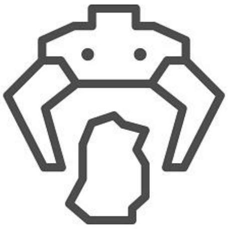
3-FINGERED END EFFECTOR

874H1: ROBOTIC DESIGN & IMPLEMENTATION



ADITYA KOMAGIRI – 245310
BERKIN DAL – 250567
RICKY AMBROSE – 244144

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ABSTRACT

A gripper is a vital component of any robotic end effector. It is used to grasp onto objects and are usually specially designed to serve a certain function, and interact with the environment the robot is placed in. Some operations require multi fingered end effector that replicates a human hand. This concept of replicating the human hand, to a robotic end effector is the main driving factor of this report and will also serve as the basis of the designing process. The goal of this project was not only to make a three-fingered robotic end effector, but also to do it using the provided components, budget, and the available rapid prototyping equipment.

INTRODUCTION

If the human body were to be considered to be a robot, the hands can be compared to a robot's end-effector. The dextrous ability of the human hand to grasp, squeeze, hold, pickup, break and turn objects is very hard to replicate because of the complexity of the muscles and bone structures. Although the main objective of this project is not to replicate the human hand, initial inspiration was taken from the biological counterpart. The complexity of the task, along with working with the pressure of tight deadlines for submissions and budget limitations, was quite a challenge in itself, and in order to be able to successfully complete the project, a one-time prototype mindset plan was required. To make this possible, a lot of academic research documents on robotic grasping and object manipulation had to be read and understood. The project not only had to work as intended, but also look great and hence many design variations were also made.

A majority of the research papers use a lot of complex electronic equipment, which made it apparent that the mechanical engineering background was not highlighted or used much. To keep the cost down and the design simple, mechanical linkages had to be used. Anthropomorphic robotic hands are widely used in the research fields, and the three fingered grippers are adequate enough to conduct research activities. The final design of the project can be customised and modified quite easily for incorporating different fingertips, actuation face angles, etc.

Fig1 : The final three-finger end effector CAD model

INSPIRATION

The main objective of the project for the group was to make something really cool, multi-purpose, challenging and completable. The group members should be able to work on the project by utilizing all of the knowledge possessed, as well as utilize most of the skills taught in the module. Dexterous and skilful articulation, that replicates the human hand would've made the project extremely challenging and almost impossible to complete with the available time and budget, hence a more achievable goal had to be planned out to reduce the complexity, while also keeping the task challenging to complete.

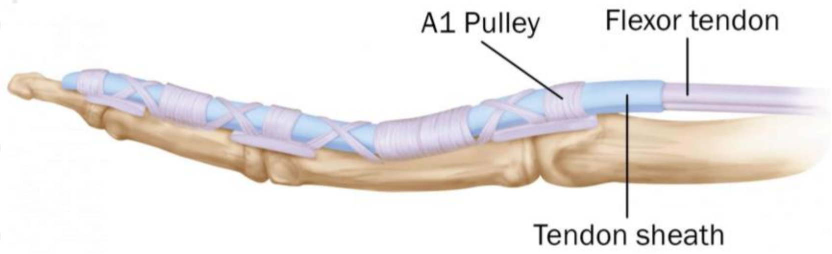


Fig2 : Human Finger bone and tendon placement

In order to make the goals realistic and achievable, some parts had to be eliminated from the equation. First, the number of fingers were reduced, and the new plan considered using either two or three finger joints. The three fingered design was considered as it would keep the task challenging enough, and multi-purpose as well. The idea was to make a robot that would be able to pick up multiple objects of varying shapes, sizes, and hardness. Inspiration for such multi-functional finger orientations and movements was from Ishikawa Group Laboratory's robot[4].

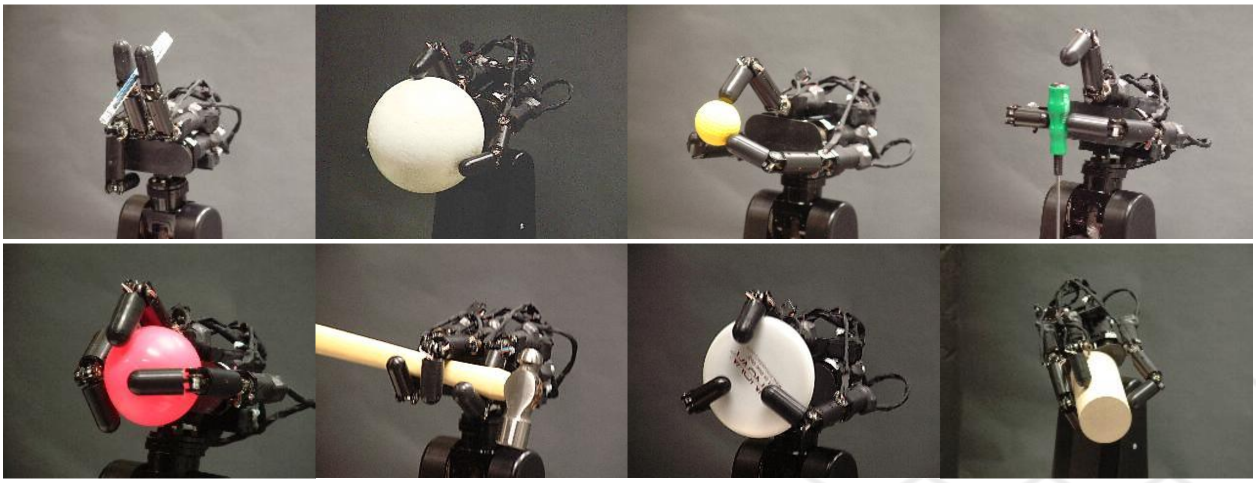


Fig3 : High Speed Multifingered hand by Ishikawa Group Laboratory holding different objects

The Ishikawa Group Lab's (IGL) robot made use of high accuracy linear actuators as well as stepper motors. The design philosophy and end objectives of the projects didn't align with this project due to various reasons. The IGL robot made use of image recognition and processing for the robot to be able to change orientation based on the object type, and also to know when to grasp the object as it approaches the gripper, there were 6-axis force/torque sensors as well as a tactile sensor mounted at each fingertip. This would've made the project extremely expensive and complex, and a lot of research time would be required to achieve this operation. To improve upon this idea to suit our limitations, the use of linear actuators was removed, and we decided to go with the servo actuation. The inspiration for the left and right thumb's kinematics was taken from this robot. The focus then shifted towards the finger design itself which had to be low-cost and constitute of mostly mechanical actuation to not only keep costs down, but also to reduce the complexity of the task at hand. The finger's kinematic linkages were to be designed in such a way that the finger could be articulated using one stepper motor only. This was planned quickly dropped because there would've been friction between the sliding joints, which would've made the rotation of the fingers quite jittery. There were multiple other ideas that were considered and dropped for a plethora of reason .

Fig 4 : Open-source 3D printed finger

The design of the finger linkages had to be done in such a way that the fingertip's face, that would be used to grip the object, always remained parallel to a virtual line that is assumed to be located at the centre of the whole robot. This is achieved by using a parallelogram setup of linkages. The use of the parallelogram mechanism would enable the design to be a lot simpler while also achieving the parallel face design requirements. This mechanism is perfectly suited for the robot because the mechanism works stably in ranges less than 90° of the input angle.

DESIGN PHILOSPHY

The design philosophy forms the basis of any engineering project that requires planning. It provides the implications, assumptions, and foundations of the project. Design philosophy is vital to every project, and it provides a path or heading for the project. The design philosophy for this project includes:

1. Extremely simple design.
2. Least electronic components.
3. Easy on the pocket.
4. Utilising the equipment provided.
5. Working design without over-the-top ideas.
6. Should have both form and function.
7. Should have at least one "smart" idea that'll provide the WOW factor.
8. Design to fit and prototype without any retakes.

Although all of the philosophical concepts of design mentioned above are vital, the last point of one time prototyping was vital because the timing of assembly was expected to be a day or two before the presentation, and with the budget restrictions it would only make sense to plan ahead of time and expect the errors that might occur way ahead of time. This was challenging considering the number of virtual prototypes that were made with different combinations and alterations of dimensions and parts.

KINEMATIC DESIGN

To make the process of kinematic designing easier and to be able to initialize it, certain points had to be considered first:

1. Linkages have to be simple.
2. Links are to be designed in the 2D plane itself.
3. The links have to be laser cut.
4. The gripper face should be parallel to the centre line, or perpendicular to the base.

In order to be able to prototype the linkages and achieve all of the above requirements, Linkage software was used. The initial designing was done on Solidworks to get a starting points for the design points on the coordinate system. Then these points are then put in the Linkage Software, where a lot of tweaks and changes are made to get the required motion for the end effector. By using point tracking for the gripper face points, the path is estimated and ensured that they follow a parallel path of motion.

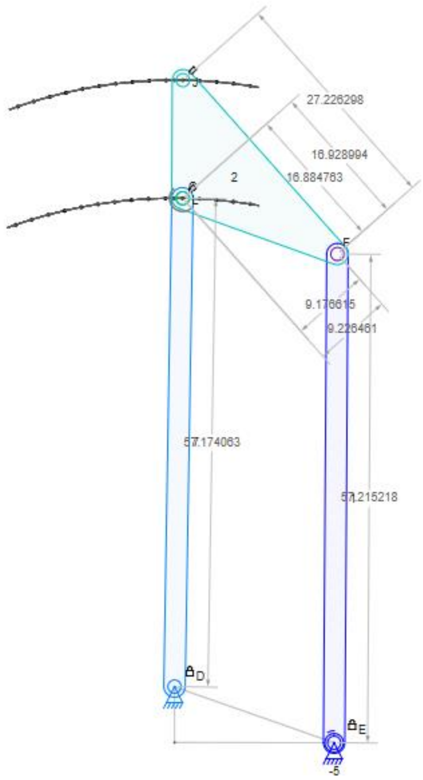


Fig 5 : Kinematics analysis using Linkage software

Another advantage of using this software is that it provides a list of the parts and the linkage lengths with the click of a single button. This process makes use of reverse kinematics where the path of the end effector is used to determine the joint lengths and angles. In the later stages, forward kinematics will be used to initialize the motion of the finger. An input angle will be provided by the link that is connected to the SG90 servo motor, and then the motor will initiate the finger movement. The MG996R motors will be connected to the base of the finger and will be used to rotate the whole finger. This motion will be achieved by using a complex retracting structure that is embedded into the base of the 3D printed base, which allows the whole setup to be able to be pulled in one direction only with a fishing wire, reducing the complexity of having a pull and push method that was planned initially.

DESIGNING PROCESS

The design process is where ideas are brought up and prototypes are thought off. This includes a lot of head scratching, brain-storming sessions, free-hand sketching, design-problem analysis, and CAD models. The design of the end effector had to be so well thought off, because we would only get one shot at prototyping and testing. The design was initialized by considering the components that were going to be used.

COMPONENTS USED

MG996R SERVO MOTOR

For the project, two MG996R servo motors were provided. It is manufactured by TowerPro and is very accurate with an upgraded gearing for better dead bandwidth and centring than the MG995. Weight is not an important consideration as this motor will be placed on the base itself. It requires 4.8V and 170mAmps when no load is applied. The motor provides 9.4kg/cm of torque when supplied with 4.8V.

ELEGOO ARDUINO MEGA 2560

The micro controller used in the project is the Elegoo Arduino Mega 2560. This board has a bigger foot-print than the Uno, mostly because of the 54 GPIO pins. Points to consider are that it has 256Kb of flash memory and it can be powered by an external 9V power supply. The microcontroller can be programmed with the official Arduino IDE.

SG90D

The SG90D servo motor from TowerPro is a very commonly used motor, which is famed for its light weight at only 9g, precise movement, easy control, and extremely durable design. This motor will be used for finger movement articulation and produces 1.8kg/cm of torque when provided with 4.8V.

OTHER GENERAL PERIPHERILS

9V POWER ADAPTER

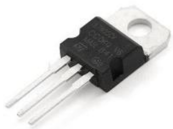
A 9V, 1Amph external AC/DC power supply was used to power the IC's and motors. 9V would go straight to the Arduino.

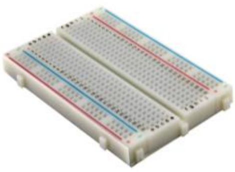
BARREL JACK ADAPTER

A 9 V barrel jack adapter was used to receive that power from the adapter and transmit it to the breadboard

5V VOLTAGE REGULATOR

Five, L7805CV 5V voltage regulator were used to regulate the voltage supply from the 9V to 5V for the motors. The reason five are used instead of one is to avoid overheating of the regulator and provide stable 5V's.





SOLDERLESS BREADBOARD

To be able to prototype and test the components, two mini breadboards were used, as one wasn't enough to contain the wiring requirements of the end effector.

CIRCUIT

The components above are selected to work in unison to make the robot behave in the required manner and perform the gripping tasks as required. The initial design and selection of components was done using TinkerCAD. A lot of prototyping was done beforehand, and some important research work as well, to figure out if the selected components would work, and not fail under heavy load conditions. The battery was replaced with a 9V, 1Amph power adapter, from which the power and ground unit is connected to the LM7805 5V voltage regulator to provide the servos with regulated power.

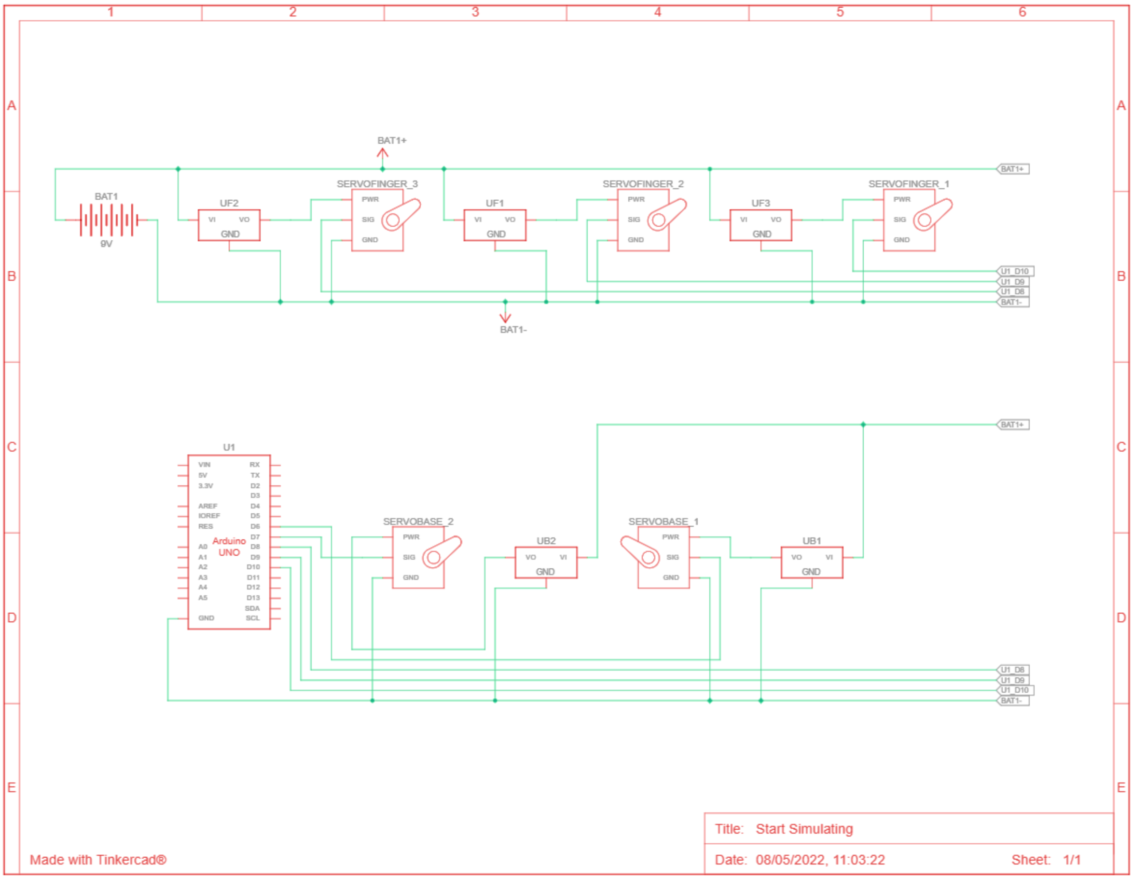


Fig 6 : Schematic view of the circuit

Once the schematic of the circuit was ready, the components had to be assembled accordingly. Two mini breadboards were used to house the circuitry wiring. The Arduino shares a common ground with the breadboard, and can be powered independently from the power source, or a PC, via the USB port.

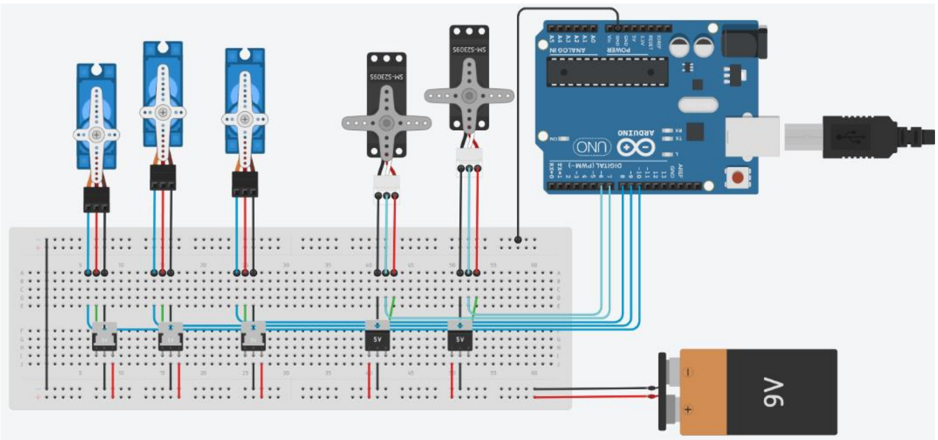


Fig 7 : Circuit component view of the circuit

PROGRAM

The program is an extremely simple code that is programmed using the Arduino IDE. The code uses inverse kinematics to move the finger. The code couldn't be executed using MATLAB due to time constraints. The program controls the angle of rotation of the 5 servo horn which translates to the rotation of the robot. The three SG90 motors used to control the finger movement are connected to the Analog outputs 8, 9 and 10, while the two MG996R motors are connected to the pins 6 and 7. All the motors always move to the initial position of the set angle of 10° which was done for the purpose of initial setup and also to avoid any unpredictable behaviours. The SG90's has to be provided with an angle of 60° for the fingers to extend completely (clasp/hold position) and depending on the size or shape of the object, this angle can be varied. The base MG996R motors turn a maximum of 180° and also pull the finger along the ride for the same 180°.

FINAL OUTCOME

There are a lot of fine details that are embedded in the final design of the end effector, most of which will be explained and discussed here. The robot had to be manufactured in sections for easy and faster prototyping, to reduce the chance of error during the rapid prototyping stage. To aid in assembly, certain "guides" and "tricks" were used, making complete use of the provided rapid prototyping processes.

ALIGNMENT GUIDES

To help in aligning the components to fit properly and look in the same direction, alignment guides were designed in the base and the pillar supports of the fingers. This was made in preparation of the assembly process to avoid any misalignment issues. The alignment of the fingers is very important as all the fingers have to be parallel to each other when in the rest position.

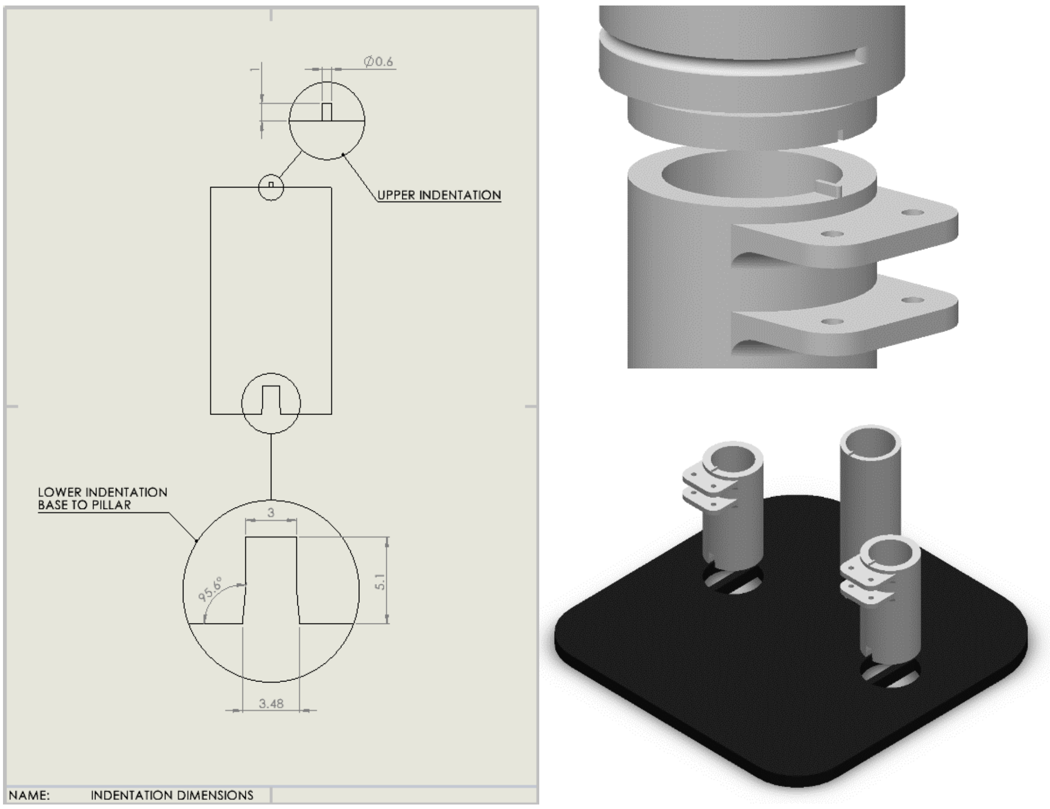


Fig 8 : Indentation and slots design

The hole where the pillars are to sit are provided with slots that are 3mm wide and 5mm high (sheet thickness), as well as the in the pillars. A male, female arrangement was created to go with this alignment setup. The slot had to be thick and strong, as it is supposed to resist the single sided pulling torque of the fishing line. The upper indentation provided on top is for aligning the base pivot to the pillar which is to be fixed to the pillar and will remain stationary. Since it is fixed, the internal spiral mechanism will be able to twist and provide rotation for the whole finger linkage assembly above. The image above also shows the mounting holes for the two MG996R motors. So, the pillar is designed to solve multiple issues, and due to the complex design, it had to be 3D printed instead of laser cutting. There are 3 pillars, two of which are complex in design, as it has to house the mounting for the motors, anti-twist and alignment guides with the robot base and finger base pivot. The pillar in the centre has only the anti-twist and alignment guides.

RETRACTING MECHANISM

Figuring out how to make the finger twist/rotate using the two MG996R servo motors was a task that took longer than anticipated. There were two issues that had to be dealt with, turning the finger a complete 180° in both directions, and making the rotation free of friction (motion had to be non-restrictive). Adding to this, the weight balance is offset to the rear, as the SG90 motor, although light, was initially placed too far off, in order to be able to get certain finger angle configurations for gripping different objects.

Fig 9 : Various prototypes to achieve rotating motion: (a) Gears for rotation, (b) Use of bearings for smooth rotation, (c) Use of extended lever type linkage (from left to right)

Some ideas included using gears to transmission of the rotational motion. This idea had the benefit of being able to use the gearing ratios to manipulate torque and rotational angle. There were multiple ideas that were either drawn, discussed, or made into CAD, but all of them had flaws or were really difficult to make using the available time and prototyping methods.

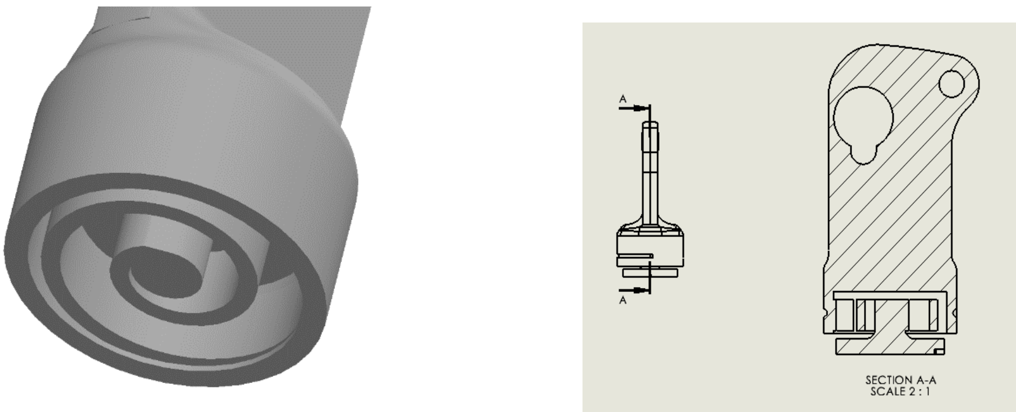


Fig 10 : Left to right: (a) Spiral CAD, (b) Sectional cut view of finger base pivot

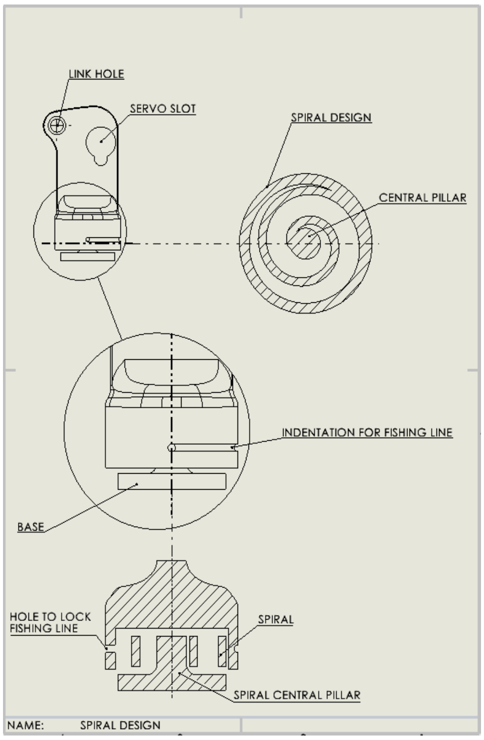


Fig 11 : Internal spiral mechanism

The final design that provided the rotational motion made use of a 3D printed torsional spring-like structure. The base is fixed, and this causes the whole finger to retract back to its initial position, which dropped the need for pull and push inputs from the servo motor. The detailed drawings provide an insight into the internal structure of this mechanism. This design solved most of the issues that were mentioned above, and also irradicated the need for assembly after the prototype was ready, hence, saving loads of time.

LOCK PINS

The locking pins serve two purposes. They are supposed to hold the linkages together tightly, and also providing rotational freedom wherever required. These requirements cannot be compromised upon, as failure in any one condition, would cause either a lockup or no proper free play in the linkages. There are 3 basic pins that are used and are very specifically designed for the location they are meant to sit in.

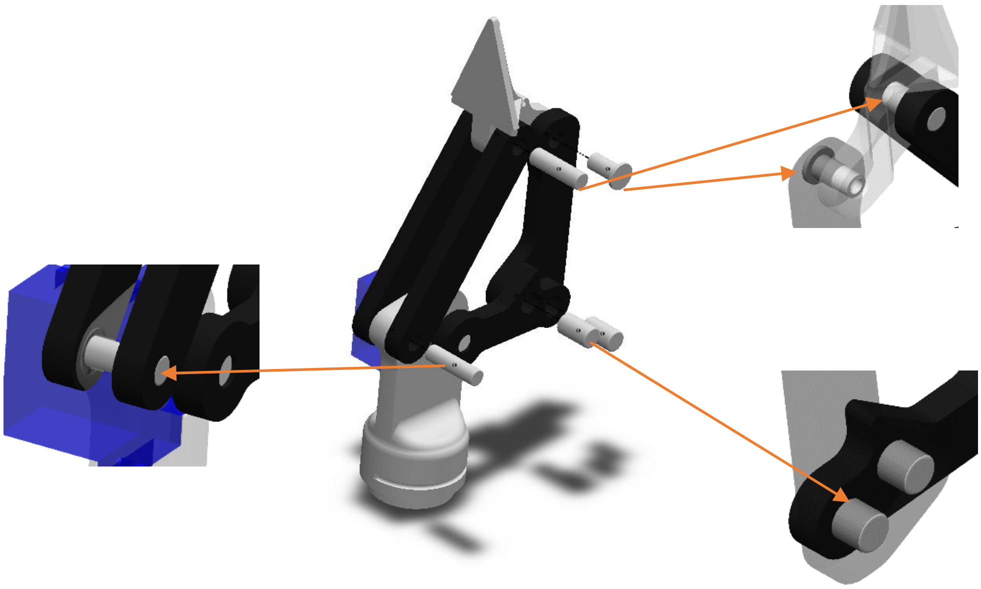


Fig 12 : Lock pins used in the project

There are a total of 5 pins used per finger, all of which had to be 3D printed to adhere to its specific requirements. Rotational freedom was provided by locking the pin to a certain link by providing the exact dimensions for a press fit, and a slightly lose fit for the other link to move freely. The fit shouldn't be very loose, as this will cause some free play, which isn't ideal.

Fig 13 : Final assembled three-fingered end effector

POSSIBLE IMPROVEMENTS

The project had involved a lot of failure analysis, in terms of the design and kinematics. But irrespective of all that, there were a few improvements that were required and overlooked, either because of lack of time, or just because the improvement became apparent only after making the prototype. The gap of 1mm provided above the spiral construction encouraged the assembly above it to tilt, which created a domino effect, causing other problems. The spiral mechanism could also be made thinner, and instead of only one spiral, two spirals would've made the retraction a lot easier and smoother. Improvements in the manner in which the fingers are actuated can also be done, by using image processing to recognise the object and have pre-set configurations of motor angles to have the gripper positioned to grip the object.

CONCLUSION

The 3 fingered end effector started out as a project that was meant to be cool, challenging and interesting, and after taking a look at the final assembled end effector, it can be said that all the check boxes were ticked. The gripper serves the purpose of holding multiple objects of varying sizes and shapes, and also has really great gripping power. Working on the project provided experience in the various fields and departments of robotics, and also made it clear that failure of any department will lead to the failure of the project. Hence, teamwork is vital in such projects, especially when everything is interlinked. The end effector is a cumulation of countless hours of work, research, and ideas. The process of arriving at the final product was made possible only because of team effort, the course content, and resources from the uni.

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