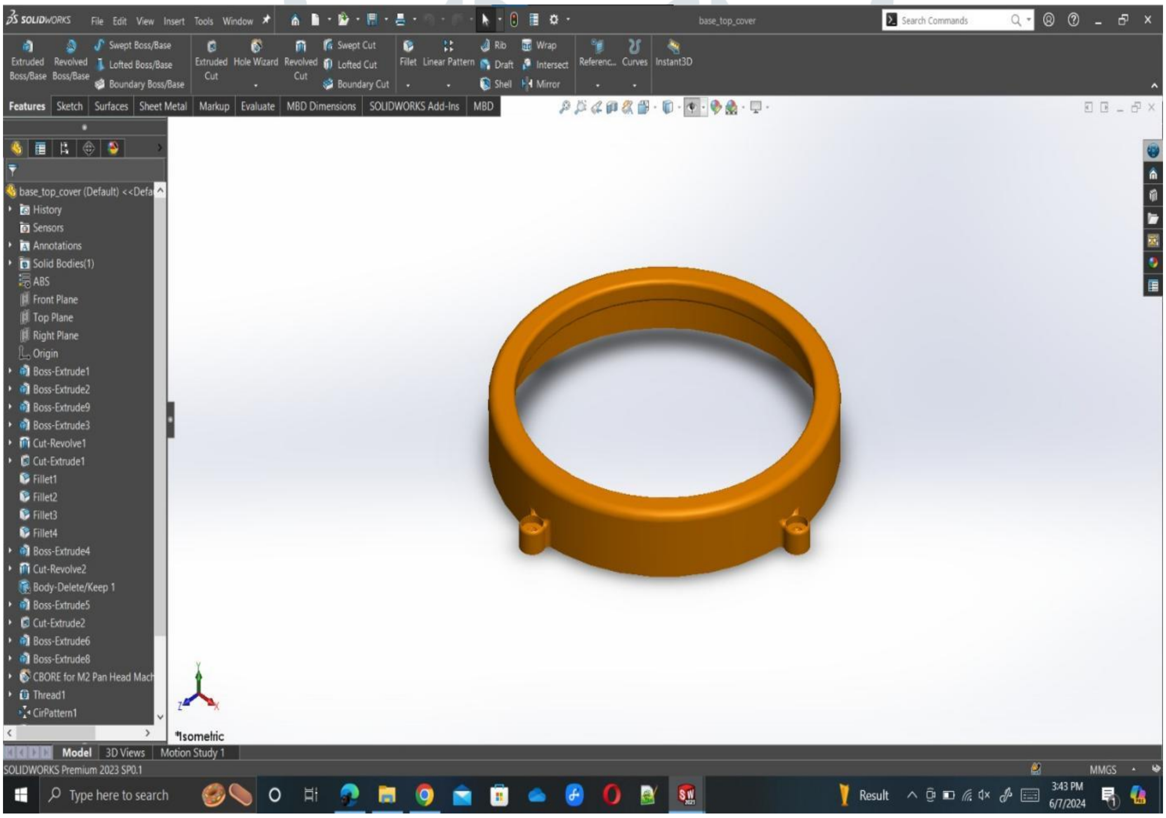

Fig 1.16 CAD Model of Base Top Cover

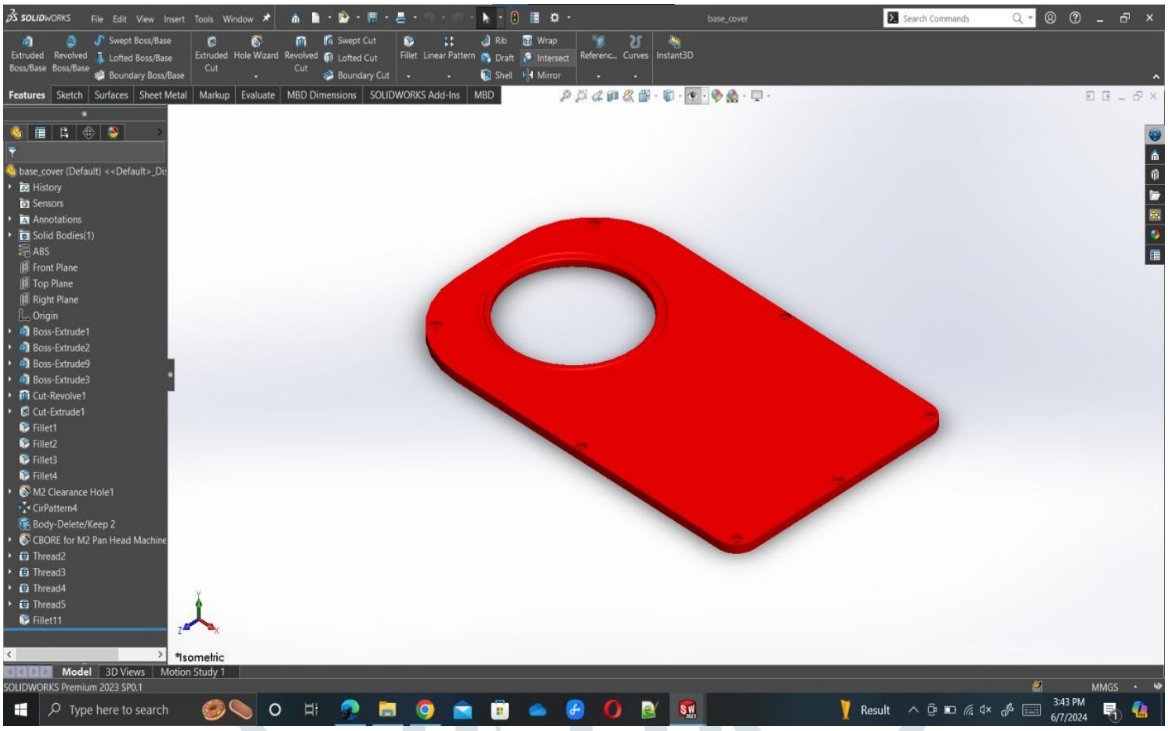

Fig 1.18 CAD Model of Base Cover

1.4] Payload Calculation

1) JOINT TYPES: - There are different types of joints that a robot can have, such as revolute, prismatic, spherical, and cylindrical. Each joint has a different degree of freedom, which is the number of ways it can move. For example, a revolute joint ca rotates around one axis, while a spherical joint can rotate around 3 axes.

2) LOAD WEIGHT: - The load weight is the mass of the object that the robot is lifting, multiplied by the gravitational accerlation. The gravitational accerlation is usually $9.81 m/s^2$ on earth, but it can vary depending on the location and altitude. The load weight is expressed in Newtons, which is the unit of the force. To calculate the load weight, you need to know the mass of the object and the gravitational accerlation.

3) ARM LENGTH: - The arm length is the distance from the joint to the load. The longer the arm, the more torque the joint needs to apply to lift the load. The arm length is expressed in meters, which is the unit of length. To calculate the arm length, you need to measure the distance from the joint to the load, or use the dimensions of the robot.

4) JOINT ANGLE: - The joint angle is the angle between the arm and the horizontal plane. The joint angle affects how much of the load weight is perpendicular to the arm, which is the component that creates torque. The joint angle is expressed in radians, which is the unit of angle. To calculate the joint angle, you need to use trigonometry or geometry, depending on the type of joint.

5)TORQUE FORMULA: - The torque formula is the equation that relates the torque, the load weight, the arm length, and the joint angle. The torque formula varies depending on the type of joint, but the general form is:

Torque = load weight x arm length x sin(joint angle)

This formula assumes that the load weight is perpendicular to the arm, and that the joint angle is measured from the horizontal plane. If these assumptions are not true, you may need to adjust the formula accordingly.

6) ILLUSTRATED CALCULATION: -

To calculate the Payload the final motor contains a torque of **15Kg-cm(15000gcm).** Since the length of the final link is roughly **6.5cm** the load calculated is as follows:

$$\text{Load weight} = \frac{Torque}{Arm\ length}$$

$$\text{Load weight} = \frac{35000}{6.59}$$

$$= 3888.89\text{g}$$

The final motor contains a torque of **35Kg-cm(15000gcm**). Since the length of the final link is roughly **9cm** the rough calculation of the load is **3888.89g.** Therefore, the robot can lift a weight of less than 2000g without any complications.

1.5] Material Selection

Robots are mostly built of common materials. Some specialized robots for clean room applications, the space program, or other "high tech" projects may use titanium metal and structural composites of carbon fibers. The operating environment and strength required are major factors in material selection. There are a wide variety of metals and composites available in the market these days. The selection of material is a very deep process.

For our project we used PLA material over ABS material as PLA is one of the easiest materials to 3D print successfully. Unfortunately, its low melting point also causes it to lose virtually all stiffness and strength at temperatures above 50 degrees Celsius. In addition, PLA is brittle, leading to parts with poor durability and impact resistance.

Although PLA is the strongest of these three plastics, its poor chemical and heat resistance force it into almost exclusively hobbyist applications.One of the most commonly used materials for 3D printing is PLA (Polylactic Acid). PLA is popular for several reason sEase of Use: PLA Biodegradability, Low Odor ,Versatility.The density of PLA (Polylactic Acid) typically ranges from around 1.24 to 1.27 grams per cubic centimeter (g/cm^3).

The physical properties of the PLA Material: -

PROPERTIES	VALUES
Density	1.24 gm/cm^3
Tensile strength	60 MPa
Flexural strength	108MPa
Elongation	9%
Young’s Modulus	3100 MPa
Short Hardness, D	85 Sh D
Melting Temperature	145 - 160 ˚C
Glass Transition Temperature	56 – 64 ˚C

Table 1.1 Physical Properties of the PLA material

We used 3dPrinting Technique to manufacture all the part below are the part and assembly of the prototype. Some printable polymers, such as Polylactic acid (PLA), allow the surface finish to be smoothed and improved using chemical vapor processes] based on acetone or similar solvents.

Some additive manufacturing techniques can benefit from annealing as a post-processing step. Annealing a 3D-printed part allows for better internal layer bonding due to recrystallization of the part. It allows for an increase in mechanical properties, some of which are fracture toughness, flexural strength, impact resistance, and heat resistance. Annealing a component may not be suitable for applications where dimensional accuracy is required, as it can introduce warpage or shrinkage due to heating and cooling.

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Fig 1.19a 3d Printed Part

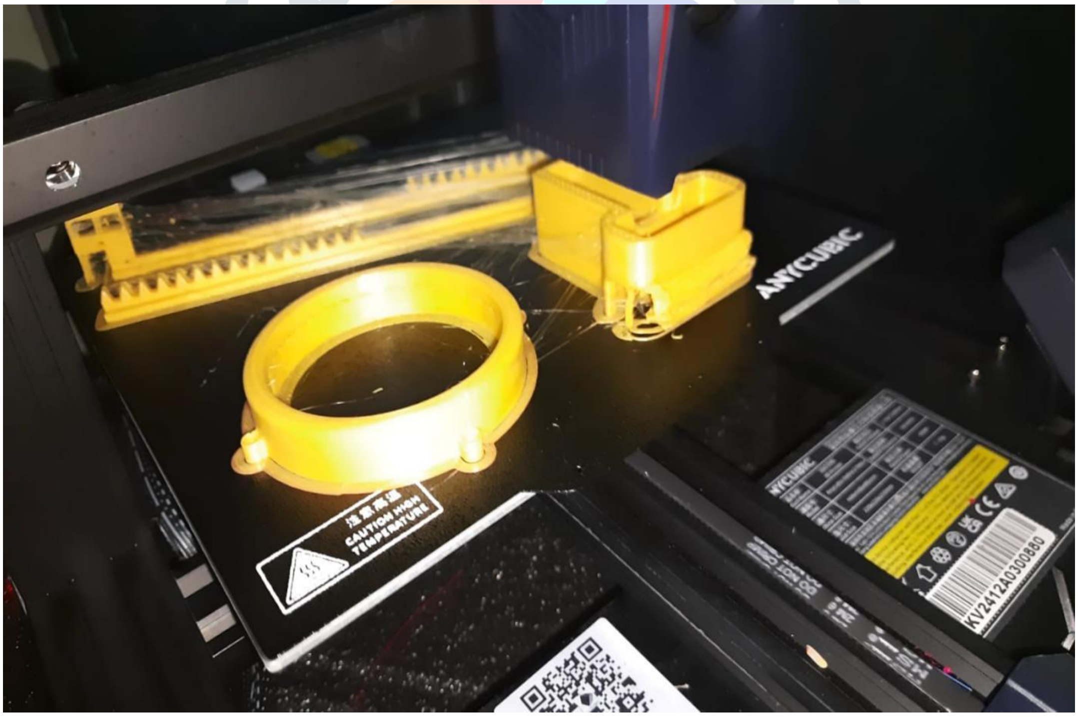

Fig 1.19 b 3d Printed Part

1.3.1] Assembly of the Prototype

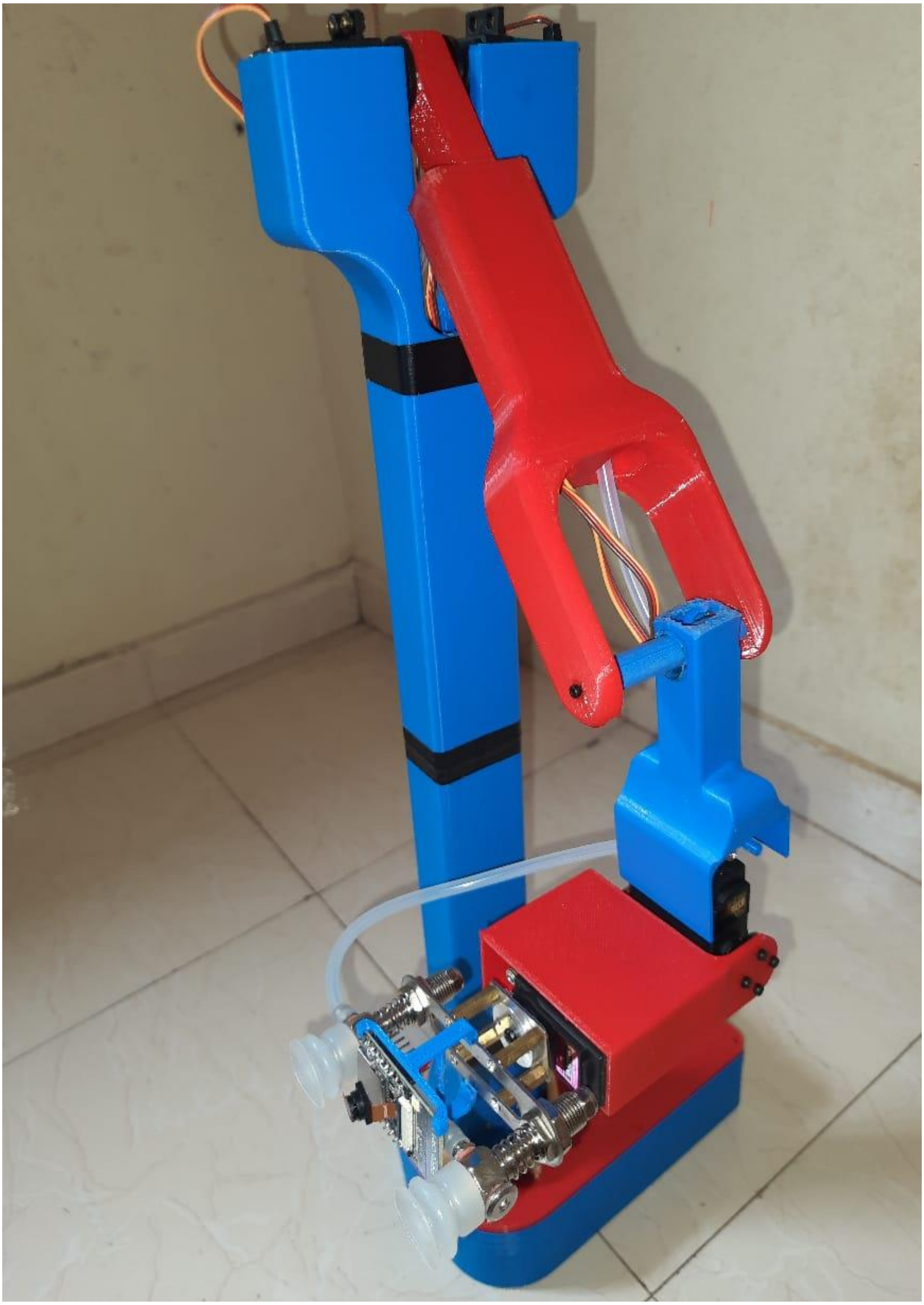

Fig 1.20 Assembly of Robotic arm (Single Handed Version)

2] Testing of the Prototype

Robotics testing is a multifaceted process designed to ensure that robotic systems perform safely, efficiently, and as intended in their respective environments. This process involves various methods, including simulation, real-world scenario testing, and user experience trials

We performed testing of the robot where the shoulder arm is of approx 33cm and with 2 motor situated of 15 kg-cm after testing we came to conclusion that it can lift upto 180 to 200 g as shown in fig 2.1

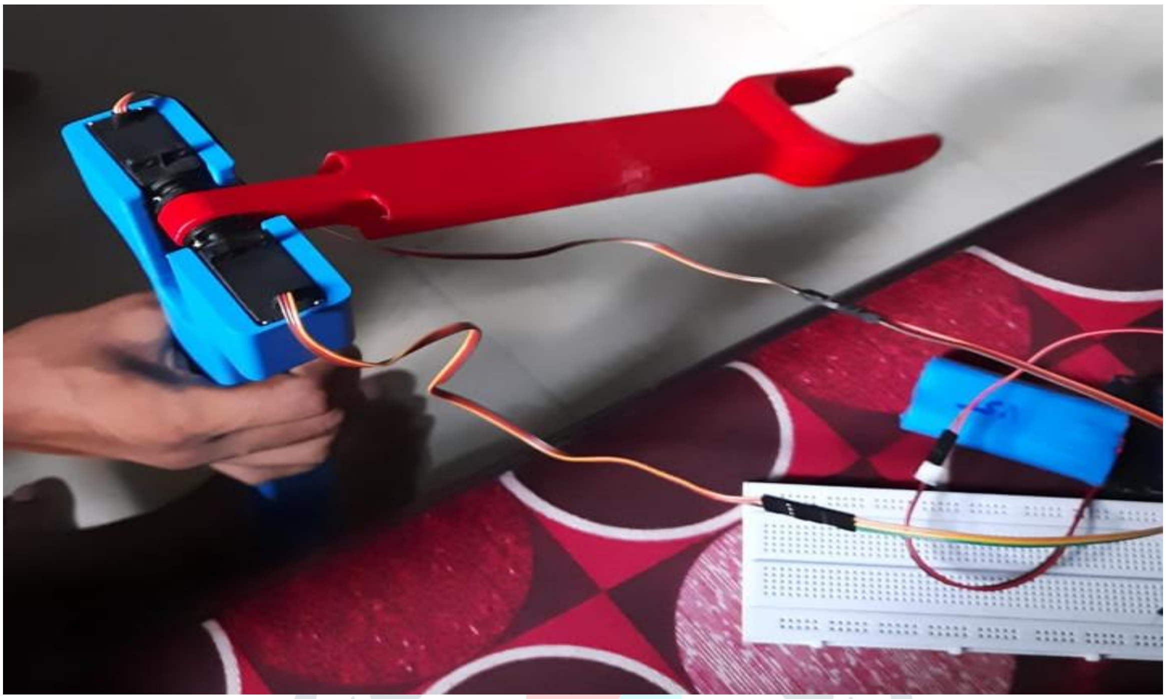

Fig 2.1 Testing Prototype

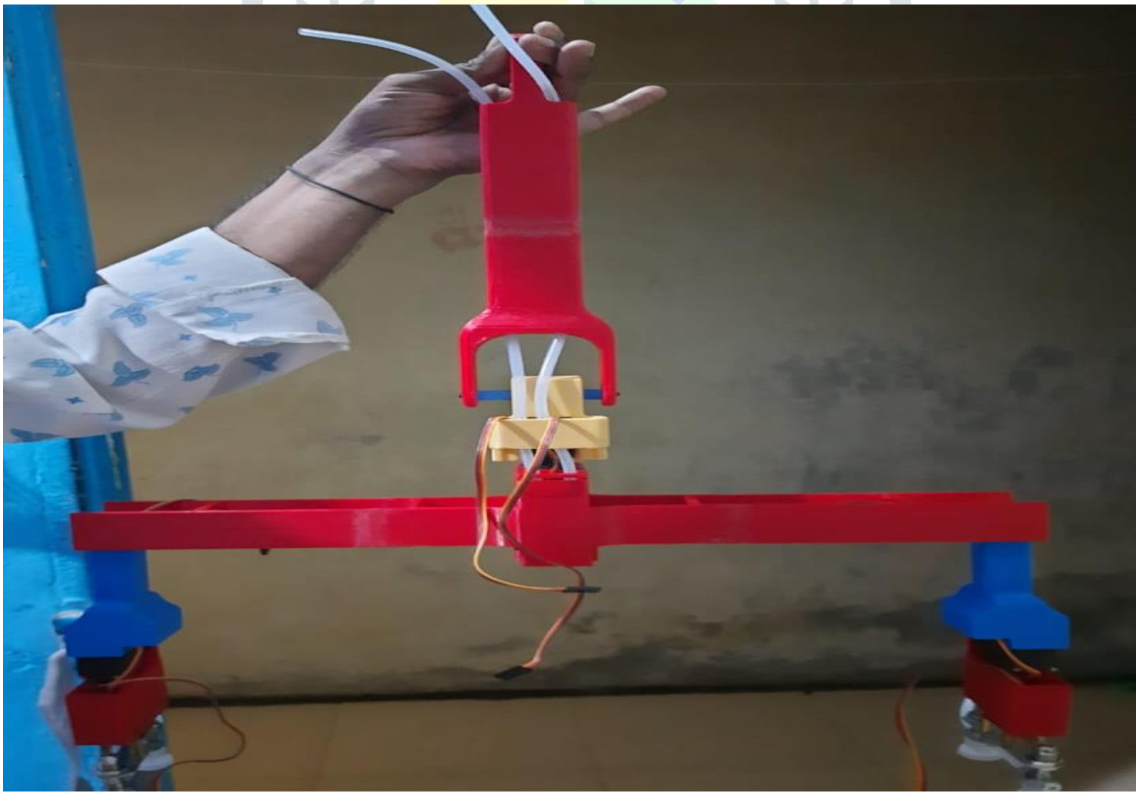

Fig 2.2 Assembly of 2 robotic arm

3] Component Selection:

3.1 Ultrasonic sensor

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. An ultrasonic sensor uses a transducer to send and receive ultrasonic pulses that relay back information about the proximity of an object.

High-frequency sound waves reflect across boundaries to produce distinct echo patterns. The working principle of this module is simple. It sends an ultrasonic pulse out at 40 kHz, which travels through the air, and if there is an obstacle or object, it will bounce back to the sensor. By calculating the travel time and the speed of sound, the distance can be calculated.

Our ultrasonic sensors, like many others, use a single transducer to send a pulse and to receive the echo. The sensor determines the distance to a target by measuring time lapses between the sending and receiving of the ultrasonic pulse.

Fig.3.1 Ultrasonic Sensor

3.2 Touch Sensor (Tactile Sensor)

A touch sensor is an electronic sensor used in detecting and recording physical touch. A touch sensor works like a switch, where when there's contact, touch, or pressure on the surface of a touch sensor, it opens up an electrical circuit and allows currents to flow through it.

Grove - Touch Sensor is based on **TTP223-B** touch detector IC. The TTP223 is a touchpad detector IC that offers 1 touch key.

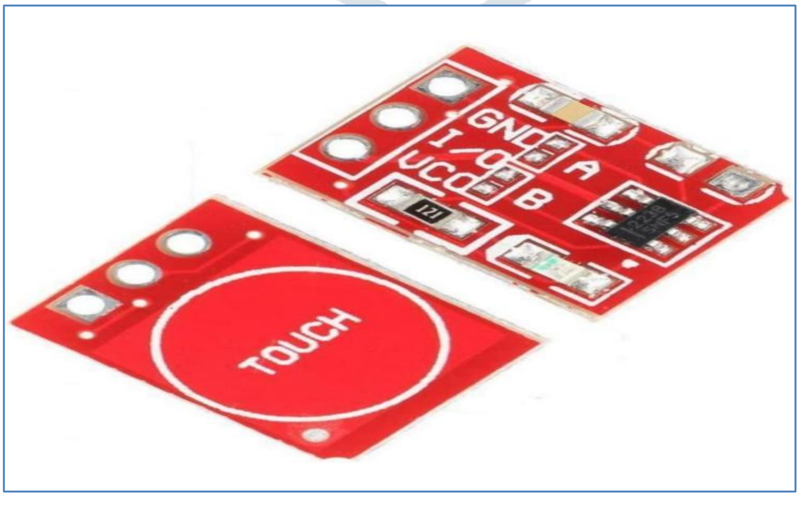

Fig.3.2 Touch Sensor

3.3 Accelerometer Sensor

An accelerometer is an electromechanical device that measures acceleration forces.

The forces may be static or dynamic. If you have the amount of static acceleration due to gravity, you can find out the angle the device is tilted concerning the earth's surface. It can be used to measure vibration on vehicles, safety monitoring devices, industrial machines, and process control systems..

. The more sensitive the accelerometer, the more easily it can measure acceleration.

Fig.3.3 Accelerometer Sensor

3.4 Jumper wire

A jump wire (also known as jumper, jumper wire, DuPont wire) is an electrical wire, or group of them in a cable, with a connector or pin at each end (or sometimes without them – simply "tinned"), which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering.

Fig 3.4 Jumper Wires

3.5 Camera Module

ESP32-CAM is a low-cost ESP32-based development board with an onboard camera, small in size. The board integrates WiFi, traditional Bluetooth, and low-power BLE, with 2 high-performance 32-bit LX6 CPUs. It adopts a 7-stage pipeline architecture, on-chip sensor, Hall sensor, temperature sensor, and so on, and its main frequency adjustment ranges from 80MHz to 240MHz. Fully compliant with WiFi and Bluetooth 4.2 standards, it can be used as a master mode to build an independent network controller, or as a slave to other host MCUs to add networking capabilities to existing devices ESP32-CAM can be widely used in various IoT applications.

Fig.3.5 Camera Module

3.6 Arduino Mega

An Arduino is an open hardware development board that can be used by tinkerers, hobbyists, and makers to design and build devices that interact with the real world. While Arduino refers to a specific type of board design, it can also be used to refer to a company that manufactures a specific implementation of these boards and is typically also used to describe the community around compatible boards made by other people or companies that function similarly.

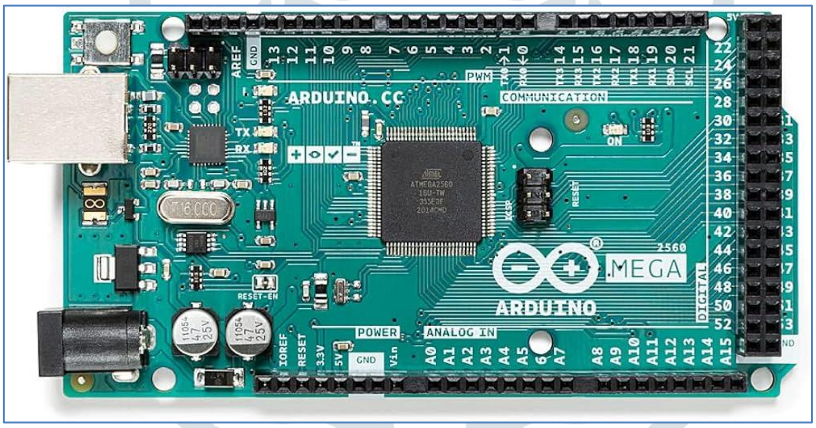

Fig 3.6 Arduino Mega

Several pins, are used to connect with various components you might want to use with the Arduino. These pins come in two varieties:

1] Digital pins, which can read and write a single state, on or off. Ithas54 digital I/O pins.

2] Analog pins, which can read a range of values, and are useful for more fine-grained control. Most Arduinos have six of these analog pins.

These pins are arranged in a specific pattern, so that if you buy an add-on board designed to fit into them, typically called a “shield,” it should fit into most Arduino-compatible devices easily.

The exact chip varies depending on what type of Arduino you buy, but they are generally Atmel controllers, usually ATmega8, ATmega168, ATmega328, ATmega1280, or ATmega2560. The differences between these chips are subtle, but the biggest difference a beginner will notice is the different amounts of onboard memory.

A serial connector, which on most newer boards is implemented through a standard USB port.

3.7 Servo Motor

Servo motors are used in robotic applications that require precise positioning and significant control of the shaft position. They are used to power robotic arms and grippers, ensuring the arms and joints move precisely to achieve the desired angles.

Fig.3.7 Servo Motor

Depending on the pulse width modulation (PWM) of the input signal, the servo will rotate a certain amount. At rest, the output spline of a servo is usually at 0°. Based on an expected pulse frequency of 20 milliseconds (ms), a pulse width of 1.5ms will make the output spline rotate 90° in one direction. A pulse width of 2ms will make the output spline continue rotating 90° further to the 180° position. A pulse width of 1 ms will make the A key feature of servos is proportional operation. A servo motor will operate only as fast as it needs to rotate from its current position to its desired position. If a servo is stopped at the 180° position but needs to be at the 0° position, the motor will rotate very quickly to get there..

3.8 Suction Gripper

Vacuum grippers are used for a wide range of products from cases to soft flexible packaging, but are most commonly seen handling objects that are smooth, flat, and solid. These grippers use soft rubber, plastic, or elastic suction (vacuum) cups to pick items so there is no damage to the product being handled.

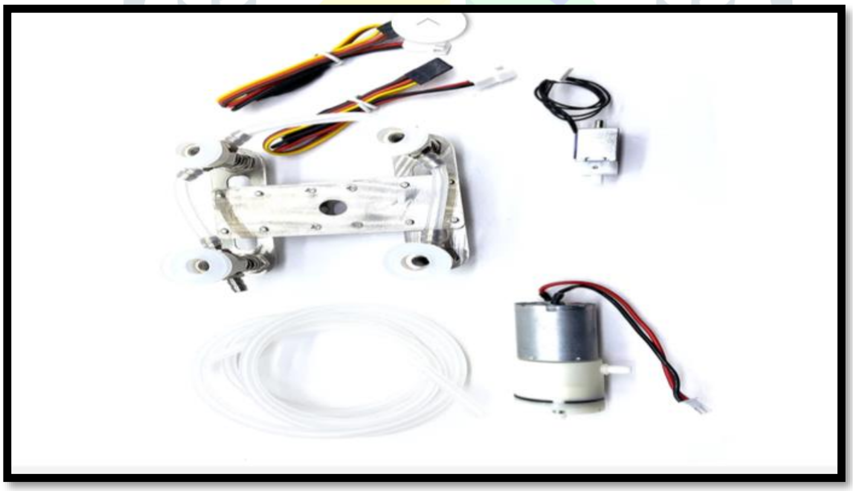

Fig.3.8 Suction Gripper

For picking up a small cuboidal cardboard box with dimensions of approximately 30 cm x 30 cm x 30 cm and a weight ranging from 200 grams to 500 grams, you would want a suction cup that provides sufficient gripping force to securely hold the box without damaging it. Here are a couple of options that would be suitable:

Flat Suction Cups: Flat suction cups are a good choice for handling flat surfaces like cardboard boxes. Choose a size that comfortably fits the surface area of your box, ensuring that the suction cup can create a strong seal. Since the weight of your box is relatively light (200 to 500 grams), a standard flat suction cup with a diameter of around 50 to 70 mm should sufficient.

Result and Discussion:

Automated parcel singulation and sorting systems represent a pivotal advancement in modern logistics, revolutionizing the efficiency and speed of parcel handling. These systems integrate cutting-edge technologies such as robotics, advanced sensors, and AI-driven algorithms to achieve swift and accurate sorting of parcels based on destination, size, and other parameters. Research indicates significant improvements in operational efficiency, with automated systems capable of processing large volumes of parcels rapidly, thereby reducing turnaround times and enhancing overall logistics performance. Companies leveraging these technologies, like Amazon and UPS, showcase tangible benefits such as reduced labor costs, increased throughput, and improved customer satisfaction due to faster delivery times. Despite initial investment costs and integration challenges, the ongoing development and adoption of these systems underscore their pivotal role in shaping the future of logistics, promising continued advancements in scalability, adaptability, and cost-effectiveness.

Conclusion and future work:

1] In conclusion, automated parcel singulation and sorting systems mark a significant advancement in the logistics sector, revolutionizing the handling of parcels with their integration of robotics, advanced sensors, and AI algorithms. These systems not only streamline operations but also offer substantial benefits such as reduced operational costs, enhanced processing speed, and improved accuracy in sorting. Companies at the forefront of this technology, like Amazon and UPS, demonstrate tangible improvements in efficiency and customer satisfaction through faster delivery times and reliable service.

2] Looking forward, the future scope of automated parcel sorting systems is promising. Further integration with emerging technologies such as IoT and machine learning promises to refine sorting processes, optimize resource allocation, and predict demand patterns more accurately. Innovations in sustainable practices and the adoption of eco-friendly technologies are expected to enhance environmental stewardship within logistics operations. Moreover, advancements in autonomous vehicles and drones could extend the reach and efficiency of last-mile delivery, complementing the capabilities of automated sorting centers.

3] As these technologies continue to evolve and expand globally, automated parcel singulation and sorting systems are poised to play an increasingly pivotal role in shaping the future of logistics, offering greater efficiency, reliability, and adaptability to meet the dynamic demands of e-commerce and global supply chains.

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