DEVELOPMENT AND ANALYSIS OF ROBOTIC ARM WITH MULTI-GRIPPER MECHANISM

A PROJECT REPORT

Submitted in partial fulfillment for the award of the degree of

B.Tech

in

Mechanical Engineering

By

KHYATEE BOROOWA - 14BME0288

ADHEESH CHATTERJEE - 14BME0855

School of Mechanical Engineering

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

APRIL, 2018

DECLARATION BY THE CANDIDATE

I hereby declare that the project report entitled "**DEVELOPMENT AND ANALYSIS OF ROBOTIC ARM WITH MULTI-GRIPPER MECHANISM**" submitted by me to Vellore Institute of Technology University, Vellore in partial fulfillment of the requirement for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering** is a record of bonafide project work carried out by me under the supervision of **Prof. Senthil Kumar S**. I declare that this report represents my concepts written in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I further declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed. Further I affirm that the contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Place: Vellore

Signatures of the Candidates

Date:

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

School of Mechanical Engineering

<u>BONAFIDE CERTIFICATE</u>

This is to certify that the project report entitled "**DEVELOPMENT AND ANALYSIS OF ROBOTIC ARM WITH MULTI-GRIPPER MECHANISM"** submitted by **Khyatee Boroowa (14BME0288)** and **Adheesh Chatterjee (14BME0855)** to Vellore Institute of Technology University, Vellore, in partial fulfillment of the requirement for the award of the degree of **B.Tech.** in **Mechanical Engineering** is a record of bonafide work carried out by him/her under my guidance. The project fulfills the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

Project Supervisor **Project Coordinator**

Head of the Department **External Examiner**

ACKNOWLEDGEMENT

We take this opportunity to express our profound gratitude and deep regard for our guide **Prof. Senthil Kumar S, Associate Professor**, **SMEC** for his guidance, support and constant encouragement throughout the course of this project. The blessing, help and guidance given by him from time to time shall carry us a long way in the journey of life on which we are about to embark.

We also take this opportunity to express a deep sense of gratitude to **Prof. Devendranath Ramkumar, Head of Department**, **SMEC** for his cordial support, valuable information and guidance, which helped us in completing this task through various stages. We would also like to extend our deepest gratitude to **Prof. Arivazhagan N, Dean**, **SMEC** for all his efforts in choosing the topic and keeping us on the right path throughout.

We would also like to thank the team of **VICARA Tech** and its founders **Mr. Adarsh Warrier** and **Mr. Abhishek Satish** for their continuous support and their generosity in providing us with the resources and the 3D printing machine that helped us conduct our project in campus successfully.

Our sincere thanks to **VIT University** for giving us the opportunity to carry out this project and for providing us with all the facilities to complete this project.

Place : Vellore **(Adheesh Chatterjee)**

Date : **(Khyatee Boroowa)**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AC	Alternating Current
ASTM	American Society for Testing and Materials
Bar	Bar Pressure
^{0}C	Celcius
CNC	Computer Numerical Control
DC	Direct Current
DOF	Degrees of Freedom
FC	Force Criterion
FCV	Force Convergence Value
GPa	Gigapascal
h	Hour
HRI	Human Robot Interface
IK	Inverse Kinematic
Kg	Kilogram
kg/m^{3}	Kilogram per Cubic Metre
kN	Kilonewton
LSC	Load Step convergence
LWR	Light Weight Robot
M	Metre
MHz	Megahertz
min	Minute
mm	Millimetre
MMI	Institute of Man-Machine Interaction
MPa	Megapascal
N	Newton
PUMA	Programmable Universal Manipulation Arm
SCARA	Selective Compliance Articulated Robotic Arm
µm	Micrometre

ABSTRACT

The development of widespread grippers and their capacity to pick up new objects of broadly varying shapes, sizes and material properties still remains a challenging test. The current design brings in a lot of complexities including a substantial number of controllable joints, a requirement for force sensing so objects can be taken care of without crushing them and the requirement for application of stress of each finger in the gripper. In this project, we utilize a new approach where individual fingers are replaced by a solitary mass of granular material which when pressed onto a target object, conforms around it and fits in with its shape. Upon application of a vacuum, the granular material contracts and jams rapidly to hold the object without requiring sensory feedback. The operating principle is the capacity of granular materials to change between an unjammed, deformable state and a jammed state with a strong like unbending nature. We depict three separate mechanisms – friction, suction, and interlocking, that add to the gripping power. Utilizing a simple model, we relate every one of these mechanisms to the mechanical strength of the jammed state. This headway opens up new possibilities for the design of simple, yet exceedingly adaptive frameworks that excel at quick gripping of complex objects.

Keywords: Jamming; Stress-strain; Friction; Suction; Interlocking

CHAPTER 1

1 INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

The term "robotics" has not only increase our overall knowledge and idea about robots but also acknowledged the immense productivity of a robot in real world. Nowadays, the gap between new research discoveries and reliable products is often so large that it is impossible to envision specific impacts with much clarity. Clarifying the real-world impact of a new technology can only occur through the process of commercialization. If a robotic technology cannot eventually exist as a successful commercial enterprise, its usefulness is dubious at best. The type of research now sometimes referred to as "rigid robotics" has successfully transitioned research-level technologies to commercially viable products time and again. The field of "soft robotics" is still very new and advancements have just started being developed in this field. The focus of our work is on gripping and not manipulation. Thus, complexities like tactile sensing and computer vision play no part. The approach we take replaces individual fingers by a material that upon contact molds itself around the object. This would make the gripper universal as it can conform around arbitrary shapes and that too without requiring sensory feedback. This reduces the number of elements to be controlled and provides various advantages like reliability of component, cost of product and gripping speed.

1.2 LITERATURE REVIEW

The robotics industry was originally developed to supplement or replace humans by doing dull, dirty, or dangerous work. They are used in applications such as: automated assembly lines, observing radiation zones, minimally evasive surgery, and space exploration. Modern industrial robotic arms excel over humans in many tasks. They are capable of lifting 1000 kg [Siciliano et al. (2008)], are repeatable to 10 µm [Monkman et al. (2007)] and are faster with accelerations up to 15 g [Krüger (2009)]. Additionally, the cost of robotic grippers is decreasing while manual labor costs are increasing. This has encouraged industry and academia to develop more advanced robotic arms and grippers addressing both form closure and force closure [Siciliano et al. (2008)], two of the main components of any robotic gripper. Robotic grippers, by directly being in contact with the workpiece, are tasked with interaction with the environment and grasping objects like human hands for human manipulation [Monkman et al. (2007)].

Advanced grasping of complicated objects is an active research area, which includes soft fabrics, microelectromechanical systems (MEMS), and synthetic sheets. In addition, grippers are being designed with different materials. This includes piezoelectric crystals, shape memory alloys (SMAs), magnetorheological (MR) fluid, carbon fiber, and many more. Recent research has also considered bio-inspired gripping mechanisms, which leverages nature to develop products that solve problems that are more industrial.

Previous papers have reviewed robotic grippers with more emphasis on specialized applications. In [Fantoni et al. (2014) and Staretu et al. (2011)], the use of grippers was covered for automated production processes. Different gripping systems, such as artificial vacuum, magnetic and mechanical gripping, were discussed in [Patel (2012)]. In [Patel (2012)], only parallel manipulators gripper mechanisms were covered. In [Smith et al. (2012)], grippers for surgical applications can be found. In [Smith et al. (2012)], only dual arm manipulation was covered. In [Hirzinger (1998)], a review of space robots was discussed. In [Naoshi et al. (1998)], plant production robots were reviewed. In [Savia et al. (2009)], only the contact strategies for micro components were examined. Some modern examples of grippers include the Kuka KR 1000 Titan.

A study on the force estimation-based compliance control of a two-link driven Robotic Manipulator presented a sensor technology for the measure of physical human-robot interaction pressure [Aksman et al. (2006)]. The system was composed of flexible matrices of opto-electronic sensors covered by a soft silicone cover allowing one to cover areas of any shape and size and measure different pressure ranges. The paper about the human arm exoskeleton for space robotics telepresence explained the use of robotic arms and their application in space technology [Schiele et al. (2006)]. It spoke about force feedback manipulations of astronaut-like robots operating in remote and harsh environments in space. The study conducted on Granular Jamming as Controllable Stiffness Mechanism for Endoscopic and Catheter Applications spoke about using granular jamming in invasive surgery [Blanc et al. (2017)]. It showed how this would provide flexibility and toughness as and when required because medical tools have to be sufficiently flexible to follow the human body natural paths but stiff enough to transmit force. The study on Design, Analysis and Implementation of a Robotic Arm – The Animator, the mechanism and mechanical structure of ASR K-250 robot and its implementation was discussed. They dealt with the issue of the robot to co-operate with human beings and display human like behaviour regarding motion, communication and intelligence. The study conducted on Robotic Arm Control Through Human Arm Movement Using Accelerometers focused on the development of the arm based on ATmega32 and ATmega640 platform along with a personal computer for signal processing, which was all interfaced with each other using serial communication. Finally, the prototype of the arm was used to overcome the problem such as placing or picking hazardous objects or non-hazardous objects that are far away from the user.

1.3 KNOWLEDGE GAINED FROM THE LITERATURE

- Force estimation-based compliance control of a two-link driven Robotic Manipulator induced an idea of removing the entire problem of force applications, finger gripper stresses and their many varied limitations.
- The human arm exoskeleton for space robotics telepresence gave us scope to try out our gripper for space applications. The materials therefore needed to be light and tough. The use of Titanium was hence preferred.
- Granular Jamming as Controllable Stiffness Mechanism for Endoscopic and Catheter Applications leads to a jamming mechanism in a gripper for manipulating objects.
- The animator gave us the idea of making sure the arm was human-like and its behavior regarding motion, communication and intelligence would be humanoid.
- The robotic arm control using accelerometers gave us an idea of how programming of the robotic arm to identify and pick objects automatically through computer vision could open up new possibilities

1.4 GAPS IN LITERATURE

The use of the Granular Jamming Mechanism for a robotic gripper would provide various advantages like reliability of component, cost of product and gripping speed. The grippers available now all have fingers which require more joints and hence control which increases complexity and use of resources in development of a gripper. This reduces and almost nullifies its use in everyday applications as it is not economically feasible. Limited work is carried out to overcome these problems.

1.5 MOTIVATION

- Adaptability

The progressively adjusting adaptability of the gripper empowers car segments makers to deal with a wide assortment of plastic formed parts in gathering apparatus stacking and emptying where item geometry changes, and repeatability and dependability are basic limitations.

- Security

The innately delicate touch of the gripper amongst holds and on approach empowers overwhelming gear OEMs to computerize the activity of ergonomic stations on the sequential construction system nearby human laborers where specialist wellbeing, disposal of squeeze focuses, and security appraisal consistence are imperatively essential.

- Ability to Handle Complex Shapes

The profoundly acclimating and versatile grasp interface of the multigripper empowers infusion formed plastic parts makers to get a custom hold while clearing muddled parts from a shape, where negligible machine change-after some time, and a protected hold on complex parts are basic execution factors.parts are critical performance factors.

- Environmental Aspect

The multi-gripper developed requires lesser resources and materials to build as compared to a normal gripper. It also requires lesser motors, tactile operators and pressure sensors to construct. The gripper can be developed from the most basic parts which are readily available.

1.6 OBJECTIVE

To develop a robotics gripper which works on the principle of jamming of granular material to transition between an unjammed, deformable state and a jammed state with a solid-like rigidity. This will help delineate three separate mechanisms – friction, suction, and interlocking, that contribute to the gripping force.

CHAPTER 2

2 METHODOLOGY AND EXPERIMENTAL PROCEDURE

2.1 METHODOLOGY OVERVIEW

Literature Survey	• Recent trends in robotics industry with respect to robotic arm and related technologies.
Material/Component Selection	• Aluminium alloy or 3D printing polymer
3-D CAD Modelling	• SolidWorks 2016 Part Modelling and Assembly contruction. • Motion Study in SolidWorks 2016
Computational Simulation	• Structural analysis in ANSYS 19 Mechanical • Packing efficiency testing for the best suitable material. • Python programming for coding
Material/component Procurement	• The materials and electrical components will be purchased from the suppliers.
Machining	• 3-D Printing of material into the component specification. • Use of drilling, milling, grinding welding etc of parts into reqd specs.
Fabrication	• Assembly of the machined components and electrical components to form a robotic arm.
Testing	• Practical tests are performed to test the compatability of the robotic arm in actual world amplications.

Fig. 2.1 Methodology Flowchart.

2.2 3 D CAD MODELLING

2.2.1 COMPONENTS

1) Base Plate

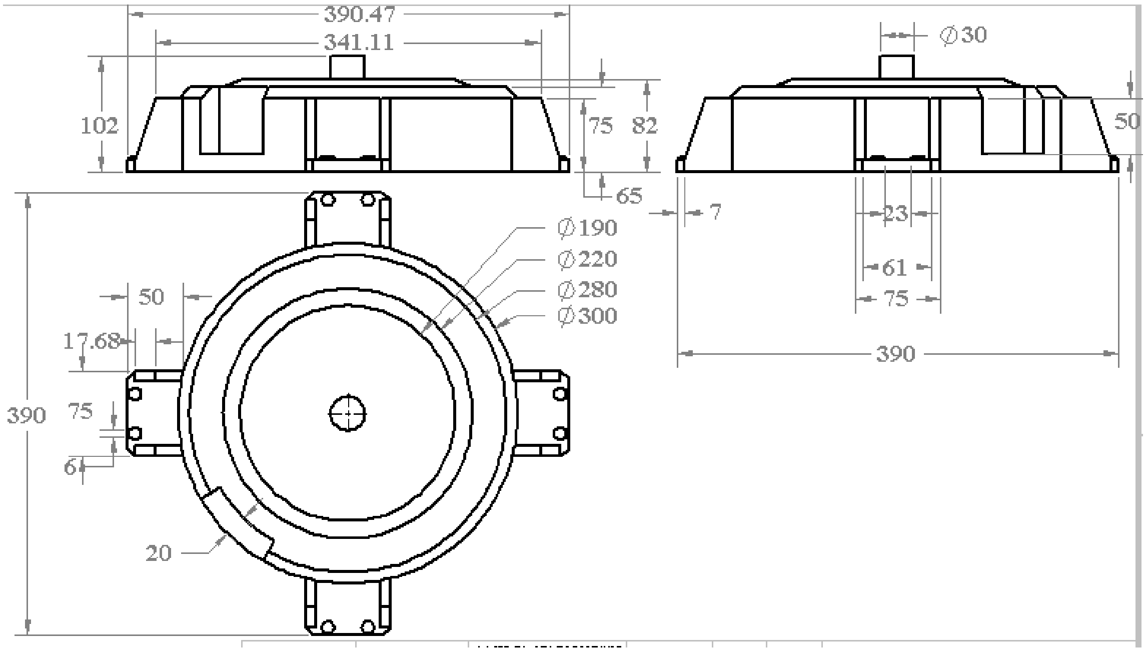

Fig. 2.2 Base Plate

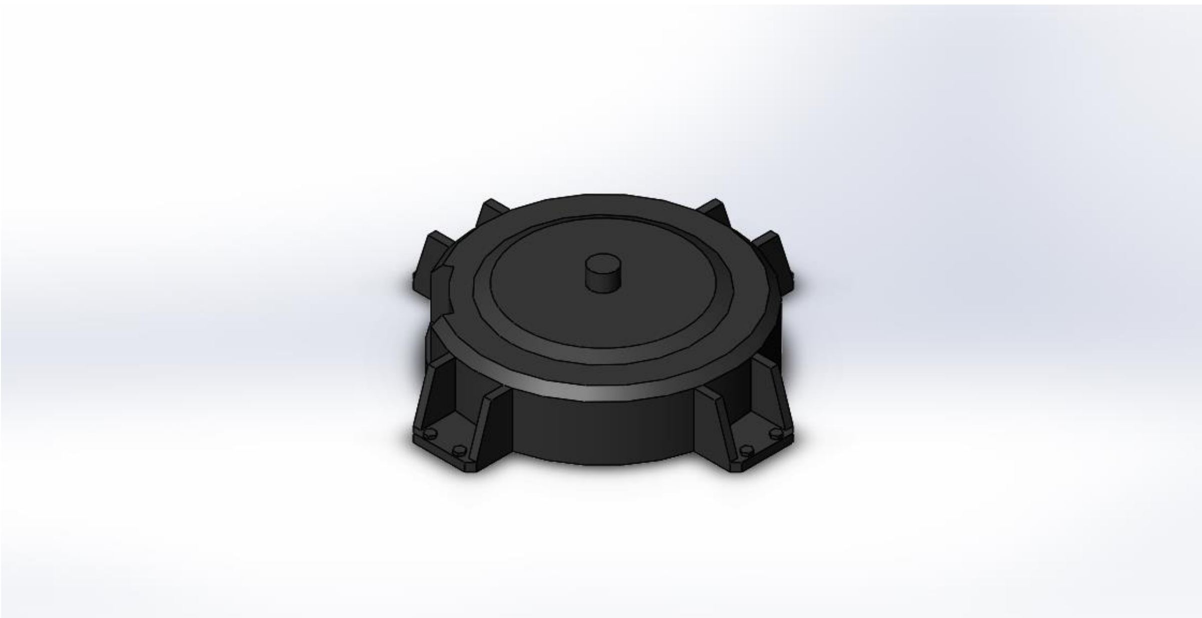

Fig. 2.3 3D view of the base plate CAD model

The Base plate is the base on which the robot stands. It is made out of Cast Iron usually as it needs to be strong enough to support the load of the entire robotic arm. This base plate is fixed and doesn't offer movement.

2) Base Arm

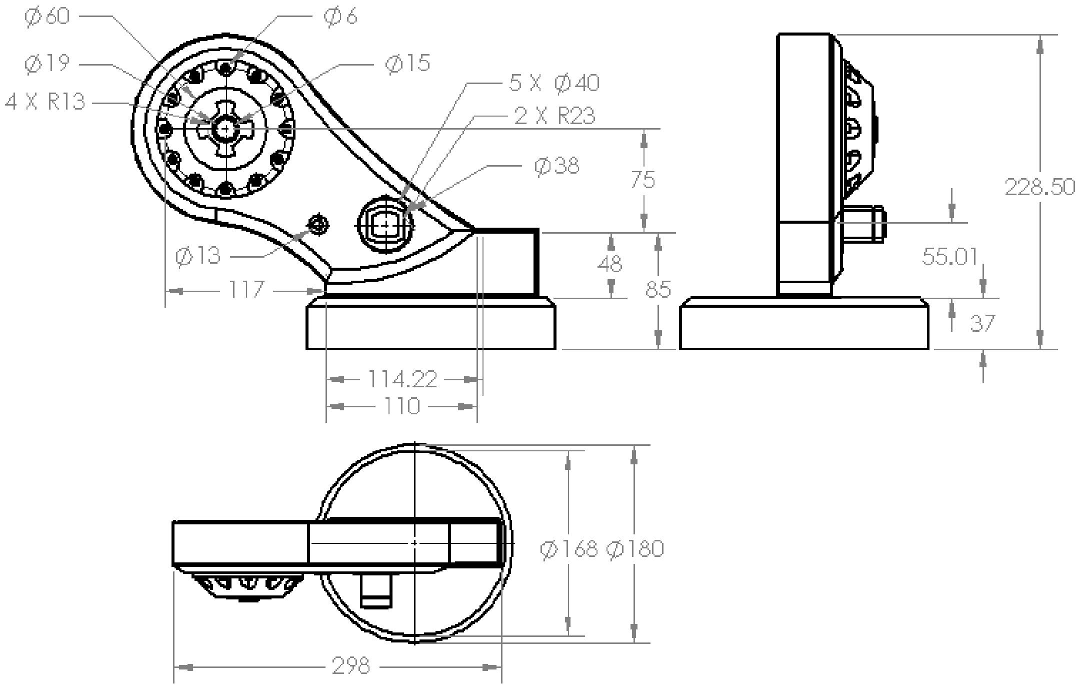

Fig. 2.4 Base Arm

Fig. 2.53 3D view of the base arm CAD model

The Base Arm is the next component which is fixed to the base plate and the extended arm. This is also called the upper limb of the robotic arm as this is the first and highest part of the arm. This part is made out steel and it offers movement as rotation on the base plate and as translation along the extended arm.

3) Extended Arm

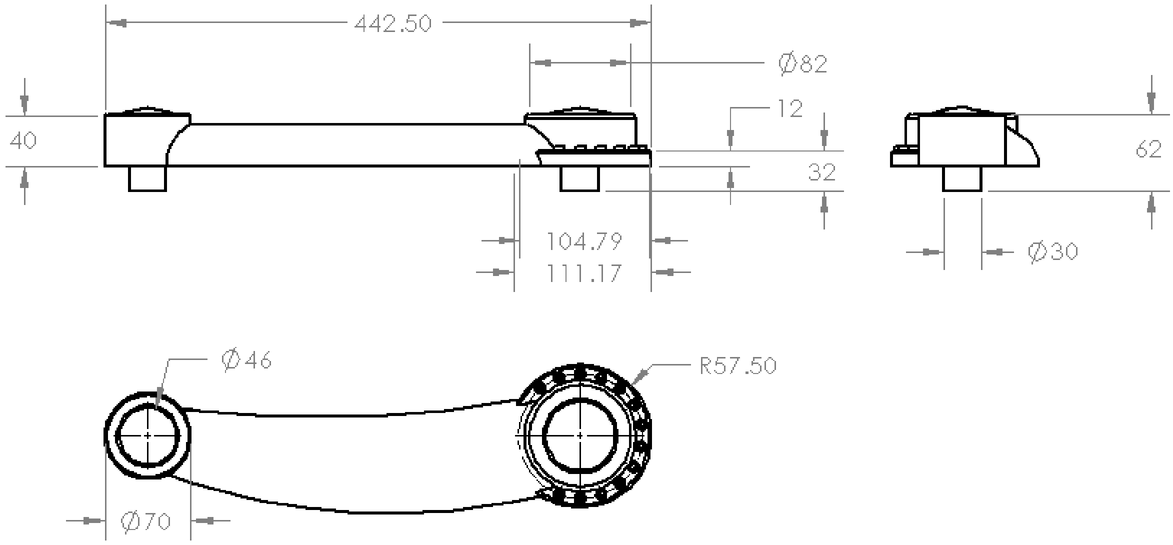

Fig. 2.6 Extended Arm

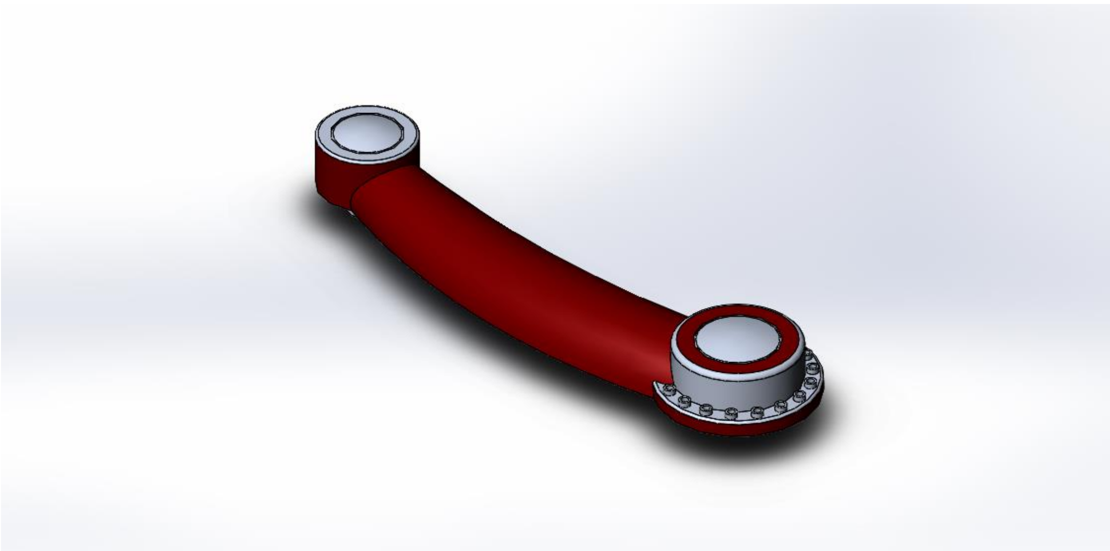

Fig. 2.74 3D view of the extended arm CAD model

The extended arm is the next component of the robotic arm. It connects the base arm to the joint. This arm is also made out of steel and it offers translational motion along the joint. It however doesn't move along the base arm.

4) Joint

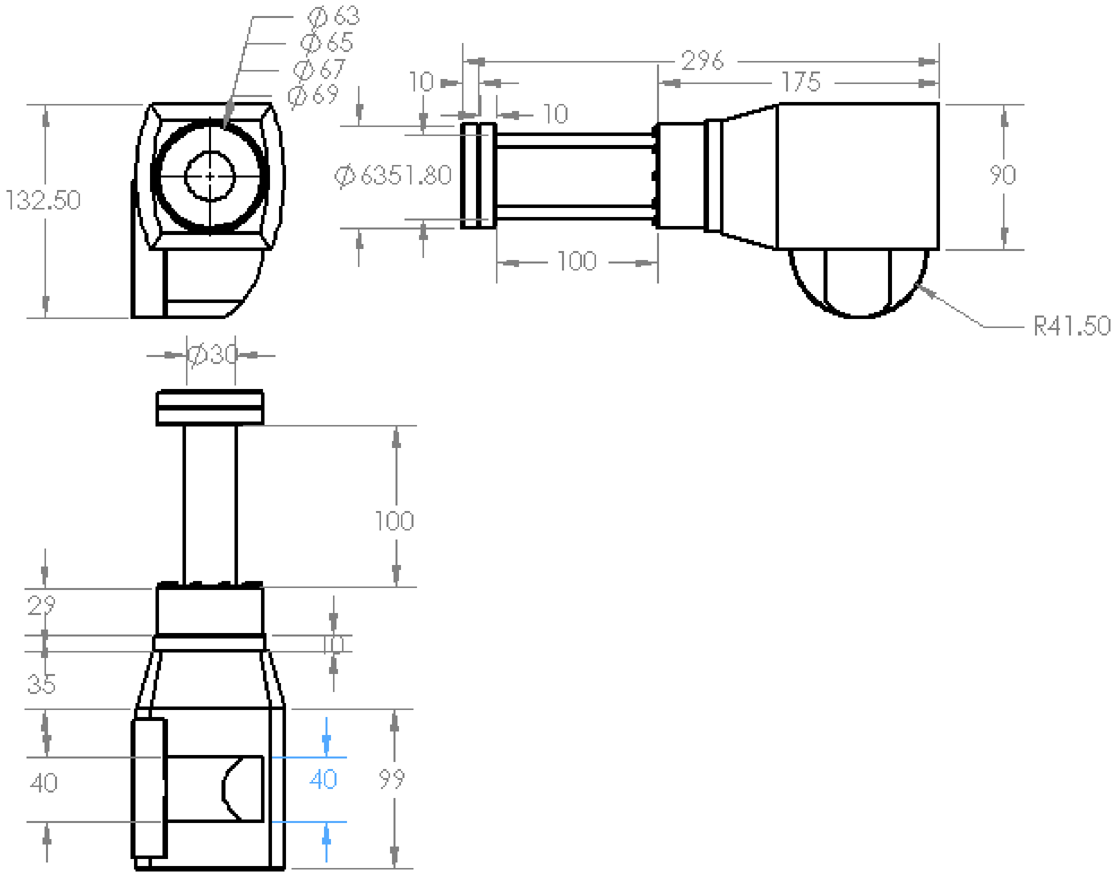

Fig. 2.8 Joint

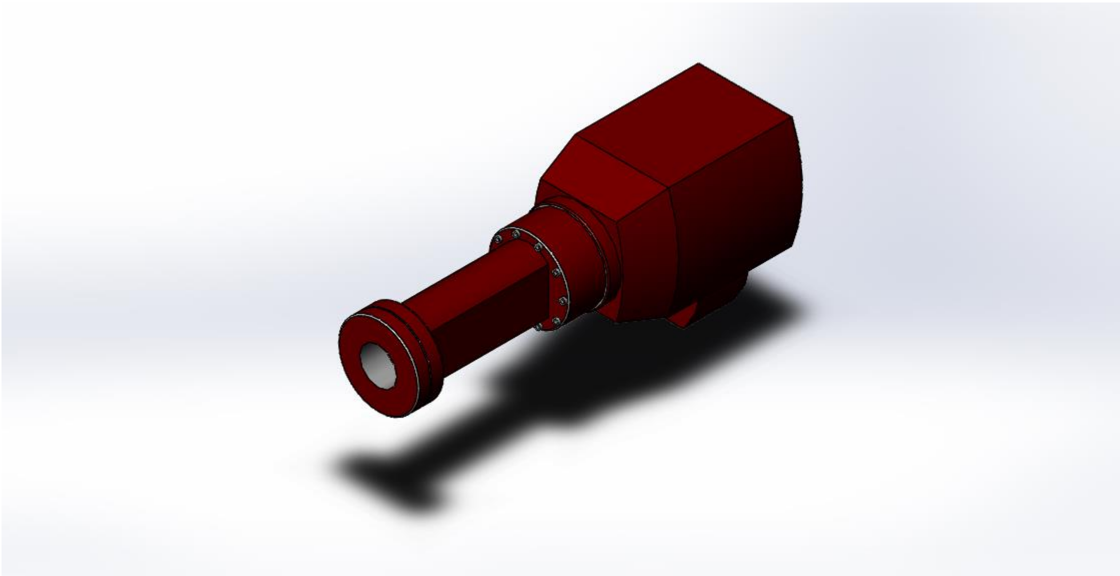

Fig. 2.9 3D view of the joint CAD model

The joint is the next component of the robotic arm which connects the extended arm at the top to the extended joint at the bottom. The Joint is also made out of Steel material and it offers translatory motion along the extended arm.

5) Extended Joint

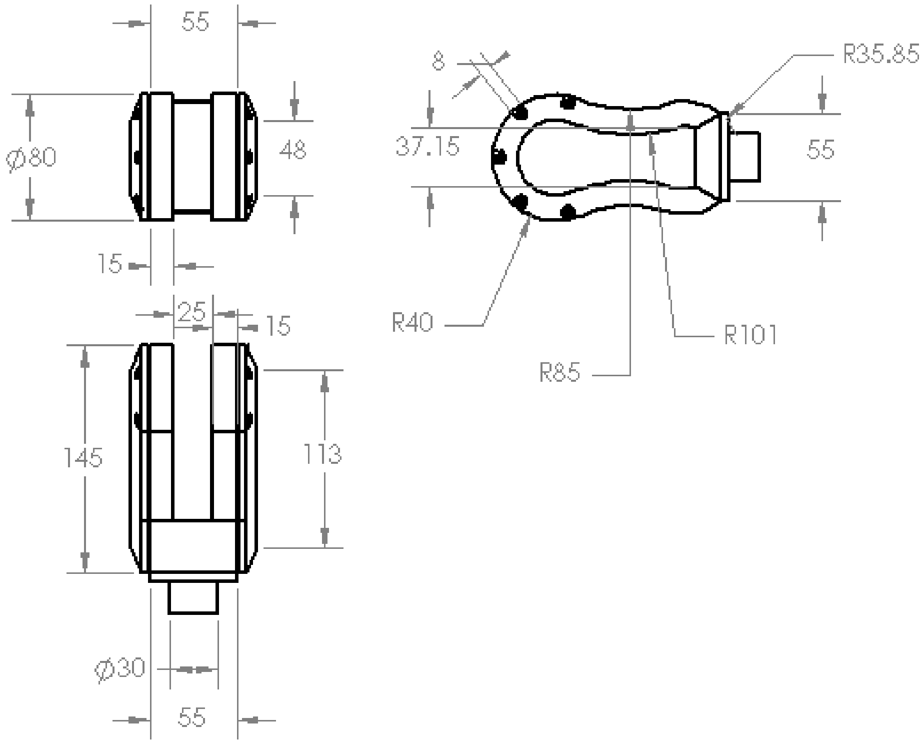

Fig. 2.10 Extended joint

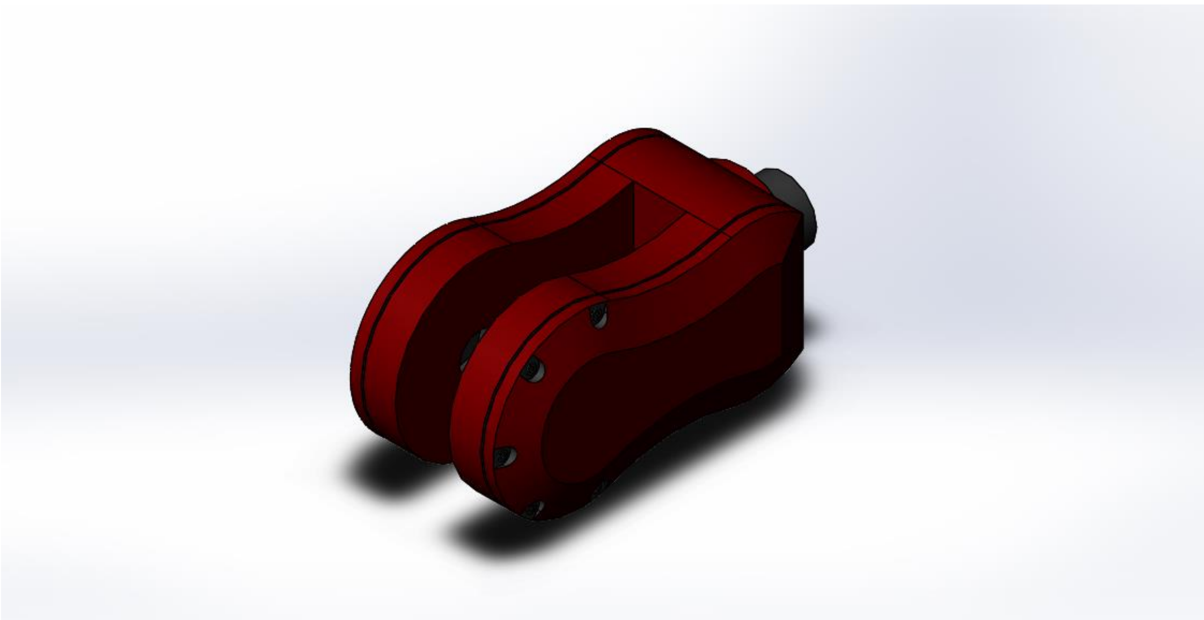

Fig. 2.11 3D view of the extended joint CAD model

The extended joint is nothing but an extension of the joint. It is made up of Steel as well and serves as the final component to offer the translatory motion.

6) Final End Arm

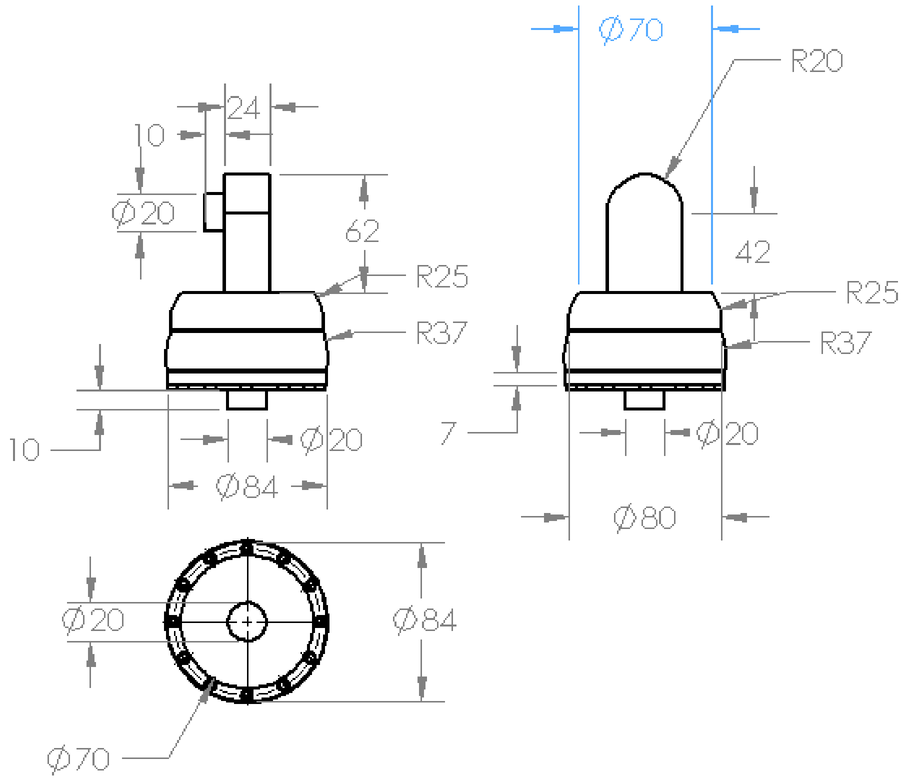

Fig. 2.12 Final end arm

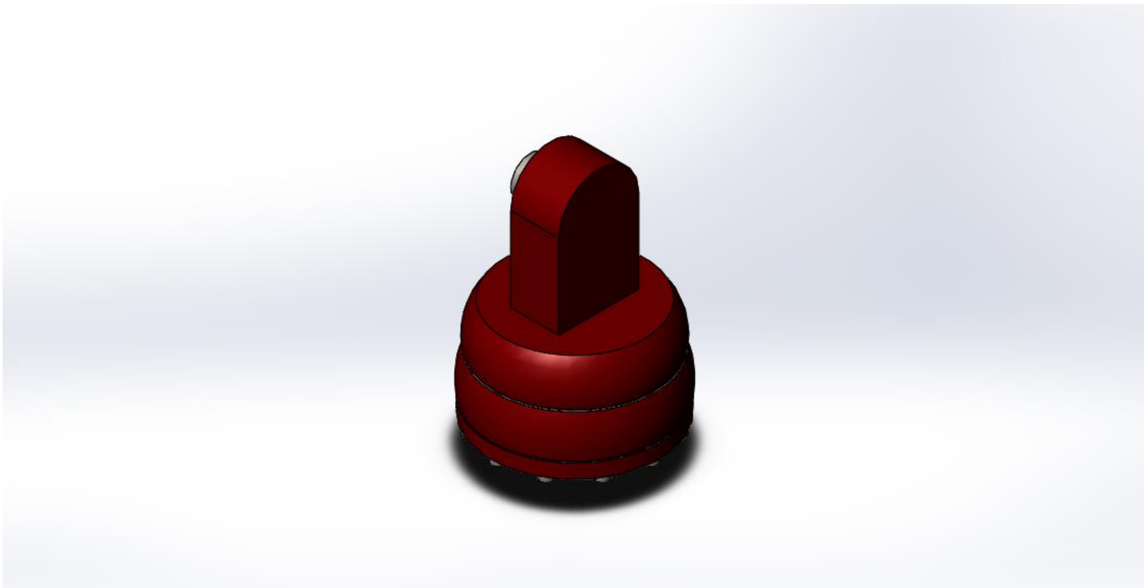

Fig. 2.53 3D view of the final end arm CAD model

The final end arm is the component from which the final part of the robotic arm starts. It acts as sort of a holder for the final end joint and offers translatory motion. This component is also made of out Steel.

7) Final End Joint

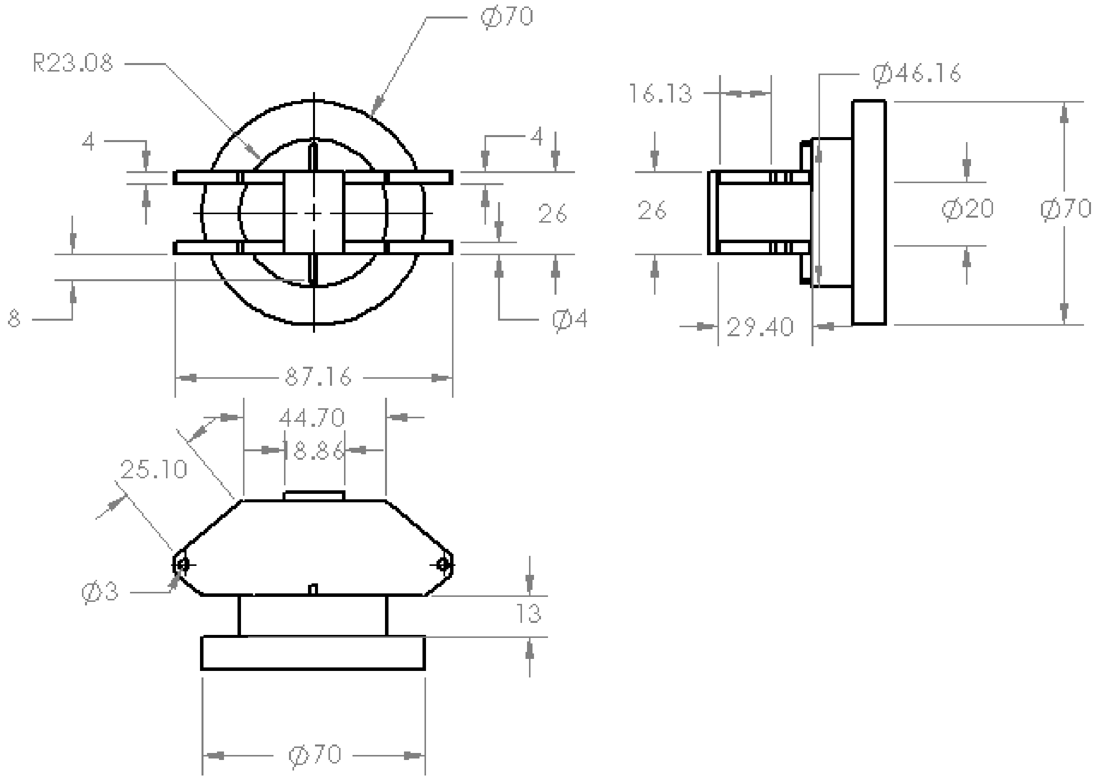

Fig. 2.14 Final end joint

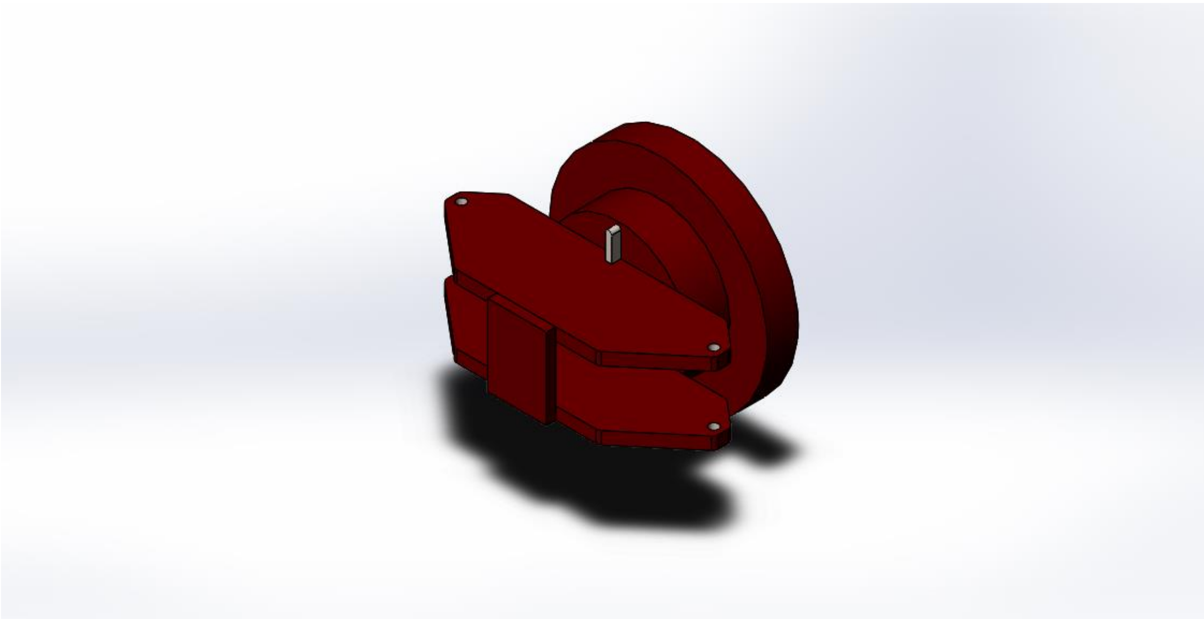

Fig. 2.15 3D view of the final end joint CAD model

The final end joint is connected the final end arm and offers rotational motion to the robotic arm. It is made out Steel material and is the final component to which the end effector is connected.

8) Pin

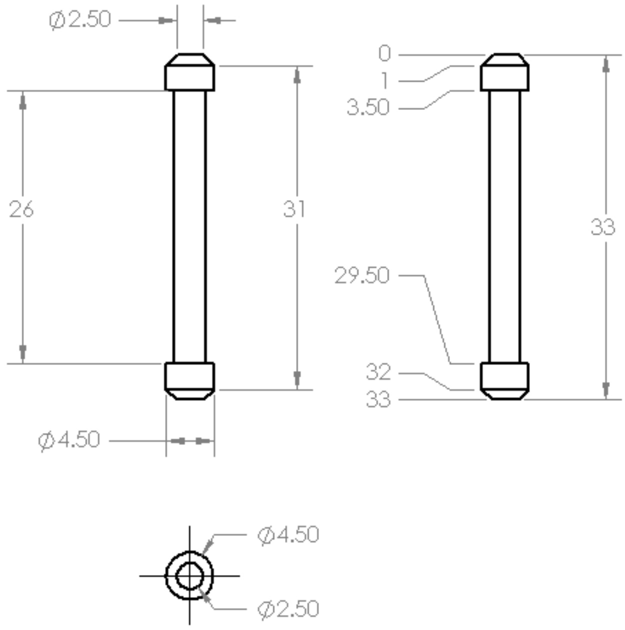

Fig. 2.16 Pin

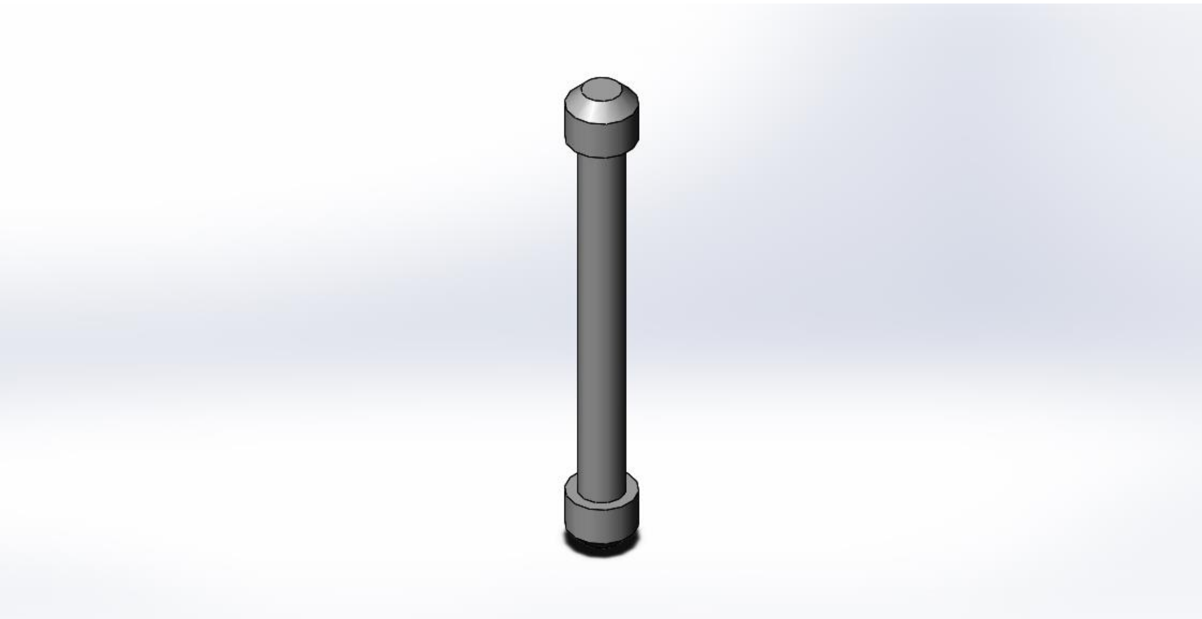

Fig. 2.17 3D view of the pin CAD model

The pin is connected to the final end joint to hold the end effector in place. It is made out of MS so that it can stand high stress without breakage.

9) Multigripper

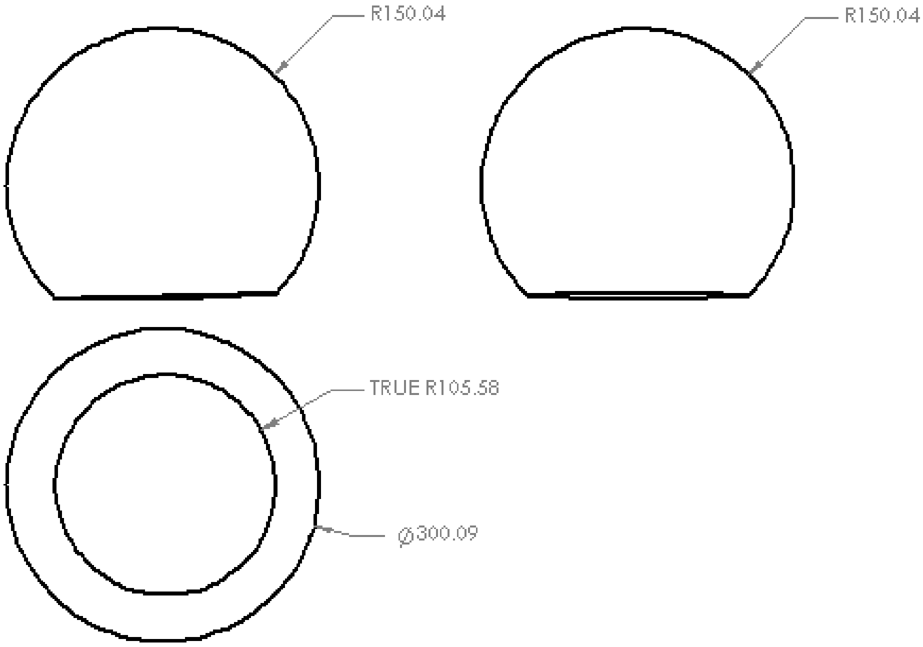

Fig. 2.18 Multigripper

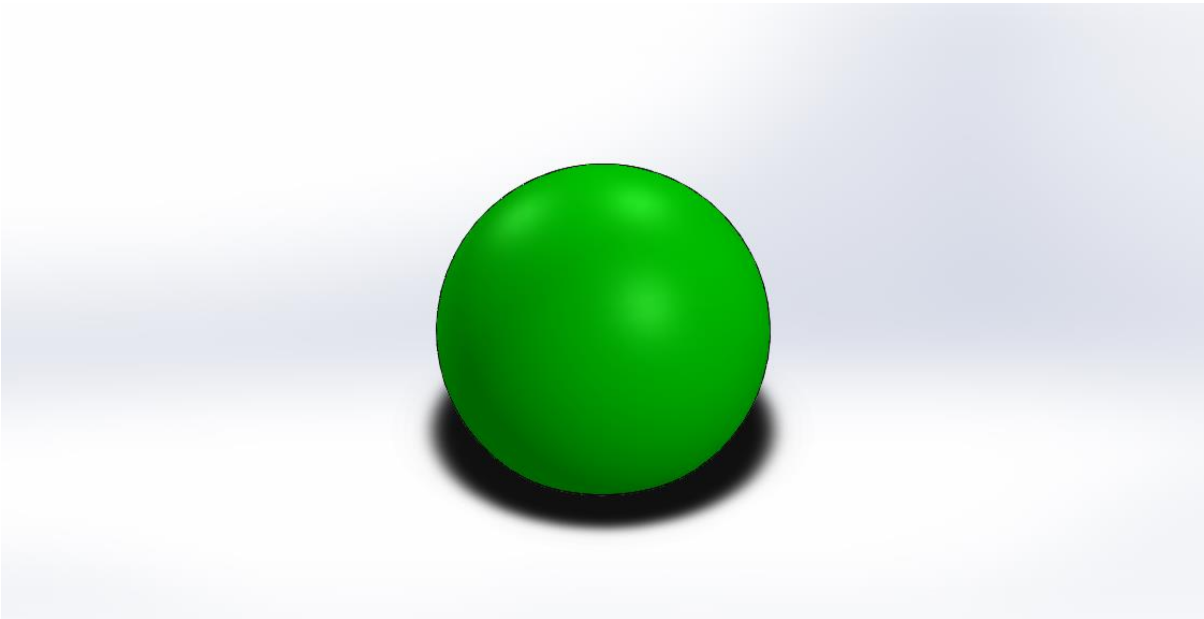

Fig. 2.19 3D view of the multigripper CAD model

The multi-gripper is the end effector we will be using in the robotic arm. The end effector is part of the arm that interacts with the environment around it. The multi-gripper is the aspect of the robotic arm that we will be developing.

2.2.2 3 D CAD ASSEMBLY

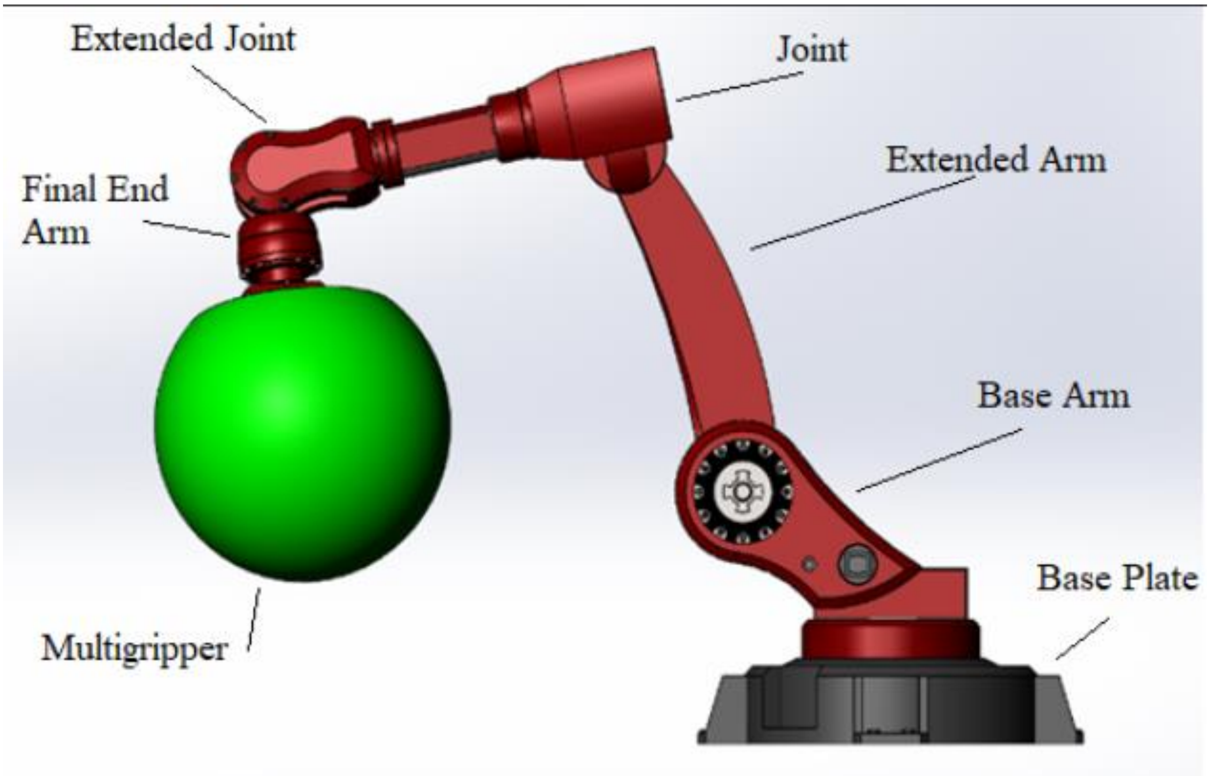

Fig. 2.20 CAD assembly

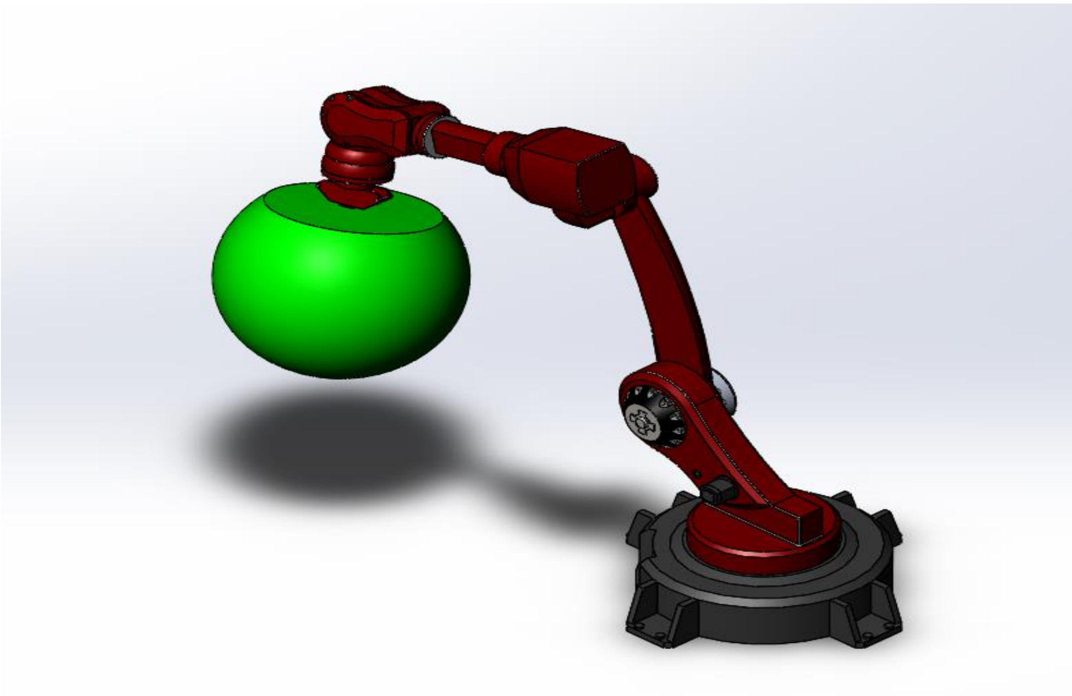

Fig. 2.21 Isometric view of CAD assembly

2.2.3 BILL OF MATERIALS

Table 2.1 Bill of Materials

Part Number	Part Name	Part Description	Quantity
1	Base Plate	Cast Iron	1
2	Base Arm	Steel	1
3	Extended Arm	Steel	1
4	Joint	Steel	1
5	Extended Joint	Steel	1
6	Final End Arm	Steel	1
7	Final End Joint	Steel	1
8	Pin	MS	2
9	Multi-gripper	Rubber	1
10	Bolt	MS	14
11	Nut	MS	14

2.3 SIMULATION

Transient Structural Analysis is performed on ANSYS Workbench 19. This type of analysis is used to determine the dynamic response of a structure under the action of any general time-dependent loads. To determine the time-varying displacements, strains, stresses, and forces in a structure as it responds to any transient loads. The results of which were conclusive and are detailed later.

The basic equation of motion solved by a transient structural analysis can be seen in Eq (1).

$$[M]\{\ddot{u}\} + [C]\{u\} + [K]\{\dot{u}\} = \{F(t)\} \qquad \text{...Eq (1)}$$

where:

[M] = mass matrix

[C] = damping matrix

[K] = stiffness matrix

$\{\ddot{u}\}$ = nodal acceleration vector

$\{u\}$ = nodal velocity vector

{u} = nodal displacement vector

{F(t)} = load vector

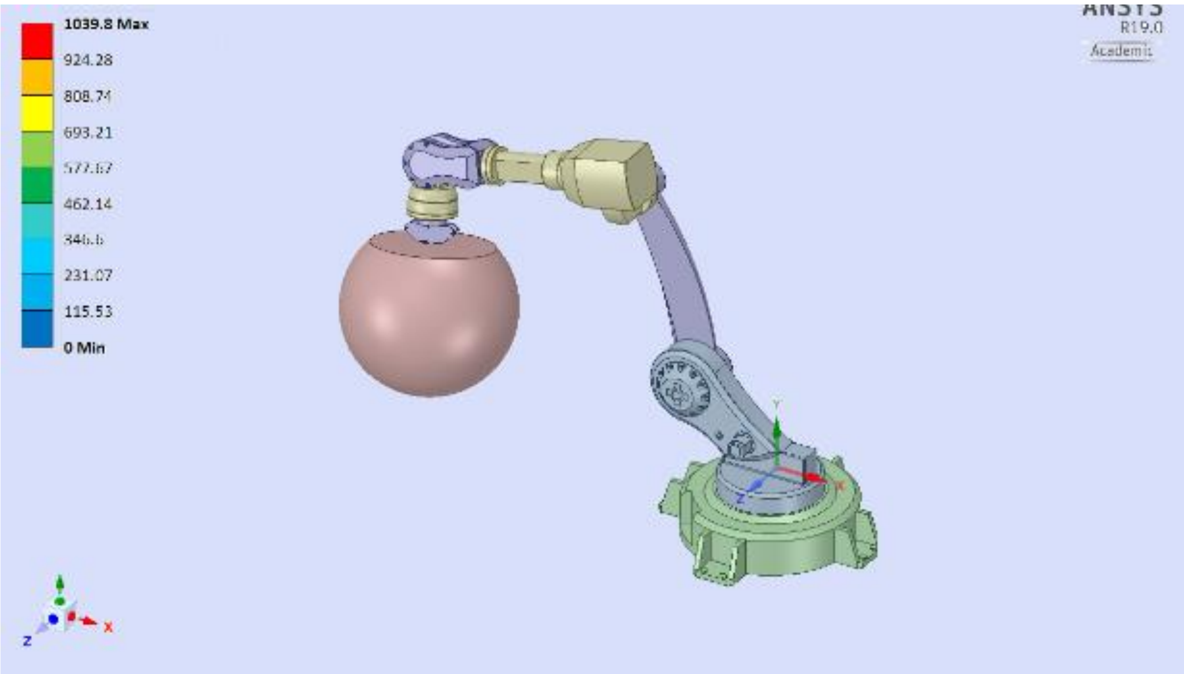

Fig. 2.22 ANSYS Analysis of Robotic Arm

2.3.1 TRANSIENT STRUCTURAL ANALYSIS

The following are the steps implemented in ANSYS Workbench 19 to simulate the Transient Structural Analysis.

Step 1 – **Create Analysis System**

From the Toolbox, a Transient Structural template is dragged to the Project Schematic.

Step 2 – **Define Engineering Data**

Material properties can be linear or nonlinear, isotropic or orthotropic, and constant or temperature-dependent. Both Young's modulus (and stiffness in some form) and density (or mass in some form) is defined.

Step 3 – **Attach Geometry**

The required geometry is attached.

Step 4 – **Define Part Behavior**

We define a point mass for this analysis type. The output from a rigid part is the overall motion of the part plus any force transferred via that part to the rest of the structure. A rigid part is essentially a point mass connected to the rest of the structure via joints. Hence in a transient structural analysis the only applicable loads on a rigid part are acceleration and rotational velocity loads.

Step 5 – **Define Connections**

All contacts are defined in this analysis.

Step 6 – **Apply Mesh Controls**

An adequate mesh density on contact surfaces to allow contact stresses to be distributed in a smooth fashion is provided. Areas where stresses or strains are of interest a relatively fine mesh is provided compared to that needed for displacement resolution.

Step 7 - **Establish Analysis Settings**

For a Transient Structural analysis, the basic Analysis Settings include: Large Deflection, Step Control, Output Control, Nonlinear Control.

Step 8 – **Define Initial Conditions**

The default initial condition for the transient structural analysis is that the structure is at rest i.e. both initial displacement and initial velocity are zero. The number of steps are set to 480 with a time step of 1s. This allows every individual part to move for a total of 60s.

Step 9 - **Apply Loads and Supports**

For a static structural analysis applicable loads are all inertial, structural loads and applicable supports are all structural supports. Joint Loads are used to kinematically drive joints.

Step 10 – **Solve**

The transient structural analysis is solved and a force convergence plot is developed. This plot defines the residual which is the difference between external and internal loads and iterates it until the residual becomes acceptably small, then the solution is considered as converged.

Step 11 – **Review Results**

All structural result types are available as a result of a transient structural analysis. We use the Solution Information object to track and monitor problems that arise during the solution.

2.4 PACKING EFFICIENCY

Iterative Study for Packing Efficiency

Consider N particles, each of a fixed volume V_0, all contained in a box of volume V. The packing fraction (φ) will be defined as –

$$\varphi = \frac{NV_0}{V} \qquad \text{…Eq (2)}$$

This gives the fraction of the total volume of the box that is physically occupied by the particles. The free volume is hence given by

$$(1\text{-}\varphi)V \qquad \text{…Eq (3)}$$

When φ is sufficiently small, particles will not touch each other and the pressure of the granular system will be p = 0. When external tension acts on the particles, they behave like particles in a gas or liquid.

Now φ is increased. This is done by starting the vacuum operation or by slowly pushing in a piston to decrease the volume V of the box while the number of particles N remains constant. As φ is increased, we reach a critical value φ_J at which the particles touch and lock into a rigid but disordered structure.

The jammed state is achieved when $\varphi > \varphi_J$ in which each particle is in a mechanically stable equilibrium i.e. forces and torques on each particle balance to zero.

This method is then tested on the prototype using various jamming materials which include –

1) Sand
2) Salt
3) Sugar
4) Coffee

Common household items are used for the testing process as they are readily available and are more economical than industrial grade jamming material.

The test is performed on these materials with different weights to check maximum load capacity before failure of the gripping mechanism.

2.5 ROBOTIC ARM AND MULTIGRIPPER DETAILS

Components used:

1) Robotic Arm
2) 9V Battery
3) DC Motor
4) Connecting Wires
5) PVC Tube
6) Rubber Balloon
7) Funnel
8) Coffee Powder
9) Vacuum Pump Module

1) **Robotic Arm**

Fig. 2.23 Robotic Arm (Reproduced from http://www.societyofrobots.com/robot_arm_tutorial.html)

A robotic arm is a type of mechanical arm that is programmable. Its functions are similar to that of a human arm. The links of this manipulator are connected by joints that allow either rotational motion or translational motion. The links of the robotic arm form a kinematic chain. The last part of the kinematic chain of the arm is called the end effector and it may or may not look like the human hand. An industrial robot arm includes these main parts: Controller, Arm, End Effector, Drive, and Sensor.

The controller is the brain of the industrial robotic arm and allows the parts of the robot to operate together. It works as a computer and allows the robot to also be connected to other systems. The robotic arm controller runs a set of instructions written in code called a program. The program is inputted with a teach pendant.

The industrial robot arm is the part that positions the end effector. With the robot arm, the shoulder, elbow, and wrist move and twist to position the end effector in the exact right spot. Each of these joints gives the robot another degree of freedom.

The end effector connects to the robot's arm and functions as a hand. This part comes in direct contact with the material the robot is manipulating.

The drive is the engine or motor that moves the links into their designated positions. The links are the sections between the joints. Industrial robot arms generally use one of the following types of drives: hydraulic, electric, or pneumatic.

Sensors allow the industrial robotic arm to receive feedback about its environment. They can give the robot a limited sense of sight and sound. The sensor collects information and sends it electronically to the robot controller.

2) 9V Battery

Fig. 2.24 9V Battery

The 9-volt battery is a particular size of battery that was introduced mainly for transistor radios. It has a rectangular cuboidal shape with edges that are rounded and a polarized connector at the top. This type of battery is commonly used in smoke detectors, walkie-talkies and toys.

3) DC Motor

Fig. 2.25 DC Motor

A DC motor is a type of electrical machine that works on the principle of rotation and converts direct current electrical energy into mechanical energy. The most common type of motor relies on the force produced by magnetic fields in the motor. All types of DC motors have an internal mechanism which is electromechanical in nature to periodically change the direction of current flow in that part of the motor.

4) Connecting Wires

Fig. 2.26 Connecting Wires

Normal connecting wires are used in the model to connect the battery terminals to the DC motor and the vacuum pump. The wires are generally made of copper with a plastic insulation around them to prevent them from touching each other and short circuiting the entire setup.

5) PVC Tube

Fig. 2.27 PVC Tube

The PVC Tube is a tubular hollow cylinder made of Poly-Vinyl Chloride. It is used to transfer substances usually fluids from one end to another. In this project it is used to connect the vacuum pump module to the multi-gripper. It is used to transport air from the multigripper and out to the vacuum module.

6) **Rubber Balloon**

Fig. 2.28 Balloon

The Rubber balloon is just used to store the material for jamming mechanism. It has a low density, low cost and provides a general gripping property because of the natural properties of rubber.

7) **Funnel**

Fig. 2.29 Funnel

The funnel is a common household object with a wide mouth and a narrow stem. It is used in our project as a holder for our multi-gripper. It holds the balloon filled with coffee in place and also aids in transporting the coffee into the balloon in the initial step.

8) Granular Material

Fig. 2.30 Granular Material

Coffee powder is our selected choice of granular material used for the jamming process. Granular Material is defined as the collection of discrete solids that undergo a loss of energy when they interact with one another usually due to friction. They also get jammed together in the presence of vacuum and all the particles together constitute a point object.

9) Vacuum Pump Module

Fig. 2.31 Vacuum Pump Module

A vacuum pump is a device that removes air molecules from a sealed container in order to leave behind a vacuum. It is used to remove the air from the multigripper and cause jamming of the granular materials.

2.6 PROTOTYPE TEST

For prototype testing, a basic prototype is developed using some basic household materials. Materials/ Components used:

1) Funnel
2) PVC Tube
3) Rubber Balloon
4) 50ml Syringe
5) Tape/Hot Glue for sealing

A normal rubber balloon is taken and filled with various materials for testing one by one. It is then passed through a funnel and stuck on the other end. A PVC tube is taken and one end is covered by cloth to prevent the testing materials from being sucked into the tube. The other end is attached to a syringe as shown in the fig. 2.32. The PVC tube with the cloth end is then connected to the balloon using tape or hot glue.

This method is then tested on the prototype using various jamming materials which include –

1) Sand
2) Salt
3) Sugar
4) Coffee

Fig. 2.32 Prototype Testing

2.7 FINAL MODEL TEST

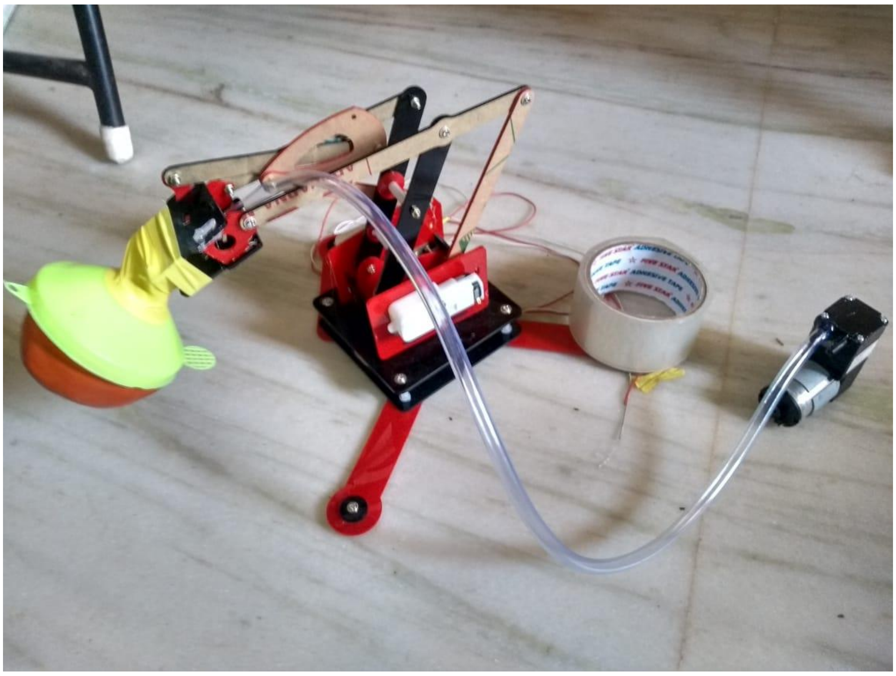

Fig. 2.33 Final Model Testing

The final testing was done with the integrated robotic arm. Various objects of arbitrary shapes and sizes were tested. The jamming mechanism worked perfectly and the model was able to lift the objects of various weights without much effort. A two-way valve was created to un-jam the multi-gripper.

The robotic arm was integrated with the multi-gripper and the vacuum module. Load lifting tests were performed on the model. The granular material chosen after prototype testing for jamming was coffee powder. The rubber balloon provided an extra gripping action.

A large size rubber balloon was taken and filled with granular material chosen i.e. coffee powder. It was then passed through a funnel and stuck on the other end. A PVC tube was taken and one end was covered by cloth to prevent the granular material from being sucked into the tube. The other end was attached to the vacuum pump as shown in the fig. 2.33. The PVC tube with the cloth end was then connected to the balloon using hot glue. The entire process was sealed airtight for maximum vacuum effect.

CHAPTER 3

3 RESULTS AND DISCUSSION

3.1 DESIGN SIMULATION

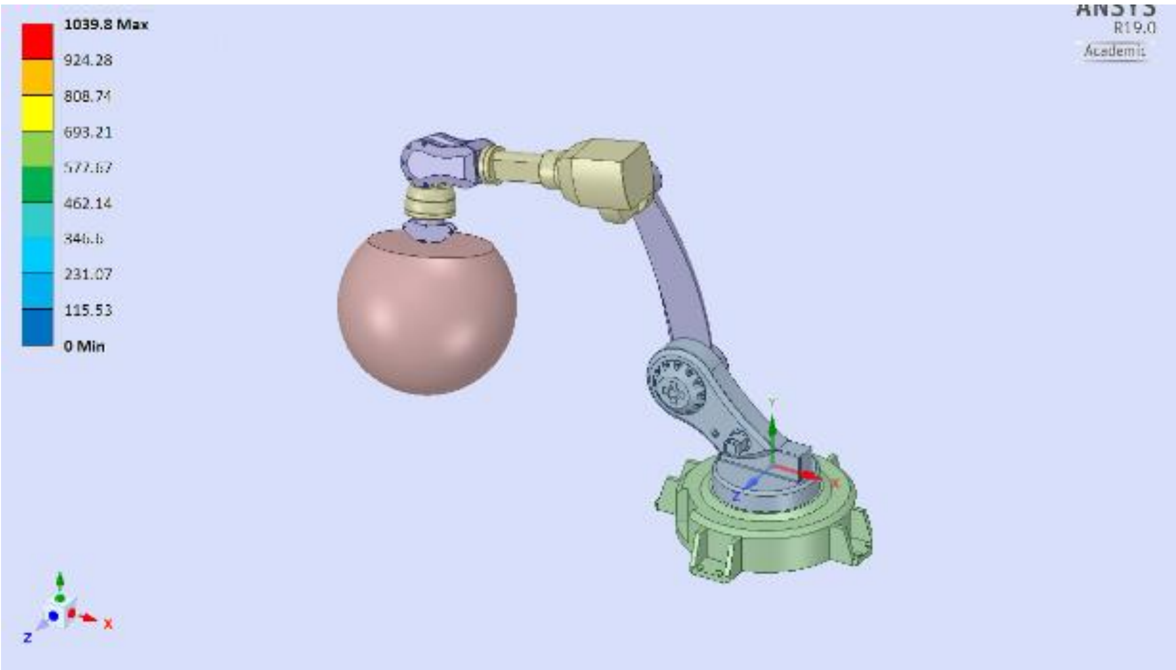

Fig. 3.34 ANSYS Analysis of Robotic Arm

Force Criterion (FC): With a nonlinear analysis there will always be inherent error in your model. The convergence criterion is the allowance of error. This is often defined as a percent of the applied load which includes is all the external forces applied to the model.

Force Convergence Value (FCV): This is the unbalanced force that is a result of the changing stiffness of the model caused by either geometric, material or contact nonlinearities. The FCV is the difference between the applied load and the summation of internal forces of the equilibrium iteration.

Load Step Convergence (LSC): This is the point of convergence and of structural integrity of the model developed. This is where the FC and the FCV intersect in the graph. Convergence occurs when the FCV or Residual is less than the Convergence Criterion.

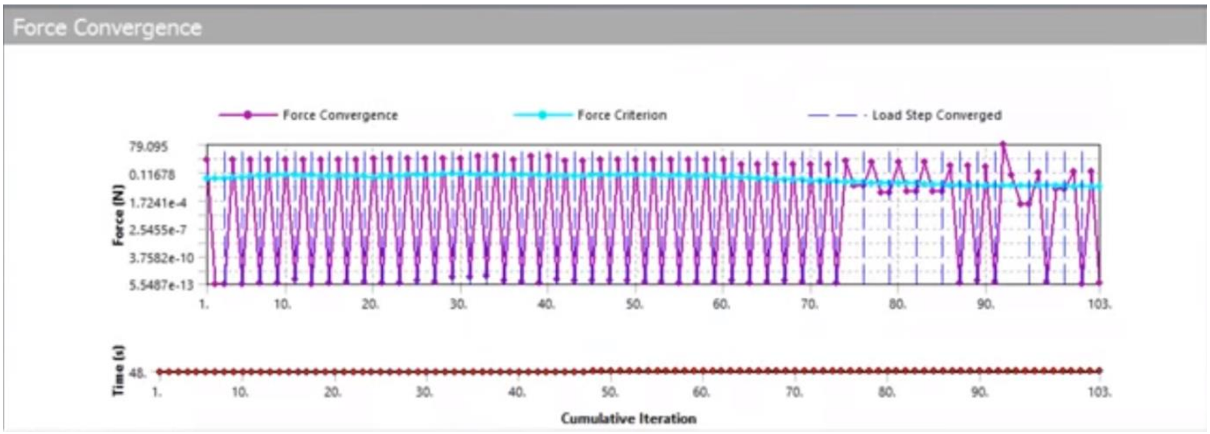

Fig. 3.35 Force Convergence Graph of Robotic Arm

The graph hence helps us get the force convergence value. The multiple points of intersection of the graph confirms the structural integrity of the robotic arm developed. The Y-axis of the graph defines the force (in Newtons) acting on it which reaches a maximum value of ~80N and a minimum value of 55 pN. The X-axis of the graph defines the time step. The entire process is run for upto 103s and the load step convergence is identified at every 1s of time step. This graph ensures the model created by us will be able to support upto 80N of weight without breakage.

3.2 FABRICATION

3.2.1 ARRANGEMENT OF MATERIALS

The materials for the robotic arm was arranged which consisted of plastic arms, screw, bolts, motor for its functioning. The vacuum pump was arranged to integrate the Robotic arm with the multi-gripper. The multi-gripper material was basically a balloon and several materials.

3.2.2 THE MAKING OF THE ROBOTIC ARM

The Robotic Arm was a challenge for us considering the weight that it could withhold that will be there in the multi-gripper. So we had find a balance between making the Arm tough as well as light weight. So we decided on using ABS (which stands for Acrylonitrile Butadiene Styrene) which is commonly used as 3-D printing material. Finally to give the Arm the sturdiness, we fixed it with Nuts and bolts. The working of the robotic arm was done by motors.

3.2.3 THE MAKING OF THE MULTI-GRIPPER MECHANISM

Our main fabrication was the development of the Multi gripper mechanism. We initially started by taking Salt, Sugar, Sand and coffee. We experimented on which granular material will be best suited for our model. Initially developing the prototype model we came to a conclusion that coffee is the best suited material. So we decided to proceed with coffee as our granular material.

3.2.4 THE MAKING OF THE PROTOTYPE MODEL

The prototype model is tested with a large syringe connect with a Cylinder pipe with the multi-gripper attached at the other end. The Syringe was used to create vacuum in the multi-gripper mechanism. We tested by lifting light objects of different shapes using different granular materials. Which gave was a idea about the the best fit material for our model.

3.2.5 INTEGRATION OF THE VACUUM PUMP

The major challenge we faced regarding the Vacuum pump was the pressure adjustment. We experimented with variety of Vacuum pumps for the best results for our model.

3.2.6 THE MAKING OF THE FINAL MODEL

The actual model was integrated by carefully testing all the components of Robotic Arm, Vacuum pump, and multi-gripper. Then we integrated the parts to make the final model. The robotic arm was connected to the multi-gripper and the vacuum module. The motors and battery were connected using the wires and the model was finally ready for testing purposes.

3.3 TESTING RESULTS

The materials were tested on various household objects of various shapes and sizes. For the purpose of tabulation a few objects have been listed in Table 3.2 with the results obtained. After conducting various tests, it was discovered that the best material to be used for granular jamming is coffee as it offers maximum gripping effect.

The results obtained through the tests proved that the project was successful. The material used for the multi-gripper and the material used for jamming purposes were perfectly chosen. The vacuum pump module was able to completely suck the air out of the multi-gripper and cause the jamming of the coffee powder. This ensured that all and any objects of arbitrary shapes were able to be lifted without much effort. The only drawback faced was that the robotic arm created out of plastic couldn’t support the weight of the multi-gripper.

Table 3.2 Testing Results

Material	Weight Lifted			
	Pencil (~50gms)	Canned Food (~500g)	Water Bottle (~1kg)	Laundry Detergent Bottle (~2.5kg)
Sand				
Salt				
Sugar				
Coffee				
Legend				
	Successful lift		Unsuccessful lift	

CHAPTER 4

CONCLUSIONS

4.1 CONCLUSION

The SolidWorks model developed helped us get a general idea of the final model to be made by us. It also helped us understand the rotating and translating parts of the robotic arm. This model was later used for ANSYS analysis.

ANSYS Workbench 19 was used to perform transient structural analysis. The results of which were conclusive and gave us an idea of how much load the model could support before collapse. The material used was titanium as it is lightweight and strong and hence provides maximum advantages. The maximum load lifted was found to be ~1000N.

The prototype model was developed to test the best material for use in granular jamming. The results of which are tabulated earlier. Coffee was found to be the best material as it offered the best packing efficiency. The prototype also helped us get a general idea of the working of the multi-gripper.

The robotic arm was finally developed after integrating the multi-gripper with the arm and the vacuum pump module. Load lifting tests were performed on the arm and it was found that the multi-gripper works perfectly.

The entire project took us 4 months to complete. The gripper developed offers us a new insight into the field of robotics. It offers us various advantages including but not limited to Health and Safety, Manufacturability, Sustainability, Economical, Environmental and Social.

We have addressed multiple constraints in our model which include prototype analysis, experimentation, design analysis, modelling and simulation.

4.2 CONTRIBUTION TO EXISTING LITERATURE

The use of the Granular Jamming Mechanism for a robotic gripper would provide various advantages like reliability of component, cost of product and gripping speed. The grippers available now all have fingers which require more joints and hence control which increases complexity and use of resources in development of a gripper. This reduces and almost nullifies its use in everyday applications as it is not economically feasible. Limited work is carried out to overcome these problems.

4.3 FUTURE SCOPE OF WORK

One of the drawbacks found was the weight of the multi-gripper was too much for the robotic arm to sustain and the arm would droop at all times. Stronger material can be used for making the robotic arm which will help sustain and operate the entire process more effectively and efficiently.

The inability of the multi-gripper to pick up flat objects like aluminium sheets is very visible. These objects however can be lifting by holding them from the side. This makes the entire process redundant as vacuum grippers exists which can lift flat objects.

The multi-gripper also needs to press down on an object to be able to lift it. Hence objects thrown at it or moving in the air are unable to be lifted i.e. the weightlessness property of the object due to its motion in air causes an issue with the lifting property of the robotic arm.

REFERENCES

[1] Aksman L.; Force Estimation Based Compliance Control of a Two Link Harmonically Driven Robotic Manipulator,Master's Thesis, *University of Maryland*, Dec. 2006.

[2] Bergren C.M, Anatomy of a Robot, *McGraw Hill*, 2003

[3] Bertelsen, A.; Melo, J.; Sánchez, E.; Borro, D.; A review of surgical robots for spinal interventions. Int. J. Med. Robot. *Comput. Assist. Surg. 2013*, 9, 407–422.

[4] Blanc L; Francois B; Delchambre A; Lambert P; Granular Jamming as Controllable Stiffness Mechanism for Endoscopic and Catheter Applications *, Université Libre de Bruxelles*, 2017

[5] Craig J.J, Introduction to Robotics Mechanics and Control, *3rd ed. Upper Saddle*

[6] Fantoni, G.; Santochi, M.; Dini, G.; Tracht, K.; Scholz-Reiter, B.; Fleischer, J.; Lien, T.K.; Seliger, G.; Reinhart, G.; Franke, J.; et al. Grasping devices and methods in automated production processes. *CIRP Ann. Manuf. Technol. 2014*, 63, 679–701.

[7] Hirzinger, G.; Brunner, B.; Landzettel, K.; Schott, J. Preparing a new generation of space robots—A survey of research *at DLR. Robot. Auton. Syst. 1998*, 23, 99–106.

[8] Krüger, J.; Lien, T.K.; Verl, A. Cooperation of human and machines in assembly lines. *CIRP Ann. Manuf. Technol*. 2009, 58, 628–646

[9] Monkman, G.J.; Hesse, S.; Steinmann, R.; Schunk, H.; Robot Grippers; *John Wiley & Sons*: Weinheim, Germany, 2007

[10] Naoshi, K.; Ting, K.C. Robotics for Plant Production. *Artif. Intell. Rev. 1998*, 12, 227–243.

[11] Nikku, S., Introduction to Robotics, *John Wiley & Sons*, 2011.

[12] Patel, Y.D.; George, P.M. Parallel Manipulators Applications—A Survey. *Mod. Mech. Eng. 2012*, 2, 57–64

[13] Patnaik A.; “Robotic Arm Control Through Human Arm Movement Using Accelerometers”, Master’s Thesis, *National Institute of Technology Rourkela*, 2013

[14] Rahman A.; Khan A.H.; Ahmed T.; Sajjad M.; “Design, Analysis and Implementation of a Robotic Arm- The Animator”, *American Journal of Engineering Research (AJER)*, 02(10), 298-307

[15] Savia, M.; Kiovo, H.N. Contact Micromanipulation—Survey of Strategies. *IEEE/ASME Trans. Mechatron. 2009*, 14, 504–514.

[16] Siciliano, B.; Khatib, O. Springer Handbook of Robotics; *Springer Science & Business Media*: Berlin/Heidelberg, Germany, 2008.

[17] Smith, B.; Karayiannidis, Y.; Nalpantidis, L.; Gratal, X.; Qi, P.; Dimarogonas, D.V.; Kragic, D. Dual arm manipulation—A survey. *Robot. Auton. Syst*. 2012, 60, 1340–1353.

[18] Staretu, I. Gripping Systems; *Derc Publishing House*: Tewksbury, MA, USA, 2011.

[19] Schiele A. and Visentin G., “The ESA human arm exoskeleton for space robotics telepresence,” in *Proc. 7th Int. Symposium on Artificial Intelligence, Robotics and Automation in Space (iSAIRAS)*, Nara, Japan, 2006.

[20] http://www.societyofrobots.com/robot_arm_tutorial.html

[21] http://www.engin.umich.edu

[22] http://gidesa.altervista.org/roboticarm.php

[23] http://curiosity.discovery.com/question/how-robots-improve-lives

ANNEXURES

ANNEXURE 1 – PLAGIARISM REPORT

17DES0098

by Khyatee Boroowa

Submission date: 06-Apr-2018 03:42PM (UTC+0530)
Submission ID: 942058507
File name: khyatee.docx (8.89M)
Word count: 4368
Character count: 23140

17DES0098

ORIGINALITY REPORT

12%	9%	11%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	E. Brown. "From the Cover: Universal robotic gripper based on the jamming of granular material", Proceedings of the National Academy of Sciences, 11/02/2010 Publication	2%
2	greathimalayannationalpark.com Internet Source	1%
3	www.cesup.ufrgs.br Internet Source	1%
4	documents.mx Internet Source	1%
5	www.pnas.org Internet Source	1%
6	Donati, Marco, Nicola Vitiello, Stefano De Rossi, Tommaso Lenzi, Simona Crea, Alessandro Persichetti, Francesco Giovacchini, Bram Koopman, Janez Podobnik, Marko Munih, and Maria Carrozza. "A Flexible Sensor Technology for the Distributed Measurement	1%

of Interaction Pressure", Sensors, 2013.
Publication

7	www.projectmechatronics.com Internet Source	1%
8	Mathew, Edwin Basil, Dushyant Khanduja, Bhavya Sapra, and Bharat Bhushan. "Robotic arm control through human arm movement detection using potentiometers", 2015 International Conference on Recent Developments in Control Automation and Power Engineering (RDCAPE), 2015. Publication	1%
9	Submitted to Thammasat University Student Paper	1%
10	Kumar, Vinod, A. Eakambaram, and A. Arivazhagan. "FEM Analysis to Optimally Design End Mill Cutters for Milling of Ti-6Al-4V", Procedia Engineering, 2014. Publication	1%
11	Michael Naylor. "A Configuration-Space Approach to Controlling a Rehabilitation Arm Exoskeleton", 2007 IEEE 10th International Conference on Rehabilitation Robotics, 06/2007 Publication	<1%
12	www.noviolence.com.au Internet Source	<1%

13	David L. Akin. "Force Estimation Based Compliance Control of Harmonically Driven Manipulators", Proceedings 2007 IEEE International Conference on Robotics and Automation, 04/2007 Publication	<1%
14	www.scribd.com Internet Source	<1%
15	www.srhip.on.ca Internet Source	<1%
16	etd.uovs.ac.za Internet Source	<1%
17	www.northernarc.com Internet Source	<1%

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		