PROJECT REPORT
ON

DEVELOPMENT OF A FIVE-FINGER ROBOTIC GRIPPER

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

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2020-2021

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CERTIFICATE

This is to certify that project entitled **"DEVELOPMENT OF A FIVE FINGER ROBOTIC GRIPPER"** submitted by **"SUHAIB UR REHMAN (17BME035), SUHAIB AKHTAR (17ME083), INTEKHAB AZAM (17BME088), AHMAD SHAMOON (17BME098), MD OSAMA MASOOD (17BME100)"** partial fulfilment of the requirement for the Bachelor of Technology in Mechanical Engineering contains the bonafide work of the above student done under my supervision & that the same work has not been submitted elsewhere for the award of any degree or diploma or any other purpose.

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DECLARATION

We declare that this project titled **"DEVELOPMENT OF A FIVE FINGER ROBOTIC GRIPPER"** submitted in partial fulfilment of the requirement for the Bachelor of Technology in Mechanical Engineering is a record of original work carried out by me under the supervision of **Prof. MOHD SUHAIB** & has not formed the basis for the award of any degree, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgements have been made wherever the findings of others have been cited.

Suhaib ur Rehman, Suhaib Akhtar, Intekhab Azam, Ahmad Shamoon, Md Osama Masood

ACKNOWLEDGEMENT

"In the name of Almighty ALLAH, the Most Beneficent, the most merciful"

First of all, We would like to thank the Almighty Allah who is the most merciful and graceful and who has given us the courage to complete this work. We are highly indebted to our mentor and supervisor **Prof. Mohd. Suhaib** for giving us the opportunity to be able to learn, work and grow under his extremely skilled and specialised supervision. We have always highly respected and admired his contributions towards academics and consider ourselves to be of utmost fortune for being able to learn from indeed one of the best in our faculty. We would like to thank him for investing his valuable time, ideas and suggestions and most importantly his encouragement. We have indeed been able to learn immensely under his guidance some important lessons, which will be used and cherished beyond our college life.

We would also like to pay our sincere gratitude to **Prof. M Emran Khan**, Head of Department, Mechanical Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, without whose guidance and support, this project would not have been possible. We would like to express our deep sense of gratitude to **Dr. Aparna** & **Mr. Waseem** for their support & encouragement. We are highly indebted to them for providing us with the important inputs and other information related to our project which helped us in accomplishing this task.

We are thankful to all **our group members** for their contribution and constant support without which this project could not have been completed. We would like to express our special gratitude and thanks to ourselves, **Mr. Suhaib ur Rehman, Mr. Suhaib Akhtar, Mr. Intekhab Azam, Mr. Ahmad Shamoon, Mr. Osama Masood** for willingly helping us out with all their abilities and for providing us with tremendous support throughout this project among many others. We cannot be more grateful to our group members for helping us out with different tools and resources.

Last but not the least, We would like to thank our **parents & family** who have always been the best of our support. We have no valuable words to express our thanks, but our heart is still full of the favours received from them.

Suhaib ur Rehman, Suhaib Akhtar, Intekhab Azam, Ahmad Shamoon, Md Osama Masood

ABSTRACT

Nowadays, manipulators are being used for many applications to make work easier or reduce the risk of work which seems impossible, risky, or difficult for human beings. Robotic manipulators may be prepared with diverse sorts of end effectors to accomplish various tasks. Despite recent successes in advancement of multi-finger robotic grippers, autonomous grasping of complex and irregular shaped objects gives rise to challenging engineering problems that require an integrated approach to perception, grasping, planning, control, and high-level manipulation mechanisms. In this thesis, we present a 3D-printed light weight and human-hand inspired design of a robotic gripper, having a tendon-based actuation system and fingers which are servomotor driven using only onboard sensing and computation. We start by developing a five-finger robotic gripper based on human hand anatomy. We then validate the design by simulating the force distribution acquired during the grasping of different object types. We further estimate and validate forces in tendons and actuation systems to identify suitable design parameters for each of them. Finally, we present sensing, control, and additive manufacturing strategies for transforming the design to a real-life working model. Extensive online experimental results and simulation study are presented throughout the thesis. We conclude by proposing future research opportunities.

Keywords

Humanoid Robotics, Multi-Finger Gripper, Grasp Analysis, Tactile Sensing, 3-D Printed Prosthetic limbs

Subject Categories

Robotics

PROBLEM STATEMENT

Design and develop a multi finger robotic gripper with the following systems:

[1] No. of finger = 5
[2] DOF = 14
[3] Use the tendon actuation system for the flexion mechanism of the finger.
[4] Use a torsional spring for extension mechanism of fingers.
[5] Use motors for tendon actuation.
[6] Apply Arduino control for actuation system.
[7] Use the suitable material for the fingers and tendon.

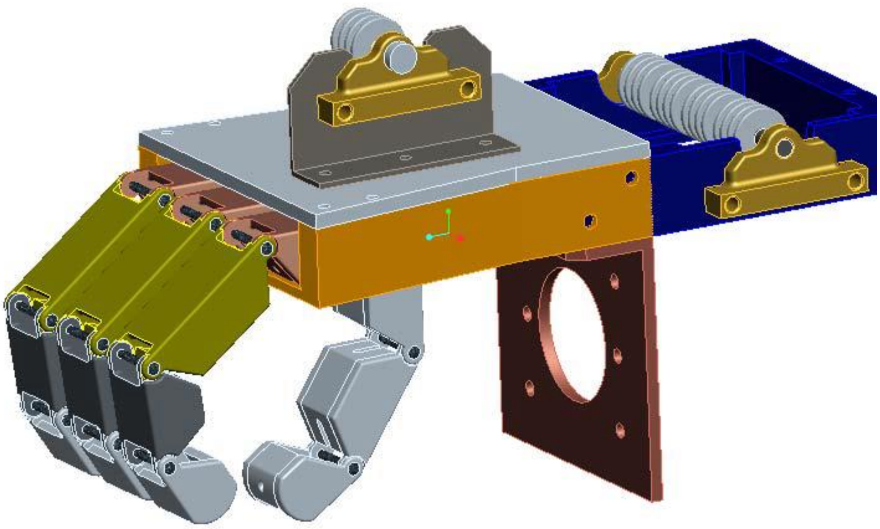

Figure 0.1: Previously Designed 4 Finger Gripper

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INTRODUCTION

Robotic gripper is defined as a component of an automated system which involves a moving arm, a gripper, and a system. Human hand is considered as the most important part of human body. The hand is a very flexible part of the human body. The basic function of the hand is to grasp and hold an object. In grasping, human hand analyses the object in observation, its size and even rough dimensions and the human brain, after receiving this information does its part.

Robotic gripper is based on this function of the human hand. The first robotic gripper was developed by Victor Scheinman, a student at Stanford University in 1969. Although this was the first controllable gripper, but it had its limitation like being uncontrollable and dangerous to work with. This gripper had a 6DOF, DC motors and the motion was generated by harmonic drives. This led to the development of many such grippers. The various types of robotic grippers differ in terms of number of fingers, DOF and their functions. In 1990, MIT developed its own version of robotic gripper called Barrett hand, which consisted of 3 fingers, servomotor, and brushless DC motors. In the present day, manipulators are being used for many applications to assist human beings including in some of the harshest terrains . Robotic manipulators can be prepared with diverse sorts of end effectors to accomplish various tasks. They are being used in space exploration programmes, bomb defusal and even in the medical field as prosthetics and even assisting in surgeries. A wide variety of such grippers is present in the market.

There are 4 types of robotic grippers which are widely used in today's manufacturing plants:

[1] Hydraulic grippers
[2] Pneumatic grippers
[3] Vacuum grippers
[4] Servo-electric grippers

The robotic hand is also a type of robotic gripper which resembles a human hand. While discussing robotic hand and grippers, an important term is to be noted dexterity. This means the ability of the hand to cope with objects and actions. Developers and researchers try to reciprocate closely as possible the kinematics and dexterity of the human hand.
A robotic gripper system mainly consists of an arm, which is essentially a chain of links that are brought into motion with the help of actuated motors. Then a robotic hand or end-effector is actuated on one end of the chain.

The advanced anthropomorphic robotic hand system contains actuators, motherboards, sensor, and mechanism. In this system grasping can be considered as set of procedures and operations that must be developed to hold/manipulate the object. Grasping is further divided into stages according to the position of the object. Then, the stability of grasp.

They also include controllers which are essentially the processors of the robotic arms, arm and drive controllers can be understood as the brain of the system these controllers are either programmed and then perform their function automatically or instruction are fed by the technician. Controllers are essentially the control consoles of robotic arm um is the main section of the system arm consist of shoulder elbow and wrist these are all joints with shoulders resting at the base of the arm . The robotic arm is already in use for multiple industrial sectors as well as in the planet exploratory missions, bomb defusal and so much more. The researchers even suggested that they can be even used as prosthetic limbs.

Earlier these arms were used for very limited applications and mostly in auto manufacturing plants and industries. They were used for material handling, welding and drilling and painting. They are designed and developed according to the application. The gripper used in the automobile sector cannot be used for robot assisted surgeries. Various grippers and arms actuate by employing different components like motors, sensors, and special actuators.

The main goal is to develop such machines that are automatic, precise, and a robotic gripper is a robotic system that consist of an arm, gripper, drives, actuators, and controllers first of all such robots for design in the 1980s. From then onwards, extensive research and progress has been made in this field. Our primary aim is to develop a five-finger robotic gripper based on human hand anatomy. This hand includes four fingers and a thumb, and the actuation is tendon driven. The design is obtained by simulating the force distribution acquired during the grasping of different object types. We further approximate and validate forces in tendons and actuation systems to identify suitable design frameworks for them so that our actual design becomes feasible. Extensive research results and simulation study are shown in this thesis.

CHAPTER 1
LITERATURE REVIEW

A SYSTEMATIC ADVANCEMENT OF MULTI-FINGER ROBOTIC GRIPPER

1. Introduction

As the interest toward humanoid robots is increasing rapidly [1], development of human hand-like robotic hands have become a major objective, and many research projects are being carried out to accomplish this. Some examples of this project include, the Robonaut hand 2 by NASA [2], the DLR hand II [3], the ultralight hand by Karlsruhe university [4]. The first robotic gripper was developed by Victor Scheinman, a student of Stanford University in 1969 [5]. Although this was the first computer control gripper, it had its limitations like being uncontrollable and dangerous to handle. In 1990, MIT developed an advanced version of robotic gripper called Barrett hand, which consisted of 3 fingers, servo motor and brushless DC motors [6].

While discussing robotic hand and grippers, an important term that should be noted is dexterity. Dexterity means the propensity of hand to cope with objects and actions. This means we are a step closer in integrating robotics in our daily lives [7]. The artificial hand can be used in so many applications we can't even possibly imagine. This means these systems can be programmed in such a way that they not only make our life easier but can even be used for scientific purposes.

In previous review papers of robotic grippers, the emphasis was more on their specialized applications. In [8,9], the use of grippers in robotized creation measures was talked about. Various kinds of grasping frameworks, as counterfeit vacuum, attractive and mechanical holding, were canvassed in [10]. In [11], just equal controller gripper components were investigated. In [12], grippers utilized in careful practices can be found. Just double arm control was examined in [13]. In [14], space robots were surveyed. Robots utilized in plant creation were canvassed in [15]. In [16], the contact systems for miniature parts were analysed. In [17], end effector control plans were covered. Some cutting-edge instances of grippers incorporate the Kuka KR 1000 Titan; Dexter on the International Space Station; the Explosive Ordnance Disposal controller on the iRobot 510; and the da Vinci Surgical controller [18–21].

The robotic arm is used in multiple industries as well as in the low-cost planetary exploration missions [22], bomb defusal prosthetic [23] and much more. The researchers even suggested that they can be even used as artificial limbs. These arms are also being used in surgeries. Earlier these arms had limited applications and were mostly used in automotive manufacturing and assembling plants. Their application included material handling, welding, drilling, and painting. But today, they can be seen performing multiple tasks in various fields, such as bomb defusal, underwater and planet exploration, surgeries. Prosthetic limbs are now available in different sizes, involve different mechanisms, are lightweight [24] and can be selected with respect to the application. Presently, robots in automotive industries have resulted in a precise and agile manufacturing process [25]. The Asian dream of human beings is to replicate themselves. For years, many universities and researchers have worked extensively on humanoid robotics. The main aim is to develop such machines that are intelligent and more precise.

Our paper focuses on robotic gripper, their classification, and the types of robotic gripper such as vacuum, pneumatic, servo-electric, and hydraulic grippers. Multi-finger grippers and their classification on the basis of the number of fingers has also been discussed in this paper. The arising uses of multi-finger grippers in different spaces, for example, in clinical, horticulture, miniature and nano control is additionally included. We accept this paper will help scientists and industry find advance getting a handle on instruments. We finish up our paper by discussing about the challenges and future opportunities in this area.

The remainder of this paper is coordinated as follows: Section 2 covers a concise presentation about automated grippers coordinated by their grouping, Section 3 exhibits multi-finger grippers with their applications and models, Section 4 examines the future heading and conversation of automated grippers, and Section 5 closes the paper.

1.1 An Introduction of Robotic Gripper

The easiest way to understand the gripper is to relate it with the human hand as both work in a similar way in holding, tightening, handling, and releasing a work piece [26]. The most distinguished thing about the human hand is that it can manipulate itself according to task [27]. Grippers act as a dynamic link between the robotic arm or grasping equipment and the object to be acquired or work piece [28]. There are secondary systems of handling mechanisms which provide a short-term contact with the work piece or job to be grasped [29]. Various research is being carried out to increase the degree of freedom of robotic grippers so that they can adapt to any task just like the human hand [30]. A robotic gripper system consists of an arm, which is a chain of links that are brought into motion with the help of actuated motors [31]. Then a robotic hand or end-effector is actuated on one end of the chain. The advanced anthropomorphic robotic hand system contains actuators, microcontroller, sensor, and mechanism. In this system grasping is achieved by deploying a set of procedures and operations that must be developed to hold/manipulate the object. The microcontrollers are the processing unit of the robotic arms and drive controllers act as the brain of the robotic system [32]. Since the robotic gripper is a machine, it cannot estimate its state or environment. To get an actual idea of the surroundings in complex environments, these systems are fitted with various sensors [33]. For example, proximity sensors are used to detect nearby objects [34], tactile sensors are used to sense the object via physical touch [35].

1.2 Classification of Grippers

The robotic gripper is extensively arranged into four primary groups [36-37]. Impactive (a direct mechanical force is applied to physically grasp the object), Ingressive (prehension of the object is achieved by physically penetrating the object surface), Astrictive (a binding or attractive force is applied to the surface of object), Contigutive (an immediate contact is required to provide an adhesion force to grasp the object) [38-40].

Table 1: Classification of Grippers

Grasping Technique	Type	Example
Impactive		Clamps (external fingers, internal fingers, chucks, spring clamps). tongs (parallel, shear, angle, radial)
Ingressive	Intrusive	Pins, needles, hackles
	Non-intrusive	Hook and loop
Astrictive	Vacuum Suction	Vacuum suction cup/bellows
	Magneto-adhesion	Permanent magnet, electromagnet
	Electro-adhesion	Electrostatic field
Contigutive	Thermal	Freezing, melting
	Chemical	Permatack adhesives
	Fluid	Capillary action, surface tension

1.3 Types of Grippers

For an operation, to grasp an object a direct contact is made between the gripper and the object, so it is very crucial to select the appropriate type of gripper for the operation to work effectively. Grippers are divided in four categories[41]. These are:

1.3.1 Vacuum Gripper

These types of grippers are very flexible due to which they are widely used in manufacturing processes[42]. In these grippers, rubber or polyurethane suction cups are used to lift the object. In some grippers, a layer of closed cell foam rubber is used in place of suction cups. [43] These types of grippers can handle and pick uneven objects of any type of material using either miniature electromechanical pumps or compressed air driven pumps are used.
Kenos KVG vacuum gripper is show below, [44]

1.3.2 Pneumatic Gripper

These types of grippers are compact in size and have light weight [45]. These grippers are suitable in the manufacturing industry to perform tasks where the space available is very less. In this gripper, the gripping fingers are moved and rotated by the effect of compressed air. They can hold from small objects to large and heavy objects [46].

1.3.3 Hydraulic Gripper

The strength of these grippers is very large and are suitable to perform the operations where a huge amount of force is required[47]. The strength of these grippers is produced by using pumps. Among all the types of grippers, these are strong but heavier than other grippers because of oil used in its operations [48].

1.3.4 Servo Electric Gripper

These types of grippers are widely used in industries because these grippers can easily be controlled by an operator[49]. In this the movement of the gripping finger is controlled by an electric motor. These grippers are very flexible and different objects can be handled using them. They are cost effective as there are no air lines present in them [50-52].

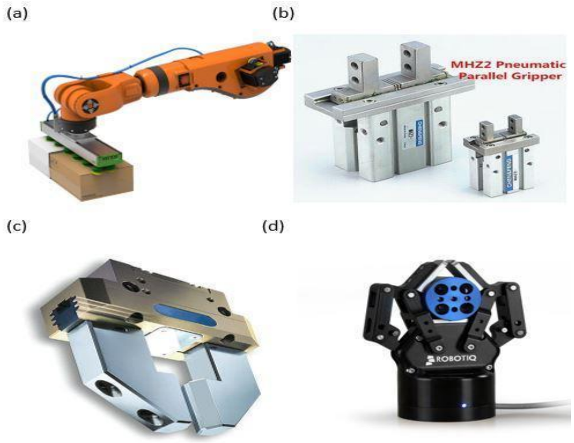

Figure 1.1: Types of Robotic Grippers; (a) Kenos KVG vacuum gripper, (b) MHZ2 Pneumatic Parallel gripper, (c) Hydraulic Gripper, (d) Servo electric gripper

1.4. Multi-Finger Robotic Gripper

Much research have been done and still going on in developing multi-finger grippers [53]. Multi finger grippers are defined as the grippers having fingers more than one, these types of grippers are used for service sectors where the handling objects did not have the specific shape and also called as exterior grasping [54]. In grasping an object, a multi-finger gripper is suitable because it provides more contact area for gripping. For gripping an object, the jaws are initially open and then close around the central pivot, having an arc motion. Angular grippers are generally used where the working space is limited. [55]. When jaws are required to move up or out of the way. External gripping is the most widely recognized approach to hold the end power of the gripper which is utilized to hold the part.

Robotiq three-fingered hand, Shadow robot hand and IH2 Azzurra hand are the examples of Multi-fingered grippers [56][57].

1.5 Classification of Multi-Finger Gripper

On the basis of fingers, multi-finger robotic grippers are classified as below.

1.5.1 2-Finger Robotic Gripper

The two-finger robotic grippers consist of two jaws or fingers to grip the objects, it is easy to operate in performing automation activities in industries. It is able to handle objects which vary in shape and size. The 2- finger robotic gripper is well suited for the process of manipulation in industry, it is used to grip the object and then place it to the predefined location in different activities performed in industries like assembling, quality check, etc. Many other tasks are also achieved by using these grippers because of having 2 different grip strokes and highly adaptive nature [58][59].

The mechanism used in driving the gripping fingers is enhanced to get two discrete contact regions, in which the one region is named as encompassing grip region, and it is located at the bottom of the fingers, and the other region known as pinch grip region, and is located on the top of the finger. There is an equilibrium boundary between these regions[60].

During grasping an object, if the contact between the gripper and object is made in an encompassing grip region, then the gripping fingers will automatically curl around the object according to the object's shape and size. On the other side, if the contact lies in the pinch grip region, fingers will continue its parallel motion whereas the object will pinch [61].

1.5.2 3-Finger Robotic Gripper

A 3-finger robot hand with force torque sensor which can hand pick an object. It has the 5 degrees of freedom., and 5 possible numbers of acts (flexion-03, fingertip-01, rotation-01). All the fingers can be controlled independently, and the fingertip angles of all fingers are controlled by one motor. The 3 –fingers are moving towards the central axis to grip the object at the centre of its axis. 3-finger grippers are found to be the best option because of having very good versatility and flexibility. These grippers can grip objects having different shape and size. 3-finger grippers are compatible with most industrial robot manufacturers. Because of its versatility with the position, force, and speed control for every finger and four different grip modes, it can almost grip any type of object. The values of grasping force and its speed can be pre-set, where the capability of the robot is to produce a grasping force of up to 60N.

The grasping performance of a 3-fingered gripper can be analysed in four different grasping modes. The very first one is cylindrical mode (also called basic mode) and is used for the objects having one side longer than the other. The second one is called spheroid mode (wide mode), it is used for round or long objects. The third one called pinch gripping mode is perfect for small brackets that have to grip precisely. Fourth, scissor grasp mode is intended for very small objects. This mode is not much more powerful than the other modes because of the involvement of only two tips in this mode. For most of the grasping mode we can do Fingertip Grasp or Encompassing Grasp. To speed up the grasping mode we have partial open-close features available.

One three-finger robotic gripper was developed [62] and then improved by integrating this with a feedback sensor system [63], this contains 87 touch sensors distributed over the end effector’s surface.

1.5.3 4-Finger Robotic Gripper

The four-finger robotic gripper can grasp an object with the help of two fingers having the same rotating centre, and then the base joint is rotating until the object reaches its pre-set position. After these the remaining two fingers come in action to perform the task. These grippers can be used for tasks like opening and closing of a bottle’s cap . Both human and robotic hands realize the same task, but the execution of the task is different. Main difference is that the human hand requires both hands for the completion of a task successfully, but in the case of a robotic hand, it utilizes a pair of hands with an arm.

For 4-fingered robotic grippers, the dual turning mechanism was introduced to generate the common rotating axis for the base joints, in this the fingers work in pairs of two, meaning rotating of inner and outer circles using gear trains. Around the axis manipulation is fully decomposed into the velocity control (around the axis) and the internal force control (in the contact line). So, the rotating motion of the object can be attaining around the axis, through velocity control for base actuators, along with the internal forces imparting by other actuators. [64].

PZV is a four-finger concentric gripper developed by SCHUNK. This gripper comes into use when two and three finger grippers are not able to grip the object, for example to grip a cylinder [65].

1.5.4 5-Finger Robotic Gripper

The 5-finger robotic grippers are very much similar to the human hand which are equipped with four fingers (little finger, index, middle, fourth) and one thumb of a human hand. Every finger has an installed actuator which makes the finger start moving. Each finger has one DOF which is responsible for its rotational movement. The thumb is designed in such a way so that the gripping is strong, for having good gripping control and appearance a thumb is provided with two degrees of freedom, means that the thumb is able to flex as well as extend. All fingers except the thumb have been designed such that each finger has 1 degrees of freedom. Servo DC motors attached to it which provides the motion to the fingers. DC servo motor also controlled the extension fingertip in order to drive the rack and pinion. [66]

SCHUNK has developed the world's first robotic gripper named SVH having five fingers, which is nearly similar to that of the human hand, it contains nine drivers due to which different gripping tasks can be done with high accuracy and sensitivity. A reliable gripping is done by using elastic material for the gripping surface of the fingers. All electronic parts are integrated into the wrist. The design of SVH is compact [67].

Figure 1.2: Multi-finger Robotic grippers; (a) 2-finger Robotic gripper, (b) 3-finger Robotic gripper, (c) 4-finger Robotic gripper, (d) 5-finger Robotic gripper

1.4 Applications of Multi-Finger Robotic Gripper

As discussed above, there are various fields where the robotic grippers are used. Some applications of robotic grippers are discussed below:

1.4.1 Industrial Grippers

At the very beginning of the robotic world, the grippers were produced for modern applications. The fundamental goal of developing the grippers is for mass production in the industry. Some points to be considered for developing an industrial gripper are, i.e., structure of the gripper and its orientation, both static and dynamic equilibrium of the gripping object [68][69].

In 1961, the first industrial robot named UNIMATE was developed and General Motors invested in it to use in their assembly plant [70]. This manipulator was so rigid as able to grip the hot die cast iron[71].From that point forward, a considerable lot of the organizations began utilizing mechanical holding innovation and they likewise built up their diverse drive instruments[71].

Industrial grippers are divided into two categories:

1.4.1.1 Grippers for Familiar Environment

In this the surrounding conditions are well known the specific task grippers are used for this condition. Assembly line of an industry lies under this condition, where information like position of the object, and the path on which the gripper is to move to place the object are predefined and the gripper can easily pick and drop the object. Different types of sensors like ultrasonic, accelerometers and photoelectric are used to determine variables like position, force, velocity, torque and acceleration [72].For a functioning forecast, arranging, and execution of the framework for catching moving articles vicinity sensors have been mounted on grippers. Schunk DPG-in addition to and Robotiq 2-finger grippers are some popularized grippers[73][74].

1.4.1.2 Grippers for Unfamiliar Environment

In certain applications, grippers are needed to work in an unexplored environment. In designing grippers suitable for working in unknown conditions, different systems such as feedback system, vision systems are used. Cameras can also be used to detect the objects near it during an operation. A gripper was developed which includes a camera system and was used to grip the random objects from bin [75].

Many improvements have been done and still much research are going on in vision systems and other devices to make the grippers suitable to grip the objects in an unknown condition[76][77]

1.4.2. Grippers to grip Fragile material

As lots of improvement is carried out in the sensors used in grippers, now the work is carried out in gripping the fragile material. An end-effector sensor was developed for the purpose of harvesting the lettuce [78]. In this gripper a machine vision device is used along with six photoelectric sensors and fuzzy logic controllers. By introducing this robotic gripper in harvesting the lettuce, the rate to plant the lettuce was increased to 5 second / lettuce and the success rate of 94.02% was achieved.

A gripper was developed to grip the food, it contains a feedback system to track whether the task is going on effectively or not [79]. This gripper works on the principle of magnetic field, making one finger at rest and the other finger will start moving when the magnetic field comes into action. The actuator is introduced inside alongside the inward magnet and the external magnet is dependable to turn the finger. One more design was developed for the purpose of gripping fruits [80]. This gripper was developed for both the purpose of holding and chopping fruits, these grippers are effective because it does not damage the fruits during chopping.

After achieving success in developing a gripper for gripping and chopping the fruits, a new design of gripper was developed which works on the principle of Bernoulli for the purpose of gripping the chopped fruits and vegetables [81]. In this air was used as the working fluid to lift the fruits, the contacting area was reduced by making the air to flow on the surface of the fruit. It is also able to decrease the moisture content present on the surface of the fruits and vegetables, which can be considered as one of its advantages.

A gripper was developed to evaluate the durability of the mangoes [82]. To test the ripeness of the mangoes, a sensor named accelerometer is used which was encased in the fingers of the gripper. Furthermore, for deciding the adequacy of the gripper, the experimental values are compared to the ripeness index.

There are lots more grippers developed for picking different materials like, different grippers are developed to grip material like tomato and cherry [83][84], both have different gripping designs. And many more developments and improvements are carried out for the task of gripping different fragile objects, in all these the main focus was on designing the feedback system and making the gripper flexible so that we can apply them in gripping different fragile objects.

1.4.3. *Medical applications of Grippers*

In early stages of robotic grippers, the grippers developed are only for specific work, there is no feedback system available to manipulate the output as per the input conditions, this became the major problem with these grippers in the medical field and due to this the tissues in humans can be damaged during a surgery.

Development of soft grippers was started to conduct surgeries efficiently without harming the tissues. This gripper makes secure contact with the tissues during the operation. For the surgeries which are performed through tiny incisions, a soft body gripper was developed which makes the secure contact with the tissues to perform the surgeries in an effective manner [85]. This gripper was able to generate a force of up to 1 N to grip during the surgery. The design of this gripper can easily scale to develop different sizes of grippers and the elastomeric material was used in the process of fabrication.

One more application of the robotic gripper in the medical field are the surgeries where the robots are assisting the doctors in performing different tasks. In surgeries using robotic grippers, the main concern is in the automation system and the safety of these grippers, as any failure or time lag in the control system can cause injuries to the patients and sometimes may lead to death.

A micro gripper was developed having the star shape for the purpose of removal of tissues [86]. After performing many experiments on living test animals, this was proven effective in removing the tissues in an operation without affecting the other inner organs of the body. A Conventional process of multilayer microfabrication was used to fabricate this, and the actuation process was based on the principle of magnetism.

For some applications in the medical field, grippers are developed which were based on the methodology of suction [80] and the purpose was to grip and lift both small and large intestines which are very flexible and slimy organs in the body. Manual pump and vacuum pump both are used for suction processes, but it is not determined which one is more effective for this application.

A small-scale gripper was developed for the task of revoking the process in minimal invasive surgery [87]. It can produce a gripping force which is up to 5.3 N. Brushless motors were introduced for adding one more degree of freedom to improve the overall performance.

A gripping device was developed using a soft pneumatic system for the purpose of manipulating the tissues [88]. This gripper is able to lift the object up to 2 mm at very small gripping force.

Many experiments are carried out in improving these medical grippers for making them more effective and easier to use in different surgeries. And the main focus is to control the gripping force for different operations to make surgery effective without affecting other organs.

1.4.4 *Grippers of micro and nano size*

Lots of research is carried out in developing grippers which are capable in gripping and lifting the micro and nano sized objects.

Micro-electromechanical Systems (MEMS) were designed for gripping the objects at micro level. The major application of these grippers is in semiconductor industries where assembling process is performed on wafer substrate [89]. These grippers are also effective for the tasks where biomaterials and nanomaterials are used [90].

Microgrippers are designed by hybrid the micro-electromechanical systems which includes the comb drive actuators having integrated vacuum devices [91]. A deflection of 25 μm can be achieved at the top of the arm and can easily pick the objects having the size between 100 to 200 μm.

A gripper was created in which the actuation process was done by thermal bimetallic material [92]. The designing of this gripper was carried out by integrating the nanofabrication technology with conventional microlithography in fabricating the gripper having size less than or equal to 100 μm.

An electrostatic gripper was developed which was able to sense the contact of the gripper with the object using the capacitive sensors [93]. It can easily grasp the object of size as small as of 12 μm at 55 V as driving voltage.

A microgripper was fabricated using polymer which was manufactured from SU-8 [94]. A sensor is embedded in it to determine the tensile force, and the actuation process is based on the principle of electro thermal effect. This gripper can displace the object up to the distance of 100 μm per 50 cycles and the force developed by this also varies.

A microgripper is developed having two fingers, Furthermore, ready to play out the assignment of controlling the position of the object at high velocity [94]. Electrostatic gripper was designed to grip the standard micro sized components [95]. This gripper was able to pick and drop the materials of different shapes and of dimensions which varies between 0.3mm to 0.1mm.

A contiguous gripper was developed in which the layer of liquid water is used between the object and the gripping finger [96]. In this the water gets frozen to ice, and this ice sticks to surfaces of both the object and the gripping finger.

As the technology is advancing daily and lots of inventions and improvements are going on using micro and nano sized particles. So, to handle these particles manually is very difficult and to overcome this problem much research are carried out and a lot more are going on in developing these types of grippers which are reliable, cost effective and easy to use.

1.4.5 Grippers for Soft Fabric

It is difficult to grip the fibric material by using normal grippers. So, it was a big challenge for the researchers to develop a gripper which is effective in gripping the fabric material having very small thickness. These grippers are also known as ingressive grippers and the application of this gripper is in textile industries to grip the fabric.

A spur wheel was used in developing one of the initially developed grippers, it easily detaches the different sheets of the fabric from each other [97]. At that point the improvement was finished by changing the plan of the gripper [98], and it had the option to isolate the back-cover sheets from the material[97].

Suction-Cup grippers were designed for gripping the fabric material [98]. Designing of this gripper was problematic because during the cutting of fabric, the fabric material should not deform. This has holes on a flat surface of 0.5cm diameter for the process of suction and the outer holes of 0.1cm diameter to maintain positive pressure. Part handling can be improved by using a proper feedback system.

To grip the profiles of different shapes like C and L, the grippers having suction cups was improved, it grips the fabric material by unfolding the fabric in different phases. Also, by revising the shape of the gripper we can achieve various shapes of the fabric [99]. For picking leather plies, a suction cup was designed which was highly reliable [99]. Advantage of this adaptable attractions cup was that it does not leave any stamp on the calfskin.

A direct contact gripper called constitutive grippers is also used for gripping the fabric material, in this the gripping is done due to the chemical adhesion. Grip interaction can likewise be performed thermally by liquefying the surface to stay with the fibric. A permatack cement alongside contact cushion is utilized in textile industries[100].

As discussed above, suction cup grippers are very effective for gripping the fabric material and the methods to make the gripping fingers stick with the fabric is continuously improving for getting better results[101].

1.5 Anthropomorphic

Anthropomorphic grippers contains more than two grasping organs, and their design resembles that of the human hand. The fingers may be solid or adaptable and their numbers vary from 3 to 6. Fully anthropomorphic hands with multi-connected jointed fingers possess great technical capabilities but has little industrial relevance [102].

1.5.1 Jointed Finger Gripper

The getting a handle on and control capability of the jointed finger hand is resolved generally by its kinematic structure. The ideal number of joints is three for each finger. The driving components are more convoluted for multi-jointed fingers since they should be initiated past a solitary level of opportunity. The drives and their interconnections should be acknowledged so that it is unimaginable for any piece of the component to arrive at a "dead point" along these lines hindering other joint developments. [103]

1.5.2 Jointless Finger Gripper

The grippers fingers depicted in the accompanying have no mechanical joints. Their construction depends on extraordinary materials, i.e., they have adaptable material joints. This impressively lessens the quantity of segments and therefore the cost. Notwithstanding, the heap conveying limit of such grippers isn't exceptionally high [104].

1.6 Dextrous

The robotic hand is also a type of robotic gripper which resembles a human hand. While discussing robotic hand and grippers, an important term is to be noted for dexterity. This means the ability of the hand to cope with objects and actions. Multi-finger grippers with moving finger joins are planned chiefly for control assignments requiring a specific measure of mastery like that of the human hand. Thus, these grippers are regularly known as dextrous hands [105].

Table 2: Examples of Prosthetic Hand

NAME	YEAR	FINGERS	DOF	CONTROL TYPE
i-limb[106]	2007	5	6	This prosthetic hand is myoelectric and employs five individually powered digits. Muscle signals called triggers are used to command the hand for activating a specific grip.
Vanderbilt hand[107]	2009	5	16	This hand uses brushless DC motors and servos. Joint coupling method = single cable for each finger
MLR/MPL hand[108]	2012	5	26	The arm and hand employs more than 100 sensors. At the individual joints, sensors measure angle, velocity, and torque. Sensors are present on the fingertips which measures force and vibration and temperature.
Osprey hand[109]	2015	5	5	Wrist flexion
Cyborg beast hand [120]	2015	5	5	Wrist flexion
K1 hand [121]	2015	5	5	Wrist flexion
Odysseus hand [123]	2015	3	3	Wrist flexion
Imma hand[110]	2017	5	6	Wrist flexion
Luke arm[111]	2017	5	18	This hand uses 100 microelectrodes that are attached to the nerves in the upper arm, and to an external computer. When in contact with an object, a burst of signals is immediately sent up the nerves to the brain, after which it stops gradually.
Taska hand [124]	2018	5	8	This hand uses myoelectric sensors to detect muscle movements.

Vincent evolution 3 [125]	2018	5	6	It uses adaptive grip, vibrotactile feedback and EMG sensors.
Bebionic hand[112]	2019	5	6	This hand uses 5 actuators and is controlled by sensors placed all over the muscle.
Hero arm[113]	2019	5	5 (for 3 motor hand) 6 (for 4 motor hand)	There are special sensors present within the arm socket that helps in detecting muscle movement and flexes. This results in an effortless and easy control of the bionic hand.

Table 3: Examples of Advance Grippers

NAME	YEAR	FINGER	DOF	CONTROL TYPE
DLR HIT hand 2[114]	2008	5	15	This hand involves the use of super flat brushless DC motors and small harmonic drives. Serial communication system which connects inside the finger to attach the finger links with a minimum number of cables.
Dexhand[115]	2012	4	12	The actuation system of this hand is based upon the geared motors which is followed by a tendon transmission system. The motors are controlled using a combination of a DSP, FPGA and motor controllers.
Shadowhand [116]	2012	5	20	Motor hand uses 20 DC motors in the forearm Pneumatic muscle hand is powered by 20 opposing pairs of 20 air muscles in the forearm. The motor hand employs force sensors for each degree of freedom.

Mac hand [117]	2014	4	12	Each finger in this hand is independently actuated with the help of four motors. The control is operated by four microcontrollers ie. one for each finger. The coordinated control of the hand is attached to a supervision computer which is connected through a CAN bus link.
EH1 Milano hand [122]	2015	5	11	In this hand, the modular actuation units are kept in flanges and customized for the operation. The cable transmission permits the remote actuation which results in enabling the use of a low payload arm.
Mia hand [118]	2018	5	5	In this hand, there are three motors embedded within the hand which permits the hand to interact with the surroundings. Embedded functions and a simple control interface based on RS-232 makes integration seamless.
DLR CLASH 3F hand[119]	2018	3	7 (3 DOF for thumb)	This hand employs two Arduino Micros (Atmel ATMega32U4) which can control up to five servos with their timers. The servos used in this hand are Bluebird BMS-3900 MH.

Figure 1.3: Examples of Robotics Hands; (a) Osprey han, (b) Cyborg beast hand, (c) Mia Hand, (d) DLR HIT Hand -II

1.7 Future Scope and Discussion

Ongoing headways in the field of mechanical and electronic designing just as material science have made the gripper more dependable, quicker, more secure, and heartier. These advances have brought about presentation of robots in applications zones like versatile climbing robots (e.g., JPL's Rock-Climbing Robot), bouncing robots, space satellites, submerged robots being utilized in investigation and pipeline fix, fast assembling, and automated medical procedure. These advancements have acquainted fields for researchers with research on utilizing new materials and plans just as joining new innovations in automated frameworks. Ongoing headway in automated gripper are examined beneath:

Versatile and self-versatile grippers: these grippers furnish adaptability in getting a handle on objects with various shapes in modern frameworks, for example, Festo Power Gripper, Finger Adaptive Robotiq, SARAH in global space stations.

Measured grippers: they comprise of standard parts, for example, finger type grippers, vacuum cups, and finding pins. These grippers are being utilized in regions where superior and adaptability are required, for example, gathering activity in space. They can cling to changes in physical, mathematical, compound, and mechanical properties of the items essentially by utilizing distinctive standard grasping segments.

Reconfigurable grippers: these grippers can change into various explicit setups and pick various articles. These grippers have applications in the car industry and space advanced mechanics.

Brilliant material-based grippers: these grippers utilize keen materials for getting a handle on objects with separate shapes, for example, getting a handle on by molecule sticking (e.g., granule-filled sack), electrorheological (ER) liquids, Giant ER Fluid, ER liquid with electro bond, pneumatic actuators, and shape adaptive paddings. Albeit these grippers are being utilized in industry since long time, on account of their straightforward activation system and low weight, executing this innovation in mechanical getting a handle on is as yet testing because of their lower holding powers contrasted with regular grippers, these are moderate actuators, and there is a control issue in accuracy incitation of these materials. The examination is proceeding to build the holding power and accuracy. This incorporates creating regulators, for example, awful power control, sliding mode control, and ANFIS regulators. It ought to be noticed that electrostatic fascination gives more noteworthy aptitude since they utilize film like layers.

Novel system plan grippers: these grippers give adaptability with a base required management by executing keen components, for example, bionic taking care of associates into the grippers. The essential target of these plans is to have superior with less control exertion.

Delicate grippers: Multiple plans of delicate grippers have been grown, for example, electro attachment grippers, single and multi-fragment grippers, counterfeit muscle delicate mechanical grippers have been created. These grippers can mirror a human's hands. Adaptable, tiny hand-like gripper can help specialists in distantly directing surgeries or performing biopsies. A considerable lot of these plans join delicate mechanical technology and fake skins for easier control and uninvolved variation. Delicate materials empower grasping robotization past the limits of current innovation. A benefit of delicate automated grippers is halfway assuming liability of the preparing part by the actual properties of delicate grippers not at all like inflexible grippers. Be that as it may, utilizing delicate quality into the plan of grippers requests another variety of plan and control standards contrasted with hard grippers. There are continuous endeavours to improve grippers in two-overlay: execution and adaptability. Execution shows accuracy, spryness, coherence, holding strength, versatile, and adaptability imply an assortment of articles that can be gotten a handle on. The vast majority of the test in this angle is whether articles are known or obscure. At the point when one is working in obscure items, the goal is to execute adaptable grippers, while in working in known conditions, the goal is to build the exhibition. Achieving adaptability and execution at the same time is as yet testing as expanding execution, diminishes the adaptability.

New advances are being done to build adaptability: grippers having fingers like human hands are one of the models, which fuses control frameworks receiving input from the collaboration between the gripper and the climate to imitate people getting a handle on. Nonetheless, doing this requires a lot of calculation and it is unpredictable as far as preparing. Albeit creating automated grippers like human hands is as yet troublesome because of detecting and activation, the utilization of counterfeit robots in enterprises and society will increment altogether later on.

Execution improvement is application subordinate. Expanding execution can be accomplished through a plan of hearty regulators, usage of sensors and amazing actuators just as actual plan. Regarding detecting, scientists will keep on imitating the human holding capacities. Vision detecting is foreseen to develop to build the learning capacities of mechanical grippers with deficient information on the general climate. What is more, consolidating visual criticism in the plan of grippers empowers them to adequately speak with obscure conditions making them powerful. For activation, fake muscles actualized in mechanical hands would possess the power and thump of the characteristic muscle and are equipped for copying the versatility of human hands. This will make holding simpler as well as more intelligent and more secure. By presenting the headways in materials just as innovations in detecting and activation, clearly the presentation and versatility of robot grippers will be extended.

Grippers having mechanical effortlessness and power like double arm gripper versus grippers with adaptability and versatility like fake hands are extraordinary targets in automated holding. Effortless mechanical grippers need simple control design and hence broadly utilized in light of low cost and straightforwardness of usage. Furthermore, their applications become restricted with regards to getting a handle on articles with power control, getting a handle on items with odd shapes, or explicitly getting a handle on conditions. In these applications, utilization of grippers with greater flexibility as that in multi-fingered grippers gets helpful with the expense of control design intricacy.

Continuous movements and applications exhibit that fragile gripper are one of the backcountries later on in robot grippers for certain applications. The emerging applications are by and large in industry and clinical. Using these movements in industry will improve the introduction through and through as definite; regardless, the cost of changing the current advancement and reviving them with the new degrees of progress is high. In clinical applications especially in mechanical operation research is at this point going to outfit operations with ensured, overwhelming or more all strong parts.

1.8 Conclusion

In studying about the robotic grippers, we found that the need for robots in different fields like automobile industries, medical field, individual use and for industries working with micro and nano particles is increasing continuously. In today’s world the main focus is to design and develop the grippers to perform different types of tasks. We have discussed different types of grippers each have their own advantages and limitations. There are so many grippers developed and improved for specific tasks. Soft grippers are developed to grip fragile materials and for medical surgery. The most difficult task in the robotic industry is to develop the robotic gripper to handle the fabric materials in the textile industry and there are grippers developed which are suitable to grip and handle these fabric materials.

The robotic industry is focusing on developing multi-finger robotic grippers which will be replicas of the human being's hand and can be used in place of humans for performing all types of work to increase the efficiency of the task and to save the human being's life by performing dangerous tasks. We have discussed different types of multi-finger grippers. We have not yet developed the gripper which has the same number of degrees of freedom as a human hand has.

Prosthetic hands are also being developed using Additive manufacturing. In future, the performance of these grippers can be improved in different applications by using advanced controllers, effective feedback systems and by designing the effective design of the grippers. Artificial Intelligence can also be used to control these grippers for performing different tasks in unknown environments by using AI these robotic grippers can adopt themselves according to the surrounding to perform the tasks effectively.

METHADOLOGY

We based our study on the previous work done by our seniors and faculties on JMI hand. The design of the hand was basic and bulky. It's a 4 fingered gripper in which each finger is attached by a pulley through a string and capable of holding a small object. The strings pass over the pulleys situated at the knuckles. We evaluated its performance and designed an advanced version. Nowadays, most robotic grippers employ various motors and sensors. The motors work as actuators. Actuation is required for the movement and curling of fingers. The main aim is to provide improved mobility for fingers employing a servo motor in place of the strings. The principal lies in the fact that just how a human hand operates, it performs work by pulling muscles.

The overview of methodology can be incorporated from following points:

1. Study and review of previously fabricated multi-finger robotic grippers and identify the possible improvements.
2. Designing and modification of robotic gripper in CAD software with possible improvement. Verification and validation of proposed robotic gripper design using CAE package
3. Implementing tendon spring mechanism for curling of finger to grip an object.
4. To execute tendon spring actuation, three servo motors in total will be used so that rotation of the thumb is independent of the other four fingers and the gripper is not bulky.
5. The Arduino will be used to control these servo motors. The program will be loaded in the Arduino board according to the tasks to be performed.

The steps in designing and developing a multi finger robotic hand according to the specifications given in problem statement are shown below:

1. Designing and modification of a five-finger robotic gripper will be done in 3D modelling software named as SOLIDWORKS and rendering will be carried out in FUSION 360. Design will be based on the human hand anatomy, so it satisfies the digit ratio. The design will be validated and verified by conducting a series of simulation studies including estimation and validation of tendon and actuation forces, torque analysis of spring & motor, and force distribution in gripper's structure while grasping different complex objects. The model contains 5 fingers having 3 degrees of freedom (1 degree of freedom for each of 3 motors).

2. For the actuation of the finger using the servomotor, we have selected the tendon-spring mechanism. During a gripping motion, the fingers will curl to grip the object resulting in an increase in tension in tendon due to stretching. Once the object is released, fingers will move back to its initial position due to restoring force by torsional spring.

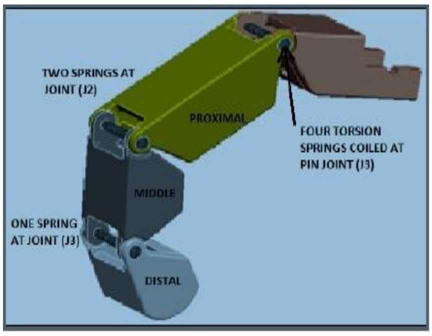

Figure A: CAD model of the finger With spring Mechanism

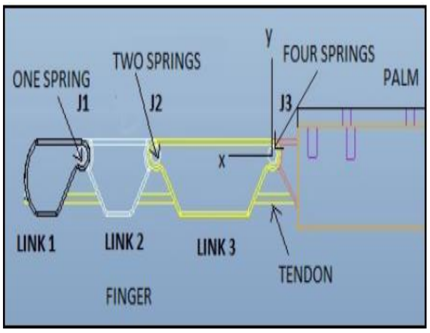

Figure B: Tendon Actuated Spring Return Mechanism

3. To stretch and release the tendon, servo motors will be used. We will use 3 servo motors (1 for thumb, 1 for index finger & middle finger, and 1 for ring & little finger) for a total of 5 fingers. 3 servo motors will be enough to provide 3 sets of independent rotation. The rotation of thumb and high torque is the biggest advantage of using servo motors .They are capable of a high starting-torque used for driving heavy loads in starting positions and for applications requiring calculative acceleration. They are also capable of constant torque over a given speed, where shaft power varies with speed. So, a total of 3 sTowerPro SG90 servo motors are used to actuate the tendon.

Figure C: TowerPro SG90 servo motors.

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Table 4: DC Motor Specification

Properties	Values
Working voltage	4.8 – 6 V
Current consumption with load	10-30 mA
Current consumption with no load	100-250 mA
Operating Speed	0.1 sec/60

4. These motors will be regulated and controlled by Arduino Mega2560 microcontrollers respectively. Arduino Mega2560 will be used to feed the instructions to the motor so that the hand can hold and release the object. The TowerPro SG90 servo motors is light in weight which makes the hand more effective. The program will be embedded in the Arduino according to the tasks to be performed. The programs will be written in Arduino IDE and will be uploaded to Arduino Mega2560 compatible board. The program libraries will be imported from https://www.arduino.cc/en/Reference/Libraries and will be modified according to the required purpose.

CHAPTER 2
DESIGN CONSIDERATION

OVERVIEW

Multi-finger robotic hand is an end effector located at the free end of the robotic arm such that the robot can hold parts, tools, and materials for performing a variety of tasks. An effective robot hand should be multifunctional, adaptive, and flexible. It consists of the base, or palm, which spans into several serial chains in a tree-like structure. As to the mechanical aspects, a wide range of design solutions are available, concerning the overall kinematical configuration, the actuation scheme, the adopted technological solutions, and the sensory integration.

Multi-finger robotic hands are controlled to perform tasks replicating human hands in order to grasp and manipulate different objects with the help of its fingers. Their main aim is to promote smooth and secure interaction with the environment. These hands are available as independent devices in such a way that they can be attached to any robotic arm known as modular hands.

Stable grasping and fine manipulation is major concern while designing any robotic gripper. The important functions of the hand are to explore or search, to grasp or restrain, and to alter or manipulate the arbitrary shaped objects in a number of ways. While grasping the object by multiple fingers and manipulating it to carry out some specific task, the grasp must satisfy a number of conditions, such as static equilibrium, no slippage and the ability of resisting the disturbances in all directions including the external and reactive ones. This requires a systematic determination of the contact locations and the related hand configuration or the kinematic structure.

2.1 DESIGN CONSIDERATION OF MULTIFINGER ROBOTIC GRIPPER:-

Among all the problems encountered in designing robotic gripper, the most crucial one concerns with the end effectors. Basic features for a gripper depend on strongly on the grasping mechanism. Thus, factors can be considered before choosing a grasping mechanism as following:

A. The characteristics of a gripper, which include a maximum payload, dimensions, orientations, a number of the composed links.
B. This characteristic of the objects, which include weight, body rigidity, nature of the material, geometry, dimensions, condition, position, orientation, contact surfaces and forces acting on the object and environmental conditions.
C. The gripper technology, for the construction of components with proper manufacturing and materials.

D. Flexibility of the grippers, whether it allows the rapid replacement or easy to adjusts and external modification or adaptation to a family of the objects that were contained within a range of specifications.
E. The Cost of design, production, application to the robot operation and maintenance. In fact, those characteristics were fundamental from a practical viewpoint for the grasping purpose; since they are many describe the range of exerting the force on the object by the fingers, the size of the range in objects which may be grasped and a particular manipulation type. Thus, a dimensional gripper.
F. Design of the gripper mechanisms may have great influence on the maximum dimensions of the grasped object by the gripper on the grasping force since this mechanism size may affect the grasp configuration and transmission characteristics. These peculiarities can be considered well known when it was considered the great different types of mechanisms which have been used.
G. It should easily fabricate with the readily available resources.
H. It should be of low cost.

2.2 FACTORS WE SHOULD FOCUSING WHILE DESIGNING THE GRIPPER:-

A. Impactive
B. Ingressive
C. Astrictive
D. Contigutive
E. Force and torque considerations

2.3 CONCEPTUAL DESIGN OF THE FOUR FINGERED GRIPPER:-

A. It should be able to grasp the irregular objects of different types of shape and size.
B. It should be able to take different loads.
C. It should be stability during the manipulations.
D. It should simulate the human hand.
E. It should be precisely controlled (through a computer or manually).
F. It should be independent of the friction coefficient between an object and the gripper.
G. Synchronization is the finger of motion.
H. Employment of minimum number of actuators.
I. It shouldn’t slip, so there should be a provision of the interlocking.
J. It should be of lightweight.

2.4 MAJOR STEPS WHILE DESIGNING THE GRIPPER:-

Once we finalized the **methodology**, Now it was time to implement it step by step.

1. The first step in our design process was to finalize the design parameter and initial layout of robotic gripper. We decided to keep 3 fingers in line with each other and the thumb opposite

to middle finger. This orientation was finalized to obtain the maximum gripping force and ensure an efficient handling of objects.

2. Components required to implement actuation system was placed on the bottom side of gripper. Motors, Electronic speed controllers and battery is not visible to outer surrounding as they will be fully covered to maintain the aesthetics of gripper. The wiring connection between Arduino and motor and the tendon actuation link between finger and motor will be done internally to protect them from outside forces.

3. Arduino was placed on the backside of the gripper. It was later covered with a transparent plastic cover to make it flexible for engineer to check wiring connection. Wiring connection will be provided internally. Programs can be loaded on Arduino without removing the board again and again.

2.5 HUMAN HAND

The human hands have always been a fascination for scientists. The studies of human hands have long been an area of interest for hand surgery, for the designing prosthetic devices and for quantifying the stretch of disability in individuals with congenital defects or wounded. The ideal end-effectors for such an artificial arm would be able to use the tools and objects that a person uses when working in the same environment. The human hands are a very complex grasping tool that can be handle objects of different sizes and shapes. The many research activities has been carried out to develop artificial robot hands with a capability similar to the human hand, which remains as a highly complex structure that in many ways defy understanding.

2.6 ANATOMY OF HUMAN HAND

There are five **digits** attached to the hand**.** The four **fingers** can be folded over the palm which allows the grasping of objects. Each finger, starting with the one closest to the thumb, has a colloquial name to distinguish it from the others:

[1] **index finger**, pointer finger, forefinger, or 2nd digit

[2] **middle finger** or long finger or 3rd digit

[3] **ring finger** or 4th digit

[4] **little finger**, pinky finger, small finger, baby finger, or 5th digit

The **thumb** (connected to the **first metacarpal bone** and **trapezium**) is located on one of the sides, parallel to the arm. A reliable way of identifying human hands is from the presence of opposable thumbs. Opposable thumbs are identified by the ability to be brought opposite to the fingers; a muscle action known as opposition.

There are numerous **sesamoid bones** in the hand, small **ossified** nodes embedded in tendons; the exact number varies between people, whereas a pair of sesamoid bones are found at virtually all thumb metacarpophalangeal joints, sesamoid bones are also common at the interphalangeal joint of the thumb (72.9%) and at the metacarpophalangeal joints of the little finger (82.5%) and the index finger (48%). In rare cases, sesamoid bones have been found in all the metacarpophalangeal joints and all distal interphalangeal joints except that of the long finger.

The ratio of the length of the **INDEX FINGER** to the length of the **RING FINGER** in adults is affected by the level of exposure to male sex hormones of the embryo in utero. **This digit ratio is below 1 for both sexes but it is lower in males than in females on average**

2.7 DIGIT RATIO

The **digit ratio** is the ratio of the lengths of different **digits** or fingers. The 2D:4D ratio is the most studied digit ratio and is calculated by dividing the length of the index finger of a given hand by the length of the ring finger of the same hand.

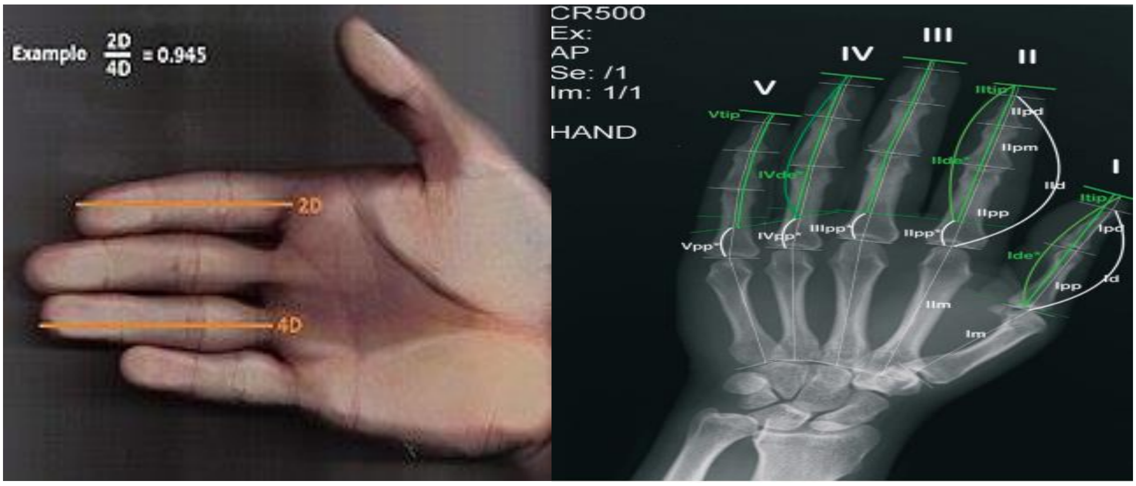


Figure 3.1: Hand with Index finger being shorter than the ring finger, resulting in a small 2D:4D ratio

The digit length is typically measured on palmar (ventral) hand, from the midpoint of bottom crease (where the finger joins the hand) to the tip of the finger. However, recently measurement of digit on dorsal hand, from tip of finger to proximal phalange-bone protrusion (which occurs when digits are bent at 90-degree angle to the palm), has also gained acceptance. A study has shown that, compared to palmar digit ratio, dorsal digit ratio is a better indicator of bone digit ratio. Moreover, differential placing of flexion creases is a factor in palmar digit ratio.

Table 5: Length of tip of finger to Joint in Percent to Finger Length

Finger index number	I	ll	lll	lV	V
tip + pd	49,36	27,80	26,32	28,25	33,92
Pm		30,97	33,11	33,61	31,99
pp*	just proximal to the 1st web space1	15.52	15.33	18.49	24.72

Abbreviation: *tip – soft tissues of the fingertip; pd – distal phalanx; pm – medial phalanx; pp* – web height from metacarpophalangeal join.*

Table 6: Comparison of human hand with artificial hands: robotic and prosthetic hands. Force indicates power grasp, Speed indicates the time required for a full closing and opening, E, stands for external, I, stands for internal.

	Size	Fingers	DOF	Sensors	Actuators	Weight (gms)	Force (N)	Speed (sec)	Control
HUMAN HAND	1.0	5	22	~17,000	38(I+E)	~400	>300 ~147	0.25	E
Utah/ MIT hand	~2	4	16	16	32(E)	----	31.8	-----	E
JPL/Stanford hand	~1.2	3	9	---	12(E)	1100	45	-----	E
Belgrade/USC hand	~1.1	4	4	23+4	4(E)	----	----	----	E
MARCUS hand	~1.1	3	2	3	2(I)	-----	----	----	I
NTU hand	~1	5	17	35	17(E)	1570	----	----	E
DLR hand ll	>1	5	7	---	7(E)	125	---	-----	E

2.8 GRIPPER DIMENSIONS

The dimensions for gripper was inspired from human hand. The length of finger, palm and their ratio was decided based on study done in human anatomy. The fingers-to-palm ratio for the healthy human lies between 0.71-1.25. While the ratio of the length of index finger to the ring finger, also known as 2D:4D ratio lies between 0.889–1.005 for males and 0.913–1.017 for females.

The maximum height of palm in our gripper is 100 mm and the maximum width is 90 mm. The length of index finger is 96.9 mm while the length of middle finger is 101.69 mm. The length of thumb is 66.9 mm. The length of index finger is equal to ring finger and thus their ratio is equal to 1 which lies in healthy adult hand range. The mean ratio of finger to palm comes out to be 0.984 which again lies in the normal range.

Table 7: Comparison of Dimension Between Human Hand and Proposed Robotic Hand

DIMENSIONS	PALM	INDEX (2D)	MIDDLE (3D)	RING (4D)	LITTLE (5D)	THUMB (1D)
HUMAN HAND	95	88.74	95.44	86.66	69.04	63.96
PROPOSED DESIGN	100	94	100.1	94	81	71.2

Table 8: Digit Ratio of Human Hand and Proposed Robotic Hand

DIGIT RATIO	PALM:F	1D:2D	2D:4D	1D:5D	2D:3D	2D:5D
HUMAN HAND	1.17	0.72	1.02	0.92	0.92	1.28
PROPOSED DESIGN	1.12	0.75	1	0.87	0.94	1.285

2.9 FORCE ANALYSIS

The force analyses of the gripper were performed. As the structure of fingers and thumb is different, the calculations are carried out in the two sections like in kinematic analysis so; gripping force is exerted by the gripper are related to the pressure is applied to the actuators of the system. So, the only tip of point force is derived inside the section. During the analysis, gravitational forces and frictional forces were neglected as they are small when compared to the gripping forces.

2.10 KINEMATIC ANALYSIS FOR FINGERS

The kinematic analyses of the gripper were performed. The analyses were performed as two separate parts. The first one was the kinematic analysis for the fingers and the second one was the kinematic analysis for a thumb. The displacement vectors were derived inside this section. Also, the velocity vectors for fingers and thumb were derived and given in Appendix G in the order to be available for dynamic analyses. At beginning of the kinematic analysis, coordinate axes and origin of the system are determined. Since the fingers were fixed at the gripper is palm, centre of the joint 1 are defined as coordinate axis origin and axis are placed.

The shape that the fingers must have for a determined purpose is determinate by studying the kinematics of the mechanism. There is a huge diversity of designs for the kinematic chain in order to transform rotational or translational motion into a particular jaw motion. Focusing on that, grippers can be distinguished between:

[1] Parallel motion (Jaws can follow whether a curve or lineal trajectory but always remaining parallel, i.e., without rotate)
[2] Rotational motion around a fixed point
[3] General planar motion of the jaws, for example rotation around a not-fixed point.

It is essential to know the transmission ratio of the kinematic chain to control the jaw travel from the motor motion. The jaw position can only be controlled by knowing the position of the actuator needed. This relation is reflected in the gripper stroke characteristic curve that gives the position and orientation of the jaw for each position of the actuator.

Knowing the dependence of the gripping force and the torque in the motor is also important when selecting the gripper mechanism or even the appropriated motor, at least to make sure that it is capable to do the force that is required.

2.11 GRIPPING FORCE

Grippers interact with the work piece by the force exerted on their surface and there is a difference between grasping (prehension) and holding (retention) forces. While the grasping force is applied at the initial point of prehension (just during the grasping process), the holding force is maintained thereafter (until object is released).

In the many cases the prehension force is higher than the retention force. Also, when moving the grasped object, the acceleration achieves increases the prehension force needed. Knowing the exact force needed for each of the mentioned cases requires a much deeper study.

It should include an analysis of the contact areas between every object and the jaw and the exact friction coefficient with each material. It makes no sense for a gripper that is thought to be used in a wide variety of items. Also, the frictions in the gears and in all the axis of the mechanism increases noticeable the torque needed in the motor.

For these reasons the force study is only a brief approximation to know its order of magnitude. An example of the torque needed for an empty beverage can in explained below. With the same procedure the torque for all the ten items of the list can be calculated.

The first step is to find the friction coefficient between the workpiece and the metal., The second step is to calculate the minimum grasping force that is the friction force(T). For that it is necessary to pose a vertical balance.
If the object is vertical,

$$m \times g = 4 \times T$$

With the condition for the stability of the prehension, the minimum force exerted by the fingers is perpendicular to the surface(N).

$$T \leq N$$

There is the relation between the force in the finger and torque in the actuator and there is one motor that handles all the four finger forces.

$$\text{Minimum torque} = 2 \times N \times \text{Torque} / \text{force}$$

With this procedure the torque needed for grasping any object can be approximately known to make sure if the gripper will be able to hold it. The most fragile object of the list is definitely the egg.

In order to know if the torque should be limited it is indispensable to know the force that needs to be applied to break an egg (25) and the diameter of a medium egg and then calculate the torque for breaking it:

$$Egg\ break\ torque = Egg\ break\ force \cdot torque\ force\ (diameter\ of\ 4{,}5\ cm)$$

$$Egg\ break\ torque = 3{,}8\ kg \cdot 4{,}2\ N \cdot cm\ N = 16{,}0\ kg \cdot cm$$

As the maximum torque achievable is 15,3 N an egg would most likely not suffer any damage. However, as the calculations are done with medium values and lack accuracy, to prevent the egg from break it will slightly limited, for example until its 80% of capacity.

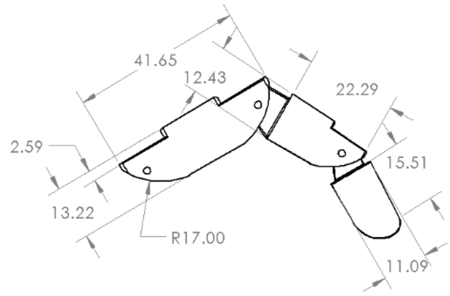


Figure 2.2: Little Finger

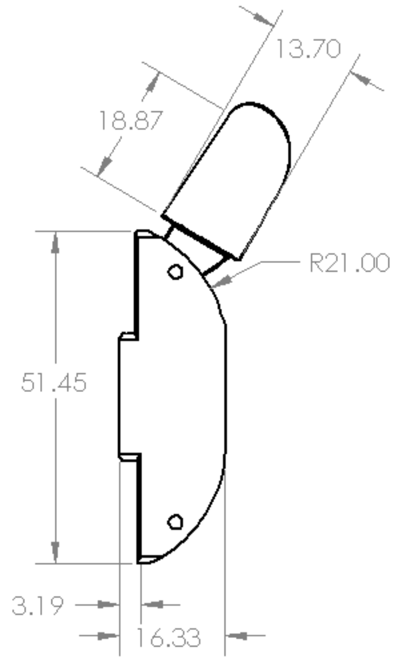


Figure 2.3: Thumb Dimension

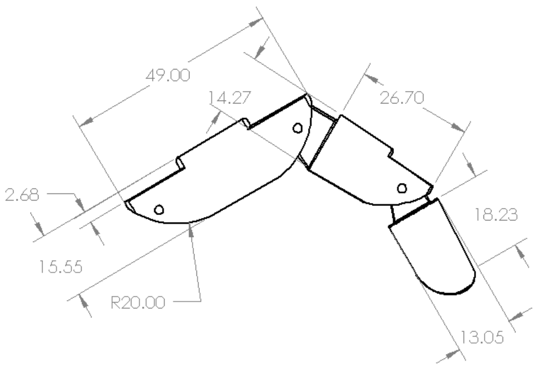


Figure 2.4: Index Finger Dimension

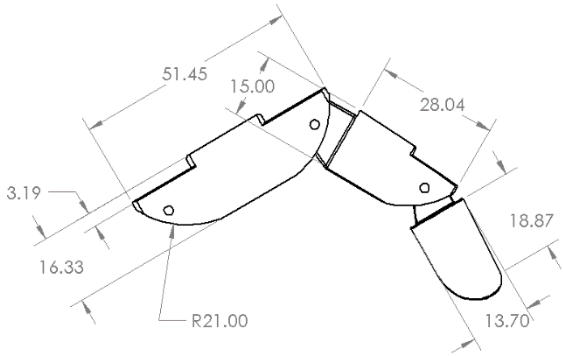


Figure 2.5: Middle Finger Dimension

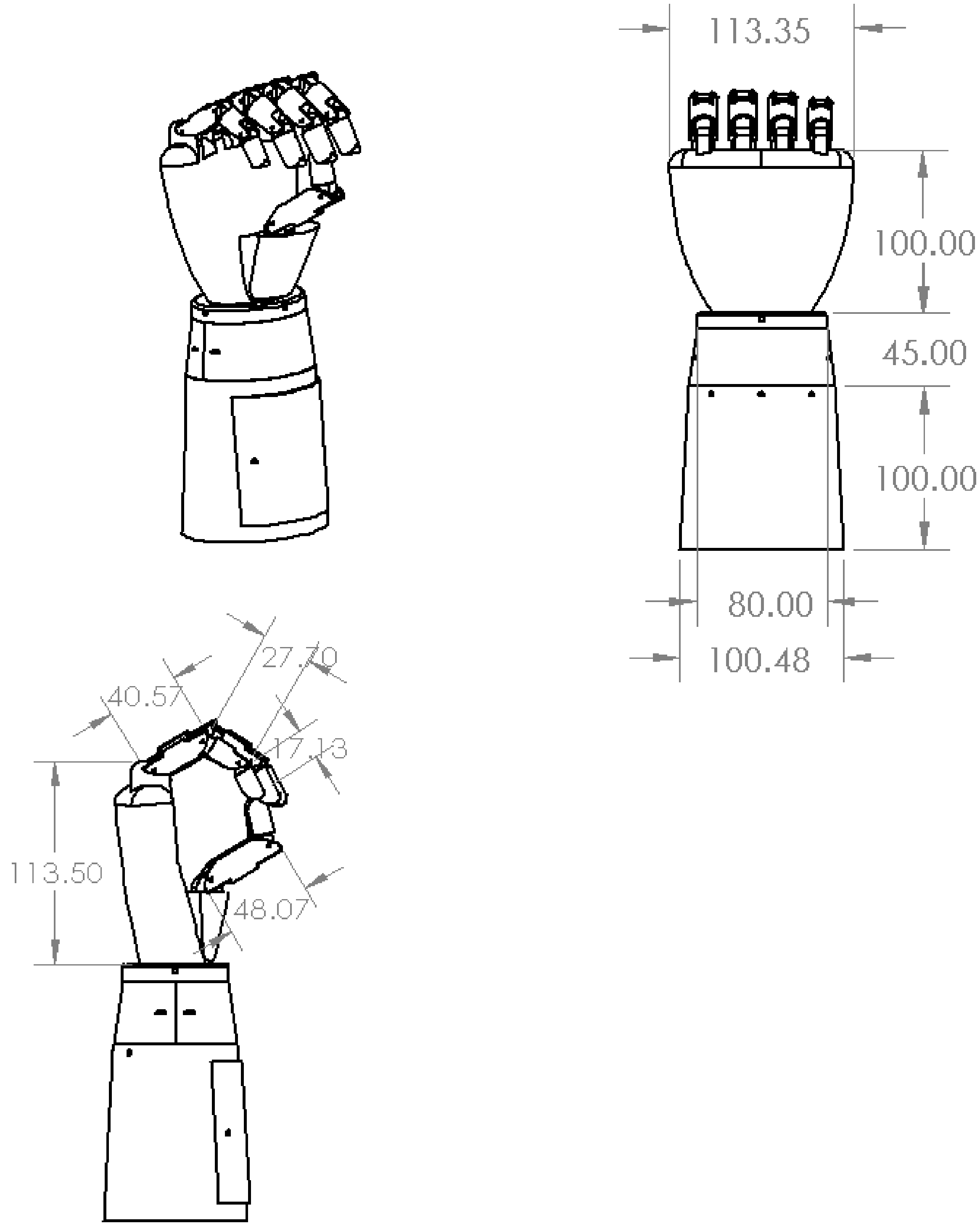


Figure 2.6: Gripper Dimension

CHAPTER-3
SOLID MODELLING OF GRIPPER

The following dimensions are according to human anatomy:

3.1 SOLID MODELLING OF PALM

a) Distance from radius to trapezoid : 80mm
b) Distance from radius to lunate : 20mm
c) Width of palm : 113.35 mm

[1] First, we created the 2D sketch of the palm.
[2] Then we added the required dimensions.
[3] It was then extruded.
[4] The sides were filleted.
[5] It was again extruded, and we finally obtained the desired 3D palm.

3.2 SOLID MODELLING OF FINGERS

[1] We designed the fingers first by designing the fingertips.
[2] They were first sketched and then revolved.
[3] Then they were filleted, and cuts were applied.
[4] Then they were extruded.
[5] Then loft and boss commands were used.
[6] Cuts and fillets were applied.
[7] Holes were made and then it was extruded.
[8] The final part was the assembly of the entire hand.

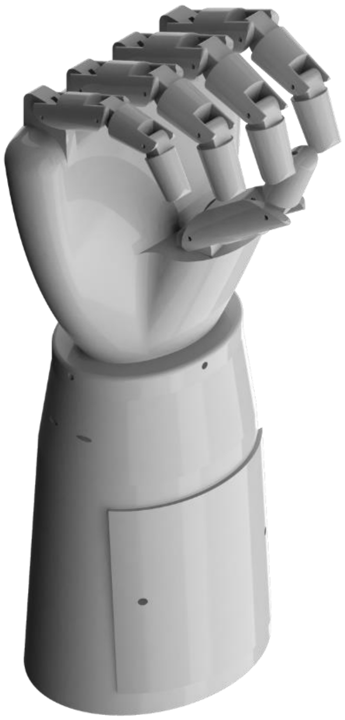


Figure 3.1: Gripper in closed position

Figure 3.2: Gripper in open position

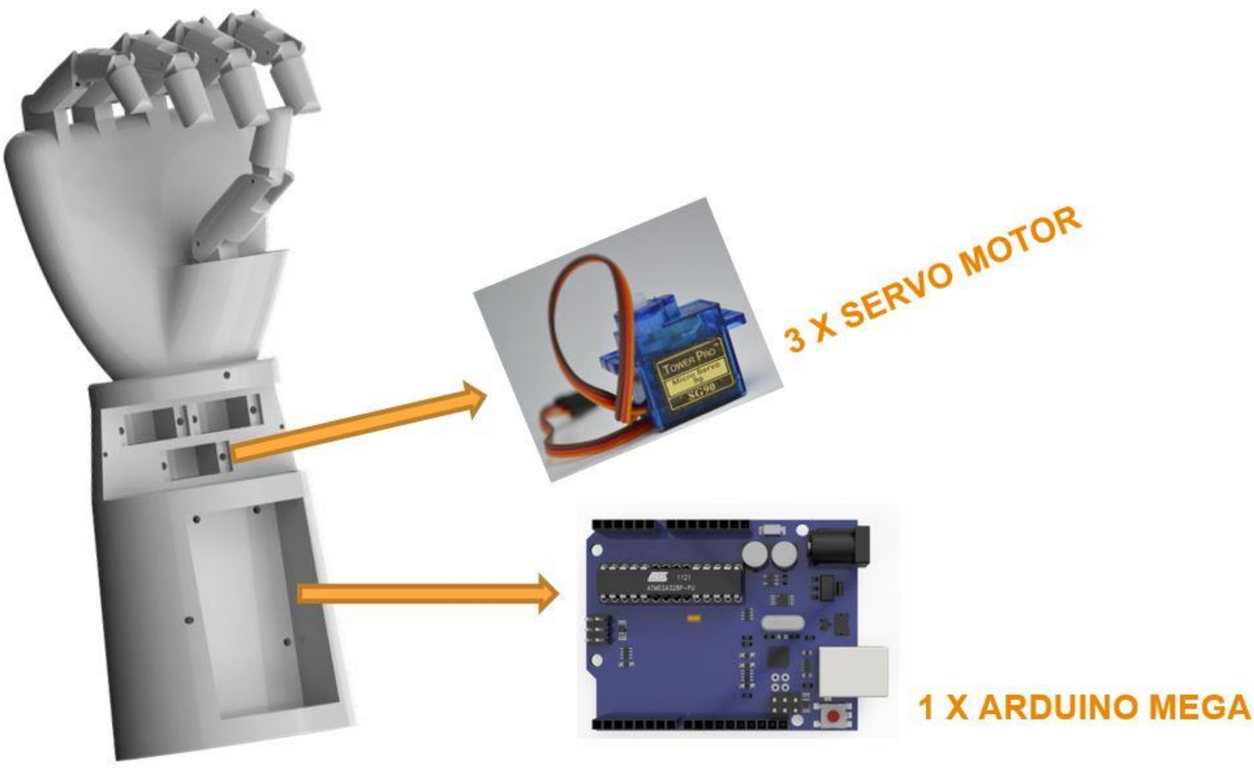


Figure 3.3: Gripper's compartments

CHAPTER 4
GRIPPER SIMULATION

OVERVIEW

Five-finger robotic hands are designed to perform secure and stable grasping of different objects similar to human hands. It is always desirable to estimate the tendon force capabilities of any tendon-driven robotic hand to maximize its grasping performance. This paper presents the design and analysis of tendons by estimating the forces in tendons for each finger to determine the required dimension for each tendon. For this purpose, a mathematical model of cylindrical shaped object with maximum load parameters was assumed. The mathematical model helped in distributing the loads on each finger. In this process torsional spring force and gripping force were determined to calculate tendon tension theoretically for the finger and thumb separately to determine the dimensions for each tendon. Lastly, the obtained dimensions were used to prepare a solid model of individual tendon and the design was validated by carrying out the linear elastic yield analysis. Tendon tensions obtained theoretically were compared with those calculated experimentally and finalized tendons were incorporated in our five-finger robotic gripper.

Table 9: Gripper Analysis Pre-Study

ANALYSIS	KNOWN PARAMETERS	UNKNOWN PARAMETERS
TENDON	1. Object Mass 2. Coefficient of friction 3. Load distribution	4. Tendon tension 5. Diameter
SPRING	1. Diameter 2. No of Active Coil 3. Young's Modulus 4. Angular deflection 5. Load point distance	6. Spring Force
MOTOR	1. Tendon tension 2. Radius of Pulley	3. Torque
STRUCTURAL	1. Gripping Force 2. Spring Force 3. Object Mass	4. Stress 5. Deflection
GRASP STUDY	1. Object Type 2. Object Shape	3. Gripping Capability

CHAPTER 4.1
ESTIMATION AND VALIDATION OF TENDON FORCES

Multi-fingered robotic hands are developed to perform tasks in various industrial environments. These hands are able to perform even in harsh environments like space and conflict zones. These hands are used to achieve the desired tasks and are capable of being adapted to the tasks along with different bodies to be grasped or manipulated [126]. Dexterous hands are qualified enough to modify its grasping skills in accordance with tasks variations. Multi-fingered robotic hands are being a topic of intense research from the past few decades due to the complexity of dexterous manipulation tasks [127]. These hands are aimed to replicate a human hand in terms of aesthetics, performance, and flexibility. The grasping and manipulating skill of different objects is a topic of intense research worldwide [128]. These anthropomorphic hands are designed for the manipulation of objects with the fingertips. Manipulation of objects requires a coordinated motion of different fingers, where each finger can be considered as an independent manipulator.

This paper develops the basic understanding regarding the kinematics and dynamics of a robotic hand. Use of grippers has indicated the need for fine position and force control for better performance. Numerous studies as well as prosthetics and industrial grippers have been developed for achieving this objective. Consequently, researchers have investigated several methods to derive these parameters from real hand motions.

The pioneering works for tendon driven robotic grippers are briefly reviewed here. This study focuses on the combination of random search and gradient descent with the numerical gradient computation for a tendon driven robotic gripper. During the unobstructed closing, the distal links remain parallel and creates exact fingertip grasps. This work describes a methodology for optimising the dimensions of the links in order to obtain enveloping grasps of a large range of objects [129].

A method of developing soft grippers by the use of IPC materials with mathematically generated topologies based on triply periodic surfaces. By properly regulating the properties of IPC materials, it is possible to design modular grippers with the same structure but different closing motions [130].

A novel synthesis of computational approach involving Monte Carlo Simulation on two representative designs, enabling the systematic design, evaluation, and optimization of tendon driven hands. This methodology obtain the full set of feasible grasp wrenches and corresponding wrench direction independent grasp quality for a tendon driven hand. [131]

Tendon-based parallel robots offer a new approach. They are energy efficient as the actuators are fixed and the payload is subdivided between actuators .Tendon-based Stewart platforms represent an innovative manipulator technology that allows the handling of heavy loads with high acceleration and low energy consumptions. The region where solutions are found is called controllable workspace. Other aspects of workspace include singularities, stiffness, and auto collisions. [132]

Our work is applied directly to small motions. Our approach has been basic and systematic regarding the kinematics of our robotic hand.

PAST WORK

The proposed hand has three fingers connected in series and one opposing thumb. Each finger comprises of three digits or phalanges, i.e., the proximal, middle, and distal phalanges. One end of the proximal phalange is attached to the base or palm and other to the middle phalange. The free end of the distal phalange denotes the tip of the finger. Each finger has three degrees of freedom (DOFs) while the thumb has two DOFs. The proximal connection of the thumb has fixed joint and is associated with the base. The various connections of the fingers have rotational joints with one DOF. In this manner, the hand has a sum of 11 DOFs. All these fingers are supported to the palm to complete the mechanism as shown in Figure 1.

The motion of each joint is controlled using the spring return tendon mechanism. In this, a tendon or wire passes inside each finger and fixed at the distal end. The tendon can be pulled from the other end in order to produce the flexion motion in the fingers. A spring return mechanism is used to produce the extension motion of the fingers. A moment is created at the pin joint which forces the phalange to move. A constant force spiral spring is used to retract the gripper to its rest position. Figure 2 shows the physical model of the developed hand, where weights are used for pulling the tendons to perform the grasping tasks.

CURRENT WORK

Design and develop a multi finger robotic gripper with the following systems:

1. No. of finger = 5
2. DOF = 5
3. Use the tendon actuation system for flexion mechanism of finger.
4. Use torsional spring for extension mechanism of fingers.
5. Use motors for tendon actuation.
6. Apply Arduino control for actuation system.
7. use tactile sensor for sensing
8. Use the suitable material for the fingers and tendon.

4.1.1 LOAD DISTRIBUTION OF OBJECT

Let mass be ‘m’ and coefficient of friction be ‘μ’
Gripping force = F_g
Force due to gravity = W = m.g
Friction force = μ.N = μ. I_g = f
To hold the object safely,
$f > W$
$\mu.F_g > m.g$
$F_g > (m.g/\mu)$
For safe design conditions,
$F_g = (m.g/\mu) \times 2$ [safe factor]
For each finger, F_g is
$F_g = \frac{x}{100} * \frac{mg}{\mu} * 2$

Table 10: Load Distrubution in Hand

PART	GRIPPING FORCE
THUMB	0.9 x 2 x (mg/μ)
INDEX	0.19 x 2 x (mg/μ)
MIDDLE	0.2 x 2 x (mg/μ)
RING	0.13 x 2 x (mg/μ)
LITTLE	0.7 x 2 x (mg/μ)

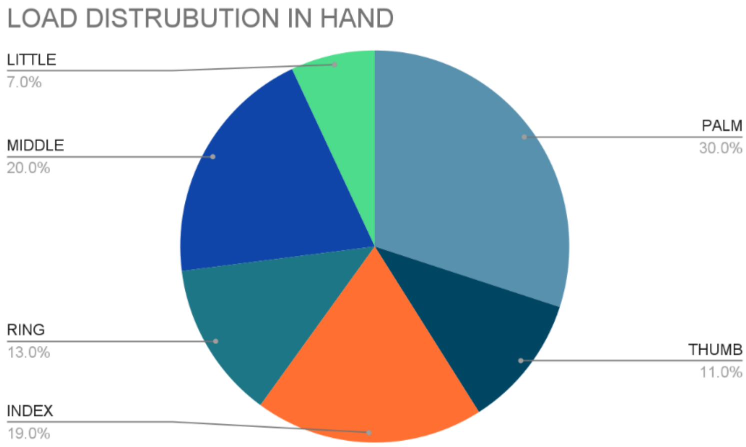


Figure 4.1.1: Pie-Chart, Load Distrubution in Hand

4.1.2 Selection of spring

A torsion spring is used to transmit the torque to a particular component of a machine or mechanism. In our model of five finger robotic gripper these springs are used at each joint of the finger for a returning mechanism.

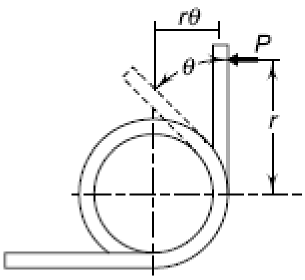


Figure 4.1.2: Deflection in spring when contact force is applied

The required force corresponding to θ deflection of the torsional spring is calculated by using the relation,

$$P = \frac{\theta E d^4}{64DrN}$$

Table 11: Spring specifications

Mean diameter (D) mm	Wire diameter (d) mm	Number of active coil (N)	r (mm)	E (MPa)
2.38	0.41	3	8	193000

Assumptions:

[1] Force due to friction at each joint of finger is neglected
[2] Curling of finger due to its own weight is neglected
[3] No extension in flexible tendon
[4] The grasped cylindrical object does not undergo any deformation while gripping

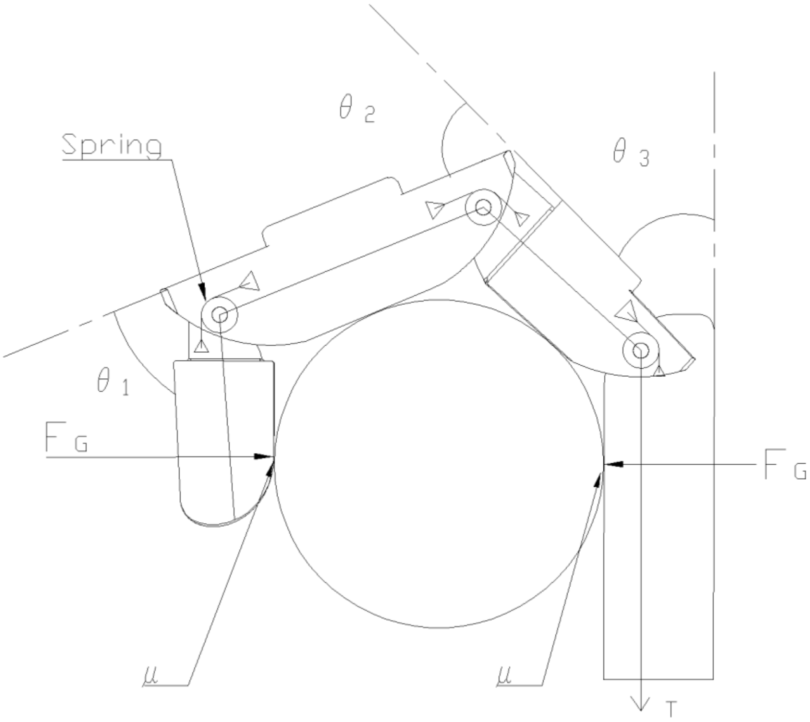


Figure 4.1.3: Schematic Representation of Finger

Table 12: Maximum rotations experienced by phalanges in our gripper model

Phalanx	Angle	Maximal rotations
Proximal	θ_1	60° ($\boldsymbol{\pi}$/3)
Medial	θ_2	60° ($\boldsymbol{\pi}$/3)
Distal	θ_3	60° ($\boldsymbol{\pi}$/3)

In the case of the thumb also the maximum rotation at each joint is 60°.

From above spring specification and maximum rotation of each joint of finger the value of force by one torsional spring corresponding to this rotation ($\theta = \boldsymbol{\pi}/3$) is calculated using relation

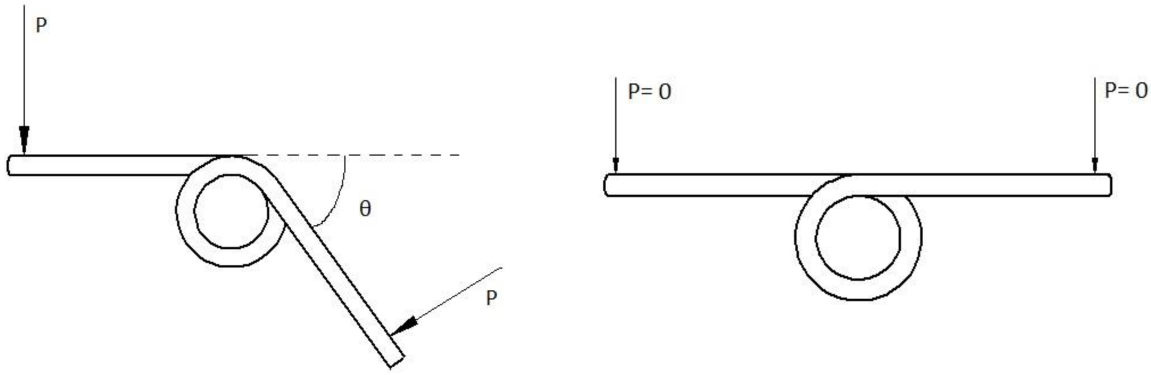


Figure 4.1.4: Spring Position before and after force P is applied

$$P = \frac{\theta E d^4}{64DrN} = \frac{\pi * 193000 * 0.41^4}{3 * 64 * 2.38 * 8 * 3} = 1.56 \text{ N}$$

We have used a different number of springs in our fingers and thumb. Based on these, the total spring force at maximum curling of finger and thumb is calculated. Let n be the total number of springs.

Total spring force = nP = n*1.56 N

Apart from this total spring force, gripping force required by each finger while gripping the object is calculated by using the relation

$$F_g = \frac{x}{100} * \frac{mg}{\mu} * 2$$

Where:
x = Percentage of load on finger and thumb
Safety factor = 2

Finally, the total force required to grip the object is calculated which is the scalar sum of total spring force and gripping force.

Total force required to grip the object = total spring force + gripping force

$$F_T = n * 1.56 + \frac{x}{100} * \frac{mg}{\mu} * 2$$

In order to grip any object (considering the maximum curling of finger and thumb) the tendon has to apply force equal to total force required to grip the object, i.e., the maximum tension applied in the tendon is equal to the total force required to grip the object.

$$\text{Tension in tendon (T)} = F_T = n * 1.56 + \frac{x}{100} * \frac{mg}{\mu} * 2$$

Table 13: Tension in each tendon

Finger	Number of Spring (n)	Value of x (%)	Tension in tendon ($T = F_T$)
Index	6	19	$T_i = F_{Ti} = 9.36 + 0.19 * \frac{mg}{\mu} * 2$

Middle	6	20	$T_m = F_{Tm} = 9.36 + 0.20 * \frac{mg}{\mu} * 2$
Ring	6	13	$T_r = F_{Tr} = 9.36 + 0.13 * \frac{mg}{\mu} * 2$
Little	6	7	$T_l = F_{Tl} = 9.36 + 0.07 * \frac{mg}{\mu} * 2$
Thumb	3	11	$T_t = F_{Tt} = 4.68 + 0.11 * \frac{mg}{\mu} * 2$

4.1.3 Design of tendon

The tension force is the maximum force applied on the tendon while gripping the object. Therefore, the stress in a tendon can be calculated using the equation:

$$\sigma = \frac{T}{A}$$

Where,

$$A = \frac{\pi d^2}{4}$$

Defining the allowable stress equation by considering factor of safety (fs) = 2 and yield tensile strength (S_{yt}) = 215 Mpa

$$\sigma_{all} = \frac{S_{yt}}{fs} = \frac{S_{yt}}{2}$$

At the limiting design condition $\sigma = \sigma_{all}$. Therefore, required diameter of tendon is given by

$$d = \sqrt{\frac{8T}{\pi S_{yt}}}$$

4.1.4 CASE: CYLINDRICAL WOOD (M= 250 G & μ=0.4)

The Tendon wire played a vital role in grasping force. Tendon wire without any tension for adjusting mechanism for the robotic hand loosened over time, and thus the tendon wires with spring to be calculated for grasping force. The main reasons of the interest in robotic tendon applications are their efficiency in the transmission of the forces from remotely located actuators to the moving parts of the robotic hand, the reliability and the simplicity of implementation of this kind of transmission system, and because they allow to reduce the weight and the cost of the overall device. Different type of Tendon wire to be used for the actuation systems like SMA wire ,SCC wire, Plastic strap is also used for driving the robotic finger.

Shape memory alloy (SMA) wire-based soft actuators have had their performance limited by the small stroke of the SMA wire embedded within the polymeric matrix. Shape memory alloy (SMA) based on NiTi (53–57 wt.% Ni), Nitinol, when plastically deformed in the low-temperature martensitic phase, can be restored to its original shape or configuration by heating above a characteristic temperature. If the material is restrained from regaining its memory shape, high stresses of up to 700 MPa can be induced. This compares with a **yield strength of the martensitic phase of 80 MPa.**

Due to the inelastic tendons used, the estimation of the hand configuration from the motor position provides excellent results.

Different grades of stainless steel are available in the market like 301, 302, 304,316.We use the Stainless steel (304) tendon wire for the Actuation system because 304 stainless steel is the most common stainless steel which can be easily available. The steel contains both chromium (between 18% and 20%) and nickel (between 8% and 10.5%).It is an austenitic stainless steel.

Grade 304 is the standard "18/8" austenitic stainless; it is the most versatile and most widely used stainless steel, available in the widest range of products, forms and finishes. It has excellent forming and welding characteristics. Grade 304 can be severely deep drawn without intermediate annealing, which has made this grade dominant.

Mechanical Properties of the 304 Grade stainless steel:

Tensile Hardness Strength (MPa) -515

Yield Strength -205 MPa

4.1.5 RESULTS AND SIMULATION

Table 14: Tension, Diameter, Stress in Tendon of each Finger

Fingers	Tension In Tendon	Diameter Of Tendon	Area	Stress(σ) In Tendon
Index	11.68	0.380	0.113	103.36
Middle	11.81	0.383	0.115	102.69
Ring	10.95	0.368	0.106	103.30
Little	10.21	0.356	0.099	103.13
Thumb	6.02	0.273	0.058	103.79

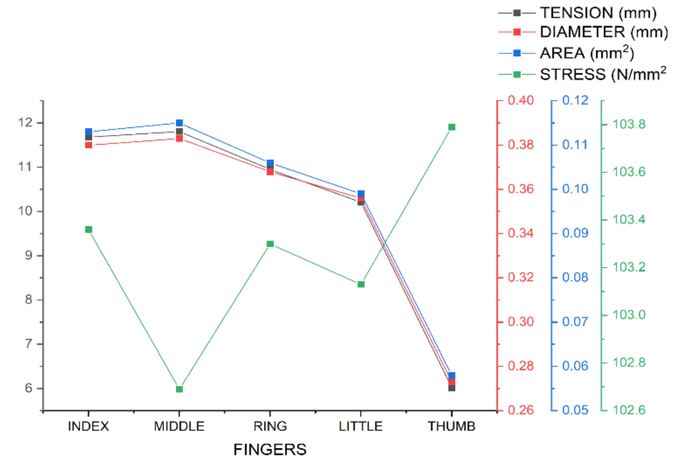


Figure 4.1.5: Variation of tension, diameter, and stress in tendon of each finger

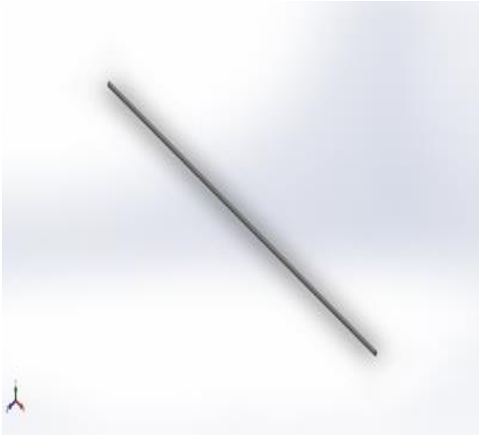


Figure 4.1.6: CAD model of tendon

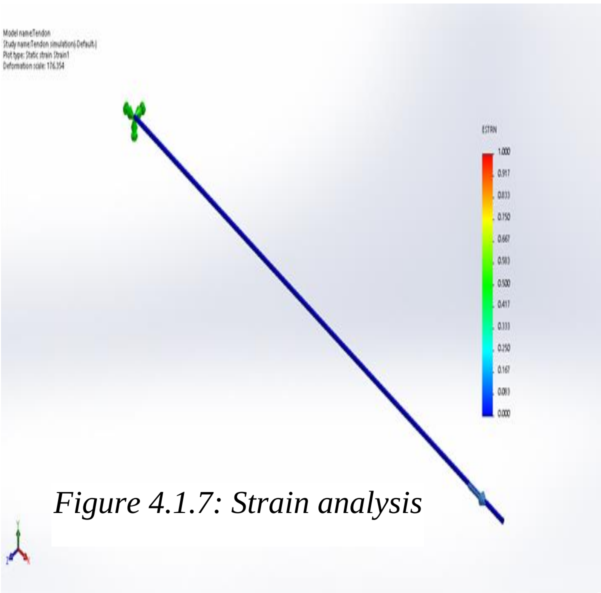


Figure 4.1.7: Strain analysis

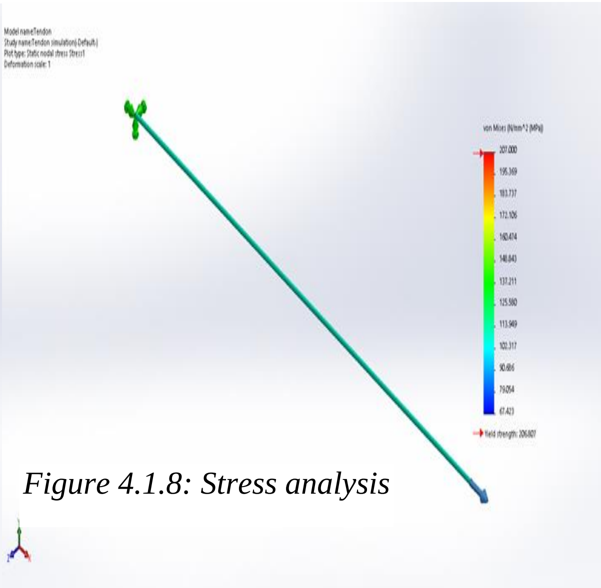


Figure 4.1.8: Stress analysis

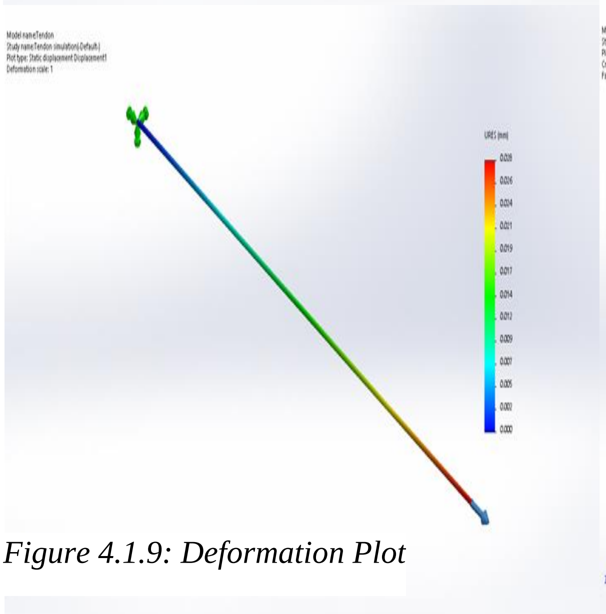


Figure 4.1.9: Deformation Plot

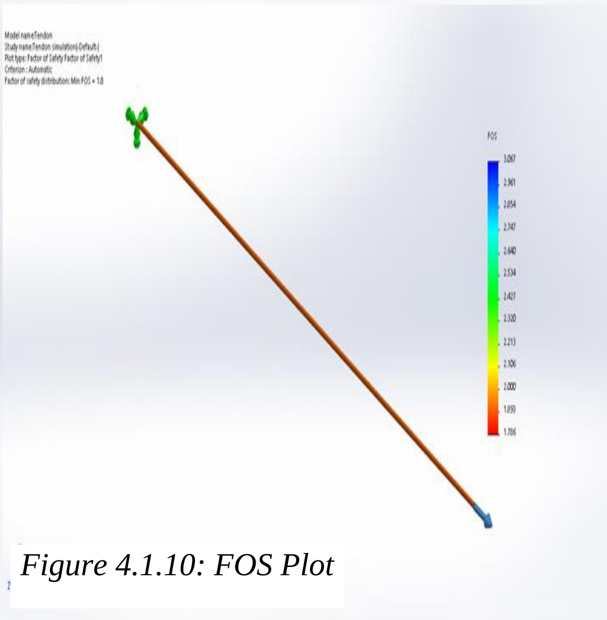


Figure 4.1.10: FOS Plot

Table 15: Simulation Study Results

STUDY	TYPE	MIN VALUE	MAX VALUE
STRAIN	EQUIVALENT STRAIN	0.000387	0.000492
STRESS	VON MISES STESS	64.423 MPa	115.78 MPa
DEFORMATION	URES	0 mm	0.0283 mm
FOS		1.786	3.067

CHAPTER 4.2
Estimation and validation of Actuation forces

INTRODUCTION

Standard industrial robots are usually designed to have very rigid links, that implies a considerable increment of the link masses, and to minimize the effects of the elastic coupling between the actuators and the joints due to the deformation of the transmission elements like long shafts, belts, or harmonic drives. These design goals are usually maintained also for the design of the control law of these robots. This approach is justified because industrial tasks usually require accuracy, repeatability, and simplicity in the implementation of the control law. On the other hand, it is well known that neglecting the elastic coupling between the actuators and the robot joints can lead to vibrations in the kinematic chain and reduce both the dynamic and static performance of the overall system.

In the last years, a large variety of robots have been developed to accomplish a completely different class of tasks, like space and submarine activities, cooperative manipulation and, in particular, to interact with humans for entertainment, domestic activities and assistance to elder or handicapped people. The main requirements for the introduction of robots in the human environment are safety and dependability of the robotic system . These requirements exclude the use of standard industrial robots for the interaction with humans. Also incrementing the sensorization and improving the performances of the controller, there are intrinsic limitations on the safety of industrial robots due to the inertia of the links and to the magnitude of the torque that the actuators can apply.

The development of lightweight robotic arms is carried out to improve the dynamic performance and reduce the weight-to-payload ratio. While this approach is suitable in case of devices for special applications, in particular for space activities, to improve the safety of robotic arms different projects have been developed, besides maintaining a low level of inertia, also introducing a high compliance at the mechanical level both in the joints of the robot and in the interface between the robot and the environment. Concerning the joint compliance in order to obtain an adequate level of accuracy preserving safety, several variable stiffness devices, and in particular antagonistic actuated joints, have been developed [39, 42, 43]. Continuous high compliant structures with antagonistic actuation are also applied to reduce the mechanical complexity, the weight, and the cost of robotic hands.
In this section, the dynamic model of a robotic arm with actuated joints is reported. Some assumptions have been made to obtain this dynamic model. In particular, we assume that the actuators have uniform mass distribution and centre of mass on the rotation axis and that their rotor kinetic energy is due only to their spinning angular velocity. From now, we refer to this kind of mechanical structure as fully antagonistic actuated kinematic chain. Applications of this methodology to mechanical structures with coupled antagonistic actuation are object of future research. The state dimension of the model of a robot with N spatial DOFs is then equal to 6N (position and velocity of each rigid body) while the input dimension is 2N (the

torques commanded to the actuators). In this case it is necessary to distinguish between the spatial and the stiffness DOFs. The former is the possibility of modifying the position of the system while the latter means the possibility of adjusting the mechanical stiffness of the device. It is important to stress the fact that, for mechanical stiffness, we mean the compliance of the mechanical coupling between the link and the actuation. Usually, this characteristic is imposed by the mechanical design, and in particular by the elasticity of transmission elements, while in this case it can be modulated with antagonistic actuation and nonlinear transmission elements. This allows to increase the safety of the robot arm in the case of unexpected collision with i.e., a human operator. In a meaningful analysis of how the mechanical coupling between the link and the actuation affects the safety of a robotic arm operating in the human environment is reported.

4.2.1 Torque Analysis of Actuator

In our model of robotic gripper, the movement of the finger is controlled by an external motor via tendon and torsional spring is used at each joint of fingers for the returning mechanism. In order to carry out torque analysis of the actuator, the first step is to calculate the tension in the tendon. While performing our mathematical analysis of actuator we have made certain assumptions:

[1] Friction force at each joint of finger is neglected
[2] Curling of finger due to its own weight is neglected
[3] The grasped objects do not undergo any deformation while gripping

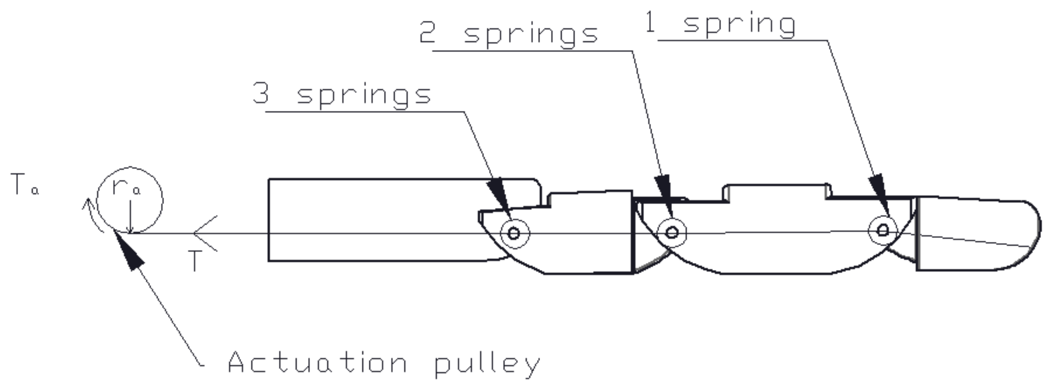


Figure 4.2.1: Schematic representation of spring and pulley in finger

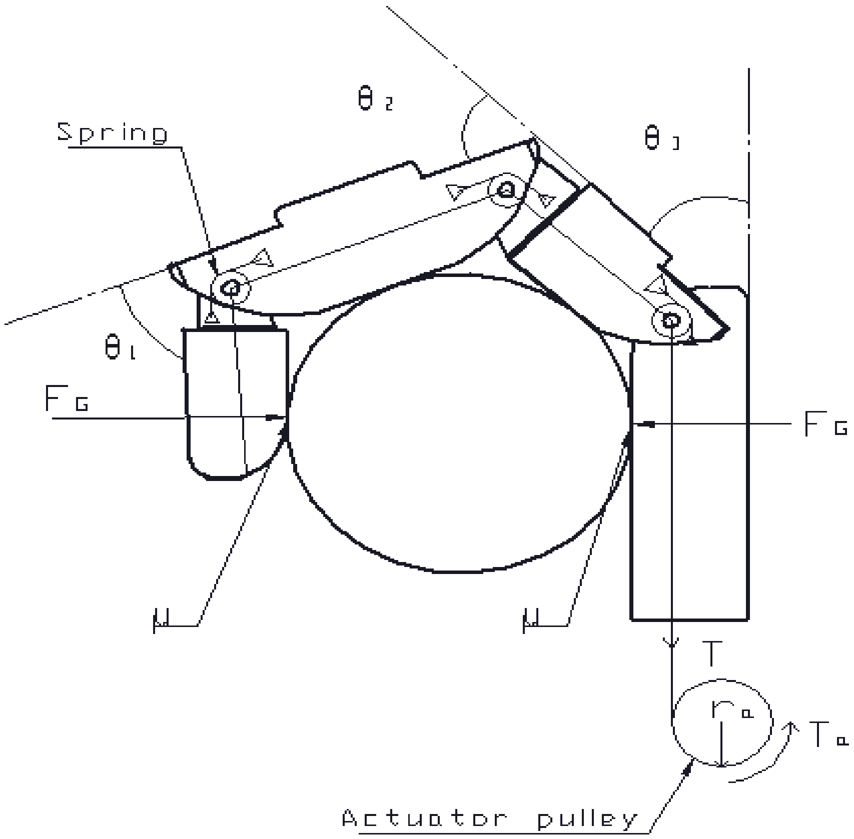


Figure 4.2.2: Forces acting on finger while holding an object

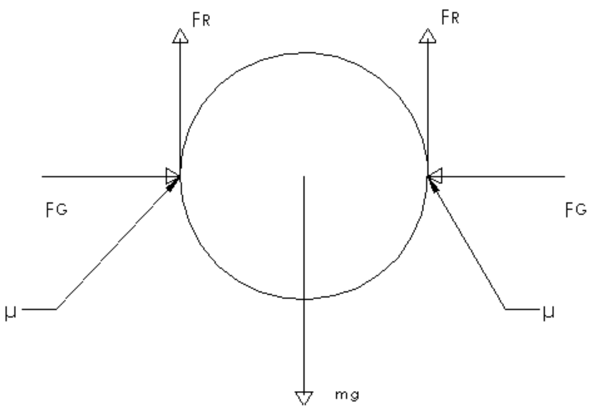


Figure 4.2.3: Forces acting on pulley

To calculate the tension in the tendon, the gripping force of each finger and the total spring force generated while gripping needs to be calculated.

Gripping force required by each finger while gripping the object can be calculated by using the equation

$$F_g = \frac{x}{100} * \frac{mg}{\mu} * 2 \text{ (safety factor)}$$

Where:
mg = weight of the object
μ = coefficient of friction
x = percentage of load on each finger

In our model, different numbers of springs are used in our fingers and thumb. Based on these, the total spring force at maximum curling of finger and thumb is calculated.
By using the torsional spring relation, the generated spring force at maximum curling of fingers (θ= $\boldsymbol{\pi}$/3) for individual spring is given by the equation

$$P = \frac{\theta E d^4}{64 D r N}$$

Table 16: Spring Specifications

Mean diameter (D) mm	Wire diameter (d) mm	Number of active coil (N)	r (mm)	E (MPa)
2.38	0.41	3	8	193000

Therefore, from above spring specification and considering maximum curling at each joint the value of individual spring will be

$$P = \frac{\theta E d^4}{64 D r N} = \frac{\pi * 193000 * 0.41^4}{3 * 64 * 2.38 * 8 * 3} = 1.56 \text{ N}$$

After calculating the individual spring force at maximum rotation of finger and thumb total spring force can be calculated as

Total spring force = nP = n*1.56 N

Finally, the tension force required to grip the object is calculated which is the scalar sum of total spring force and gripping force.

$$\text{Tension in tendon (T)} = n * 1.56 + \frac{x}{100} * \frac{mg}{\mu} * 2$$

The schematic representation of a finger is shown in figure. After determining the tension force in the tendon, the torque value of the actuator is calculated.

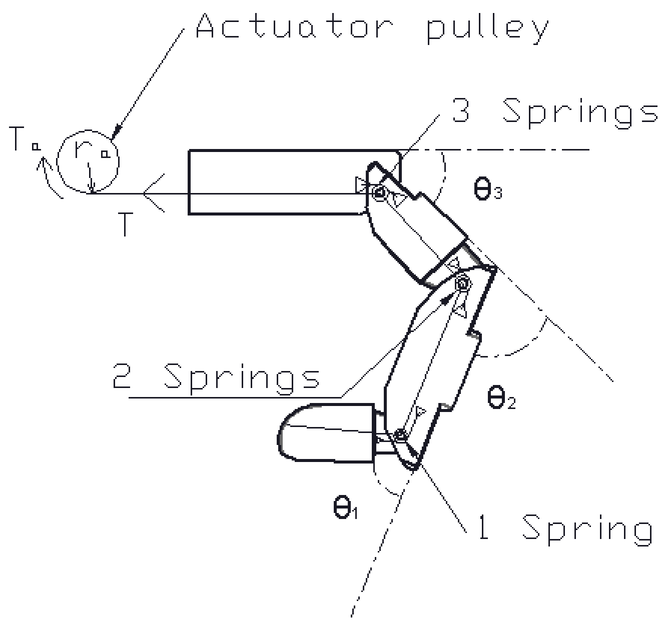


Figure 4.2.4: Phalanx's rotation

It is seen from the figure, the torque of actuator is given by,

$$T_a = T * r_a$$

Where,
T_a = Actuator torque
r_a = Radius of actuator pulley
T = Tension in tendon

Table 17: Torque in Each Finger

Finger	Number of Spring (n)	Value of x (%)	Actuator torque ($T_a = T * r_a$)
Index	6	19	$T_{ai} = \left(9.36 + 0.19 \times \frac{mg}{\mu} \times 2\right) * r_a$
Middle	6	20	$T_{am} = \left(9.36 + 0.20 \times \frac{mg}{\mu} \times 2\right) * r_a$
Ring	6	13	$T_{ar} = \left(9.36 + 0.13 \times \frac{mg}{\mu} \times 2\right) * r_a$

Little	6	7	$T_{al} = \left(9.36 + 0.07 \times \frac{mg}{\mu} \times 2\right) * r_a$
Thumb	3	11	$T_{at} = \left(4.68 + 0.11 \times \frac{mg}{\mu} \times 2\right) * r_a$

3.2.2 CASE: CYLINDRICAL WOOD (M= 250 G & μ=0.4)

The robotic finger is actuated by artificial tendons and their structure is presented with dashed lines. The distal, middle, and proximal phalanges as well as the flexure joints (areas of reduced thickness) are implemented with an elastomer material. The MCP spring loaded pin joint is responsible for the adduction/abduction. We target this motion because it enhances the grasping capabilities of robot hands.

The tendon-driven mechanism has been extensively investigated; it typically involves setting the pulley position symmetrical to the joint or the centre of the link to facilitate a simple calculation of the robot finger posture and force. It has been indicated that the pulley position affects the finger motion because the force of the wire is added to the pulley and the joint torque in a rotational joint is changed by the pulley position.

In the tendon-driven mechanism, multiple joints are driven simultaneously by pulling a wire that passes through points, e.g., pulleys attached on links. It has been indicated that the pulley position affects the robot motion because the force of the wire is added to the pulley and the joint torque in a rotational joint is changed by the pulley position.
The joints were driven by the force applied to the pulley. The joint torque was determined by the amount of pulling force T, the length of the moment arm between the joint and pulley, and the angle between the moment arm and the direction of pulling force.

A model for spatial motion is provided that relates the actuation modes with the finger motions. A static balance analysis is performed for the computation of the tendon force at each joint.

The mechanism improves the reachable workspace and amplifies the exerted finger forces. We present the design of a versatile adaptive finger, and we describe a tendon-driven actuation mechanism that allows the finger to perform both flexion/extension and adduction/abduction.

We employ a spring-mass system to model the finger and its compliant flexure joints. we provide the final tendon force required to fully flex the finger.
This is another servo bracket which I did to get more development pulling when the pulleys are rotating. Hopefully even servos with a restricted rotation from 0 to 90 will be able to get the fingers fully moved.

4.2.3 RESULTS AND SIMULATION

Table 18: Radius of pulley and actuator torque for each finger

FINGER	RADIUS OF ACTUATOR PULLEY (r_a) (mm)	TENSION IN TENDON (T) (N)	ACTUATOR TORQUE ($T_A = T * r_a$) (N-mm)
Index	13	11.68	151.84
Middle	13	11.81	153.53
Ring	13	10.95	142.35
Little	13	10.21	132.73
Thumb	13	6.02	78.26

Table 19: Simulation Study Results

STUDY	TYPE	MIN VALUE	MAX VALUE
STRESS	VON MISES	0.0021 MPa	28.925 MPa
STRAIN	EQUIVALENT STRAIN	0.000031	0.011
DEFORMATION	RESULTANT URES	0 mm	0.165 mm
FOS		1.382	19.033

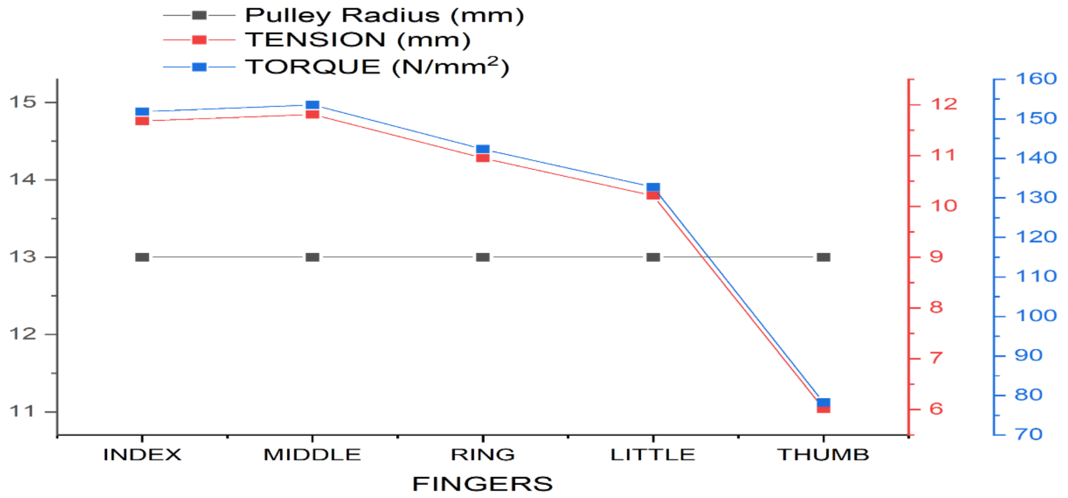


Figure 4.2.5: Variation of Pulley's radius and torque for each finger

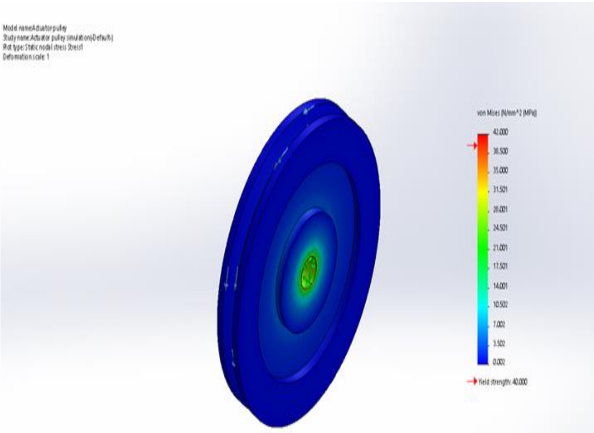


Figure 4.2.6: Stress analysis

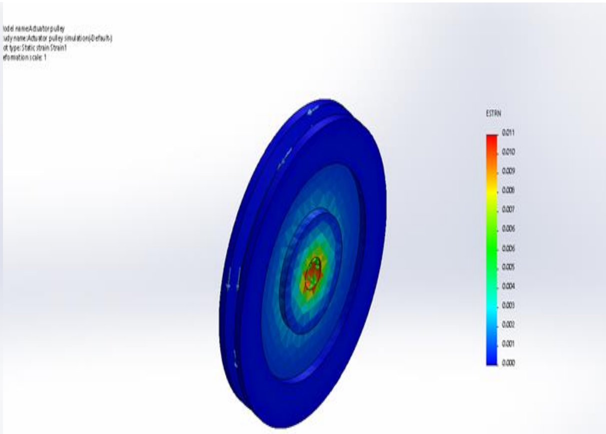


Figure 4.2.7: Strain analysis

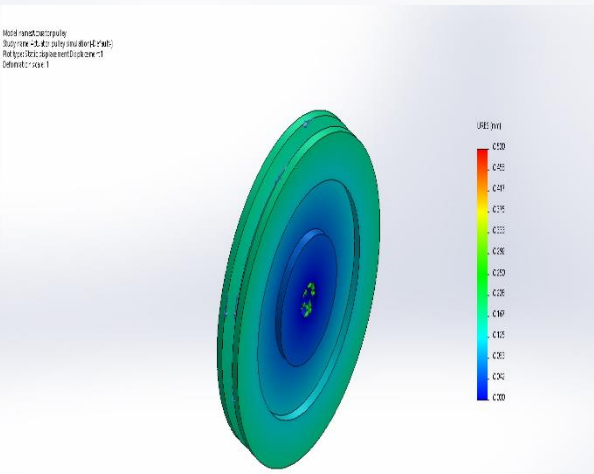


Figure 4.2.8: Deformation Plot

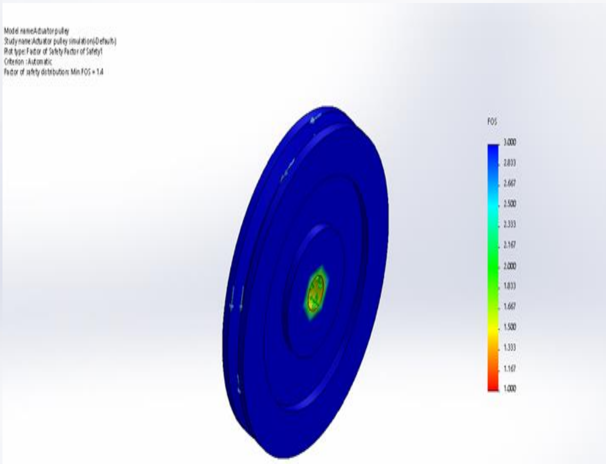


Figure 4.2.9: Factor of Safety Plot

CHAPTER 4.3
Grasp Analysis of Gripper

Grasp study analysis for gripper using various software to understand and enhance the grasping ability of gripper for three different cases:

[1] Case 1: CYLINDRICAL WOOD (M= 250 G & μ=0.4.)
[2] Case 2: rubber tennis ball (M= 60 G & μ=0.7.)
[3] Case 3: plastic water bottle (M= 1000 G & μ=0.3.)

The performance of the five-fingered tendon actuated robotic hand is evaluated for grasping operations in order to find the contact forces of each of the fingertip on the surface of the grasped objects. Simulations are carried out in virtual environment by incorporating a control scheme for each finger to grasp and obtain contact forces while grasping objects of varying shapes, mass, and material. The developed hand mechanism involves tendons to actuate the fingers in order to perform the flexion motion of fingers. In order to perform any grasping task, it is desirable to apply some load at each tendon. Therefore, a relation between the contact points and the applied load is determined.

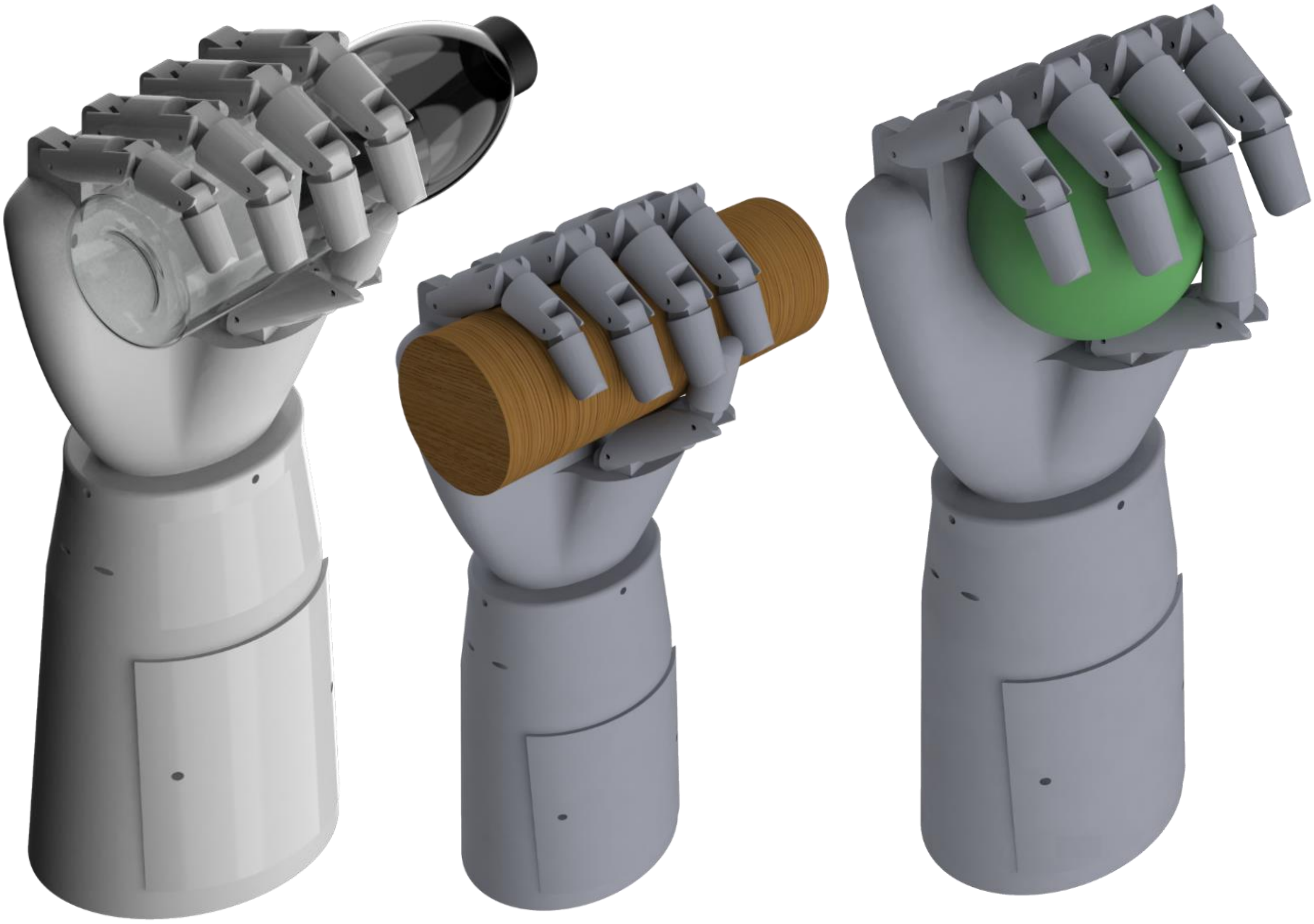
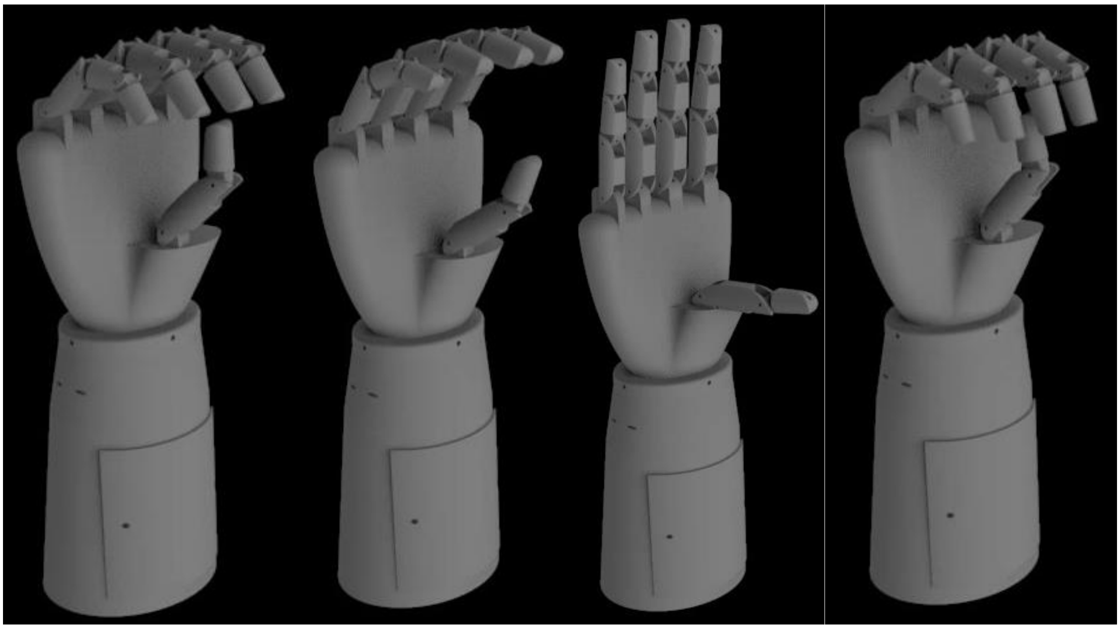


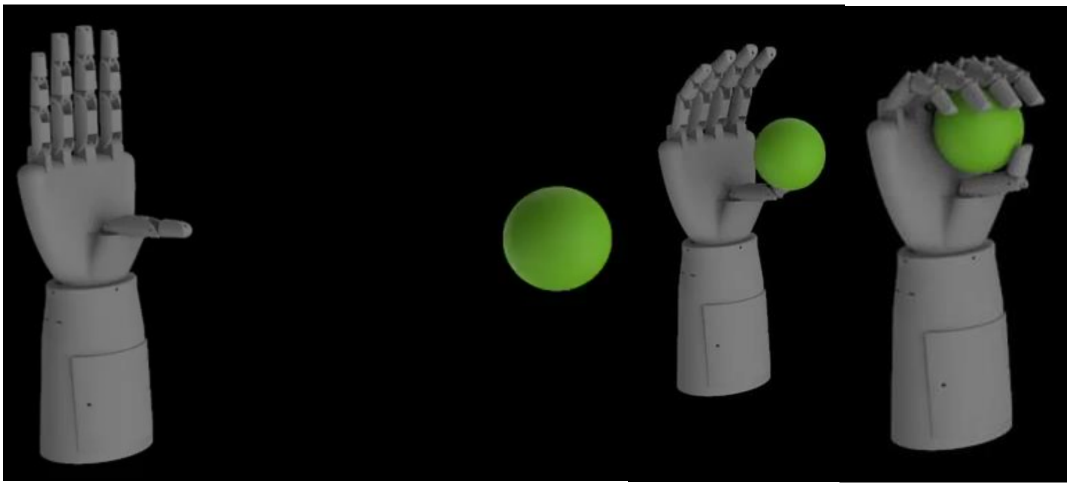
Figure 4.2.10: Gripper grasping different shape of object

4.3.1 GRASPING IN VIRTUAL SIMULATED ENVIRONMENT

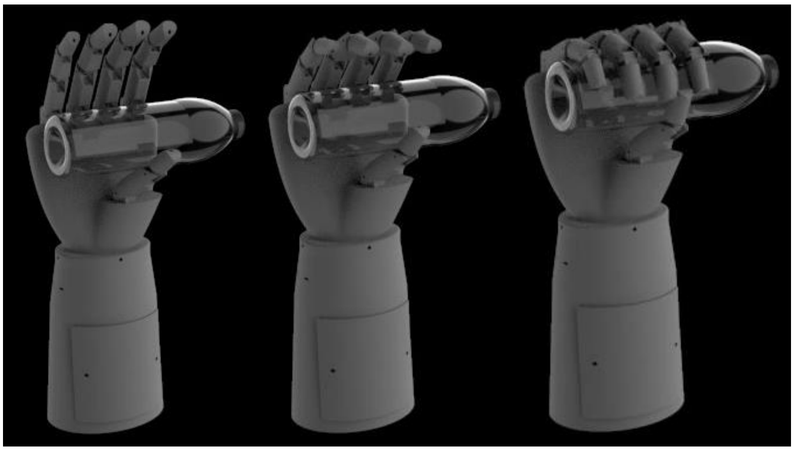
4.3.1.1 GRASPING IN FREE AIR ENVIRONMENT: SAMPLE GRASPING



4.3.1.2 GRASPING OF CASE 2 (TENNIS BALL)



4.3.1.3 GRASPING OF CASE 3 (PLASTIC WATER BOTTLE)



4.3.2 RESULTS AND SIMULATION

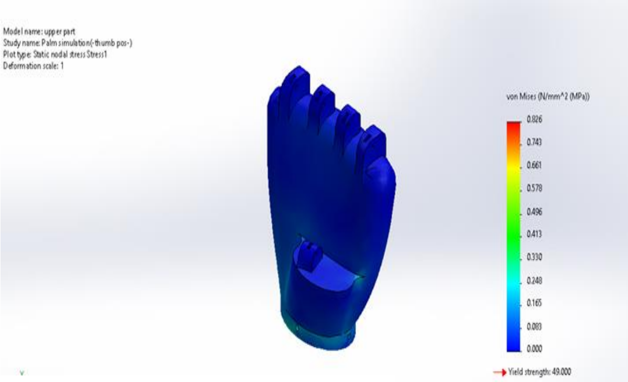


Figure 4.2.11: Stress analysis

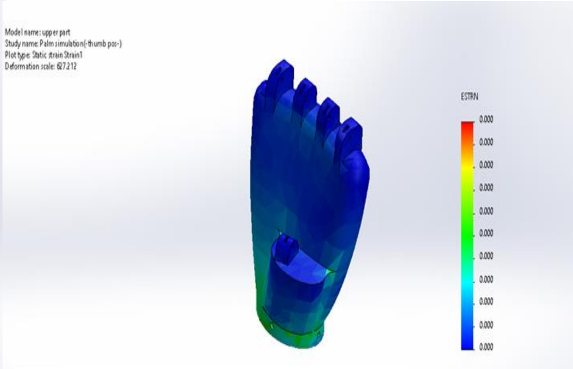


Figure 4.2.12: Strain analysis

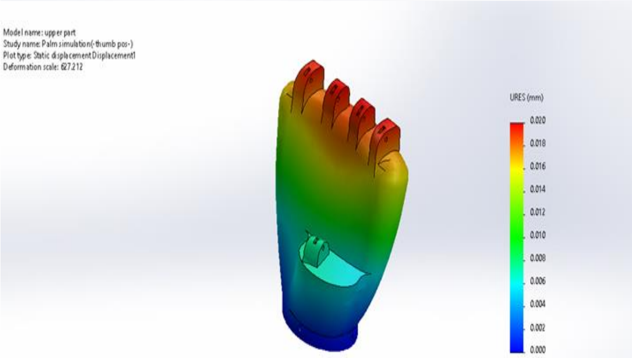


Figure 4.2.13: Deformation Plot

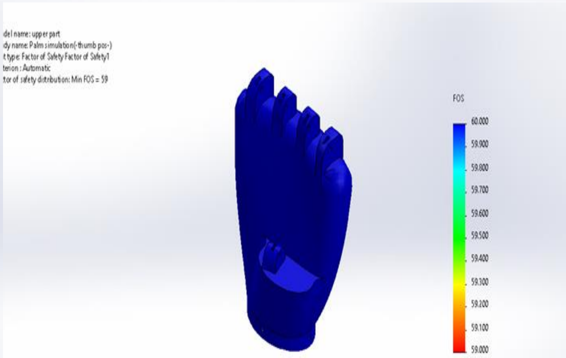


Figure 4.2.14: FOS Plot

Table 20: Simulation Study Results

STUDY	TYPE	MIN VALUE	MAX VALUE
STRESS	VON MISES	0.000 MPa	0.826 MPa
STRAIN	EQUIVALENT STRAIN	0	0
DEFORMATION	EQUIVALENT DISPLACEMENT	0 mm	0.020 mm
FACTOR OF SAFETY		5.9	12.071

CHAPTER 5
FABRICATION OF GRIPPER

5.1 3D PRINTING OF GRIPPER

This is the final step of our project development phase. This involves the fabrication of our gripper. The gripper was produced by the process of FDM. This is a production method used for fabrication and production applications. This method employs melt extrusion method that is manufacturing of 3D object layer by layer. FDM method was used for the fabrication of the gripper because :

[1] FDM is the most cost-effective way of producing custom thermoplastic parts and prototypes.
[2] FDM has the lowest dimensional accuracy and resolution compared to other 3D printing technologies
[3] FDM parts are likely to have visible layer lines, so post processing is required for a smooth finish.
[4] The layer adhesion mechanism makes FDM parts inherently anisotropic.

The material used was PLA. This is the most common printing material. Polylactic acid is a bio plastic and thermoplastic made from natural materials. PLA is widely used in other production contexts due to its unique properties and has a great printing performance.
PLA offers a toughness of 16.2 kJ/m^2 and its ultimate tensile strength is 26.4MPa.
Also, PLA doesn't require a heated bed, enclosure or direct drive extrude and is widely available. PLA is quite tolerant of varying print setting and can be printed more quickly than other materials.

5.2 STEPS INOVLVED IN 3D PRINTING OF GRIPPER

[1] The solid modelling of the gripper was done on SolidWorks. The gripper is anthropomorphic, and all its dimensions correspond to those of human hands. Then the solid model was saved in a pen drive.
[2] The model was then imported to the 3D printing software Cura.
[3] This was then inserted in the printer and fabrication was done.

Table 21: Fabrication Details

PROCESS	FDM (FUSION DEPOSITION MODELLING)
MATERIAL	PLA (POLY LACTIC ACID)
MATERIAL COST / KG SPOOL	$15 TO $45
COMPANY	CADDMAN GURGAON (DELHI)

Table 21: Selected Material Specification

PLA SPECIFICATION	
TENSILE PROPERTIES	
Toughness	16.2 kJ/m2
Tensile Modulus	2.3 GPa
Ultimate Tensile Strength	26.4Mpa
Tensile Strength at Yield	35.9 MPa
3D PRINTING PROPERTIES	
Expected Max Linear Printing Speed	90mm/s
Hardness	95D
Density	1.24 g/cc
THERMAL PROPERTIES	
Heat Deflection Temperature	49 C
Coefficient of Thermal Expansion	41 x 10-6 m/m·K
Heat Capacity	1,800 J/kg·K
Thermal Conductivity	1,800 J/kg·K

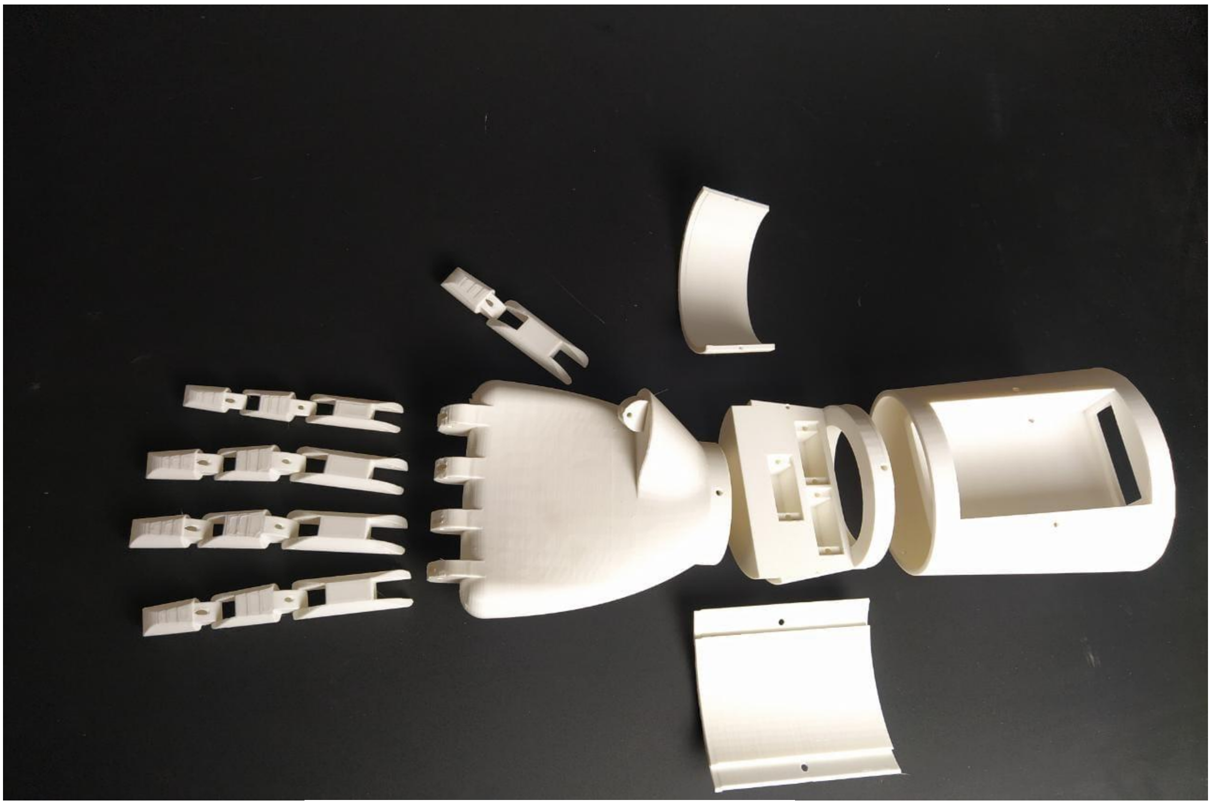


Figure 5.1: Final 3D printed gripper

CHAPTER 6
Sensing & Control System Design

6.1 COMPONENTS USED

The following components were used in the circuit:

[1] 3 - SG90 motors
[2] 23- Jumpwires
[3] 3- potentiometers
[4] 1 - LiPo 3s 3000 MAh battery
[5] 1 - Arduino mega 2560
[6] 1- STMPE 610 resistive touch sensor
[7] 1 – breadboard

6.2 SETTING UP CONNECTION STEP BY STEP

[1] Battery is directly connected to the BB.
[2] External battery VCC and GND connect to the BB
[3] Arduino GND connects to the BB's GND input.
[4] Servomotors have 3 pins: orange input - signal input
   - red input - power input (VCC)
   - brown input - ground input (GND)

6.3 POTENTIOMETERS CONNECTION

[1] One outer pin connect to BB's VCC input
[2] One outer pin connect to BB's GND input
[3] Middle pin connect to arduino's analog input

6.4 WIRING PROCESS

[1] The digital pin of each servomotor is connected to the arduino's digital pin.
[2] GND of each servomotor connects to BB's GND input.
[3] Signal pin of each potentiometer connects to the analog pin of arduino.
[4] One outer pin of the potentiometer connects to BB's VCC and GND input.
[5] The GND pin of the touch/tactile sensor connects to GND of BB's pin and its digital pin connects to the digital pin of the arduino.
[6] The resistive touch sensor detects an object through measuring touch and responds to the pressure applied. It consists of two conductive layers and a non-conductive separator.
[7] After an object has been detected, the fingers curl to grip the object. The program fed to arduino males the curling stops accordingly.

[8] The potentiometer provides resisting forces to control the servomotors and provide provides position

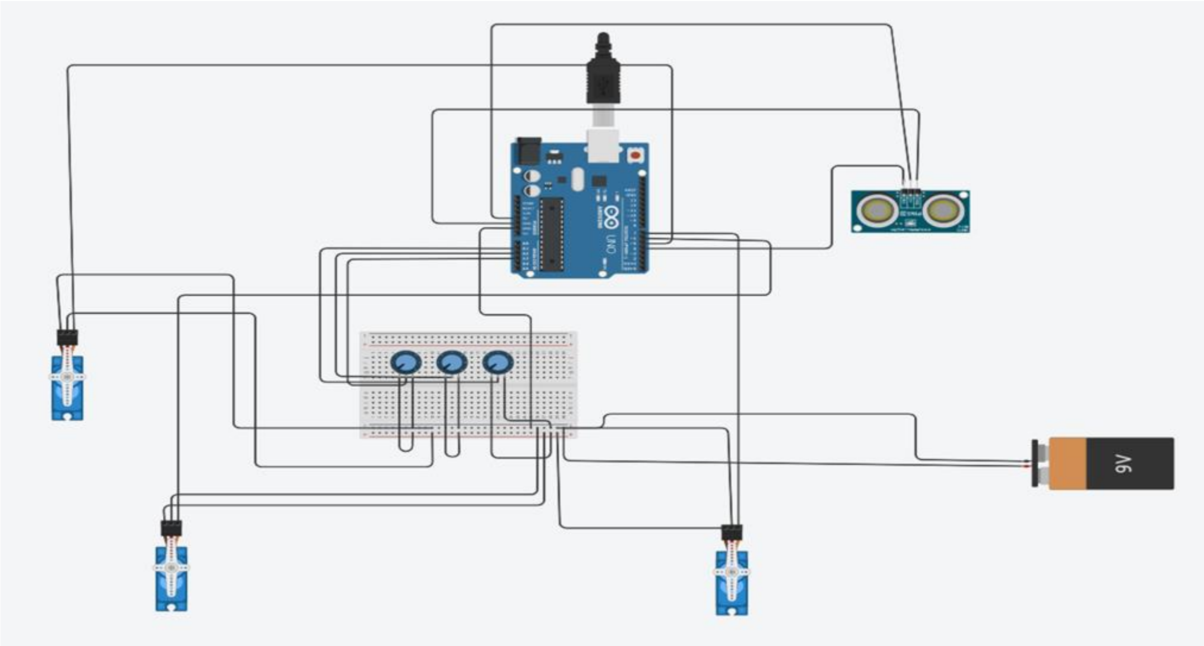


Figure 6.2: Wiring layout w.r.t single tactile sensor

Table 23: SG90 Servo Motor Specifications

TORQUE	**2.5kg-cm**
WEIGHT	**14.7gram**
PHASE VOLTAGE	**4.8-6V**
RANGE	**180 DEG**
GEAR TYPE	**PLASTIC**

Table 24: Arduino Mega2560 Specifications

OPERATING VOLTAGE	**5V**
ANALOG INPUT PINS	**16**
FLASH MEMORY	**256kb**
CLOCK SPEED	**16MHz**
DIGITAL I/O PINS	**54**

Table 25: STMPE610 Sensor Specification

OPERATING VOLTAGE	**1.8-3.3V**
AIR-GAP ESD PROTECTION	**25KV**
HBM ESD PROTECTION	**4KV**
INTERFACE	**I2C & SPI**

Table 26: Battery Specification

BATTERY	**LIPO 3S 3000 MAH**
WIRES	**23 JUMPER WIRES**

6.5 PROGRAM WITH RESPECT TO 3 SERVO-MOTORS AND SINGLE TACTILE SENSOR

```
#include <Servo.h>

#define SERVOS 3

Servo myservo[SERVOS];

int servo_pins[SERVOS] = {5,6,7};
int potpins[SERVOS] = {A1,A2,A3};
int potpin_val[SERVOS];
const int buttonPin = 8;
const int ledPin = 2;
int buttonState = 0;

void setup()
 {

        for(int i = 0; i < SERVOS; i++)
    {
        myservo[i].attach(servo_pins[i]);
        pinMode(2, INPUT);
        Serial.begin(9600);

     }
  }

void loop()
  {
        for(int i = 0; i < SERVOS; i++)
      {
```

```
    potpin_val[i] = analogRead(potpins[i]);
    potpin_val[i] = map(potpin_val[i], 0, 1023, 0, 180);
    myservo[i].write(potpin_val[i]);
   delay(15);

   buttonState = digitalRead(buttonPin);

     if (buttonState == HIGH)
         {

              digitalWrite(servo_pins[SERVOS], LOW);
          }
      else
          {


              digitalWrite(servo_pins[SERVOS], LOW);
              delay(500);
   }
}
```

FUTURE SCOPE AND CONCLUSION

Figure Z: Future Scope

In the present day, these grippers are already being employed in many different applications:

SPACE

Recently China deployed a powerful robotic arm which is attached to the core module of its Tiangong Space Station. This arm was used to gather and steer space debris.Its capable of lifting heavy objects and can move around on the outside of the station.

WAREHOUSE AUTOMATION

In order to reduce human dependency, many industries use warehouse automation. The workers are exposed to health risks while loading and unloading heavy goods. Let us consider the example of e-commerce giant Amazon.

It is important to note that Amazon is more aggressive than others in the industry when it comes to documenting injuries. In order to overcome this, they began using robotic arms in the warehouses. Even the simple process of identifying an object and picking it up without having been trained on that object before requires a series of complex, sophisticated software, and hardware.

PROSTHETICS

The concept of prosthesis has been used since the early times. The robotic grippers or arms can also be used as prosthesis limbs. This arm is a blessing for accident victims, army veterans and people who lost their hands or arms to diseases.

Let us consider the case study of the Hero arm. This prosthetic arm was developed by Open Bionics. This is a lightweight and affordable myoelectric prosthesis. The arm is powered by high-performance motors, advanced software, and long-lasting batteries. The full prosthesis is robust, and the innovative socket is comfortable, adjustable and breathable, making it easy to take on and off.

INDUSTRIAL ROBOTICS:

Industrial robots are automated, programmable, and capable of movement on three or more axes. Typical applications of robots include welding, painting, assembly, disassembly, pick and place for printed circuit boards, packaging and labelling, palletizing, product inspection, and testing. This includes welding robots, material handling robots, palletizing robots, painting robots and assembly robots.

Let us consider the example of SCARA ARM. SCARA stands for Selective Compliance Articulated Robot Arm. They are robotic arms that have a versatile range of motion in the X-Y plane. This robotic arm is commonly used for pick-and-place or assembly operations where high speed and high accuracy is required.

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