Design of a New Modular Reconfigurable Gripper

Ahmed Khalid Ahmed [1], Safeen Yaseen Ezdeen [2], Ahmad Mohamad Sinjari [3]

[1] Electrical Engineering Department, Salahadin University -Erbil, ERBIL, IRAQ (ahmad.ahmed@su.edu.krd)
[2] Mechanical Engineering Department, Salahadin University -Erbil, ERBIL, IRAQ (Safeen.ezdeen@su.edu.krd)
[3] Electrical Engineering Department, Salahadin University -Erbil, ERBIL, IRAQ (ahmadsinjari@gmail.com)

***Abstract* – An entirely new reconfigurable gripper is designed and shown in this paper. The new gripper comprises six modular fingers, which can be rearranged to form any number of fingers between three and six. CAD, CAM, CAE, and PCB software Fusion 360 was used to design the gripper. Also, the gripper fingers are rotatable, so the finger bases can touch each other side-by-side and form one finger. In addition to showing the reconfigure ability of the gripper, several scenarios for grasping different shapes were presented and tested.**

***Keywords* – Reconfigurable gripper, modular gripper design, Fusion 360, grasping.**

1. Introduction

Robotic manipulators are a suitable and valuable tool that is becoming increasingly popular in the industry and of interest to researchers, engineers, and clinicians. Many definitions have been proposed for mechanical manipulation, but in general, mechanical manipulation is the act of force on an object that causes movement or deformation. For example, one of the tasks that manipulators can do is gripping. Therefore, grasping can be defined as the act of holding objects.

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Corresponding author: - ,
affiliation
Email: -

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The gripping task can be taken over by grippers that can be attached to the manipulator's end-effector [1].

The grippers have different shapes, sizes, classes, and configurations. There are many types of grippers based on the number of fingers. For instance, in reference [2], one finger gripper is presented and developed. The gripper uses variable van der Waals force to perform the grip, move and release spherical nano/micro-sized objects. A two-finger gripper to reorientate grasping objects without accidentally dropping them is presented in [3]. Significant reorientation was achieved (over $\pi/2$ rad) using the kinematic of the hand object alone without relying on the active and involved controls for the surface of the gripper or without using contact sensor or actuated sensors. Similar work is presented in Ottaviano's work. The force control for a two-finger gripper was presented and designed with a simple mechanical design and it is low cost at the same time [4].

Three-finger grippers are another type of grippers based on the number of fingers. For instance, a three-finger gripper was fabricated, with each finger having three links and two joints in reference [5]. Furthermore, the joints actuated using six electric motors. In addition, in [5], a three-finger gripper was fabricated using a 3D printer, and force sensors were used to collect force data and the actions of the gripper controlled using Arduino. Moreover, a power-efficient gripper with four fingers is presented in [6]. However, the gripper uses only one motor to actuate four fingers. Therefore, the Geneve mechanism was used to overcome the issue of using one motor instead of four motors per finger.

More research was also conducted on flexible finger grippers, for example, a flexible four-finger gripper based on the Fin Ray Effect [7]. Additionally, in [8], a flexible robotic gripper based on rubber material and pneumatic actuation was designed, analyzed, and tested. As a result, the gripper is tested and approved to grasp different shapes of different geometries without losing control over the object.

One of the crucial types of grippers is Adaptive (reconfigurable) multi-finger grippers. For instance, Cavallo studied and designed a reconfigurable three-finger gripper for grasping limp sheets. The design suggests that the gripper will hold the multi-point gripping and the peaceful transfer of the slack sheets to the sorting buffers in the shoe manufacturing factory. Furthermore, the study investigated a mechatronic device capable of multiplying one-layer leather sheets and firm hold [9]. Likewise, Yeung and Mills designed, developed, and described reconfigurable six degrees of freedom grippers based on the Flexible Fixtureless Assembly. Using Flexible Fixtureless Assembly technology, traditional jigs in automotive body assembly have been replaced by robots using multi-fingers to precisely grip different parts and hold the parts rigidly in space, then locating the gripped part for assembly. This work is based on three-finger gripper development. Each finger is with two joints and two contact points for grasping. The finite element method is used to simulate the deflection of the gripper parts underwork [10]. Besides, the steps of structural, kinematics, CAD synthesis, and analysis of a reconfigurable gripper have three fingers presented in [11],[12]. Thus, it is demonstrated that three-finger grippers have four main configurations. ADAMS software was used to validate the operation, CAD simulation was performed and dynamically tested the gripper. The fingers are articulated bars, which provide good gripping and safer operation than wires and rollers.

Moreover, Grain-Filled Flexible Ball Grippers have a balloon filled with grain or other materials to grasp the object. The balloon is sucked in air, causing the gripper shape to adapt to the object's shape intended to be grasped [1].

The Bellows Gripper is another type of gripper. Festo, for example, has introduced a line of bellows grippers designed to solve the problem of transporting or holding fragile workpieces using pneumatic automation. A pneumatically powered piston actuates a flexible bellow that expands in diameter to grip a workpiece's inner surface tightly. Bellows grippers from Festo are suitable for various processing and manufacturing industries, including the food, pharmaceutical, general, and electronics industries [13].

Finally, O-ring Grippers are another type of grippers. The O-ring type is a particular device designed to handle O-ring seals. The o-ring gripper has six or sometimes eight fingers that expand and grip the inner diameter of the o-ring [14].

Actuating the gripper is critical as it is the part that enables gripping. According to the operating mechanism, some grippers actuated using cables, for instance, the cable-based gripper in [15]. The study presents a design of an end-effector for handling consumables commonly found in chemistry labs. The system uses a cord loop to grip any prismatic or cylindrical object, making it ideal for handling vials and other containers commonly used in laboratories.

Besides, other grippers can be actuated using a Vacuum. The gripper designed in [16] is a good example. This type is widely used in industrial production systems, especially for handling sheet metal parts. Pneumatic-based grippers are also necessary types of grippers. For instance, the innovative pneumatic soft gripper consists of four soft fingers and a movable suction cup. The soft pneumatic dexterous gripper has four convertible grasping modes, which can grasp a wide range of objects due to the proposed conversion mechanism [17].

Furthermore, hydraulic-based grippers have an enormous capacity in generating high gripping power compared to other types of grippers, and they are also considered to have significant stiffness. However, one of the main downsides of hydraulic grippers is that they need continuous maintenance [1], [18].

In addition, grippers based on the Electric-Servo are widely used nowadays in many applications. For example, intelligent electric motors were used in [21] to actuate the intelligent gripper with adaptive gripping technique.

However, the most crucial type of gripper is reconfigurable grippers. This gripper is primarily interested in innovative industries, manufacturing, and limp material handling. This gripper application can be expanded to grip various objects of different shapes, sizes, and weights. Furthermore, these types of grippers are adaptive, and they can change the configuration of the fingers to different arrangements, giving the gripper tool expanded uses. In addition to the reconfigurable properties of these grippers, they can also be inexpensive, light, and robust. The essential advantage is that this type of gripper can be used to grasp different objects without changing tools, which reduces the time lost in changing the end effector when the requested application is changed [19], [20]. This paper will showcase the design of a new modular, reconfigurable gripper based on rigid-type material.

2. Modular Gripper Assembly Design

This paper will showcase a new modular and reconfigurable gripper design and synthesis. The new design comes after building several CAD models and testing them for modularity and adaptability. The new gripper consists of six modular fingers that can be actuated using electric motors. In addition, the gripper incorporates six motors; one motor for each finger to rotate the fingers separately and one motor to provide clamping forces. The overall look of the newly designed reconfigurable gripper is shown in Figure 1.

Figure 1 exposes the six modular fingers. According to the object's geometry and shape, the gripper can be reconfigured to any number of finger arrangements

(Three fingers, four-finger, five fingers, and six fingers).

Figure 1. New Modular Gripper Assembly

The adjustability of the fingers can be achieved using the six motors. In addition, the main finger assembly consists of two links and one joint mechanism with two degrees of freedom. Therefore, the gripper has twelve degrees of freedom (12 DOF) with six fingers. The CAD model was implemented using Autodesk FUSION 360. Figure 2 shows the exploded view of the whole gripper design.

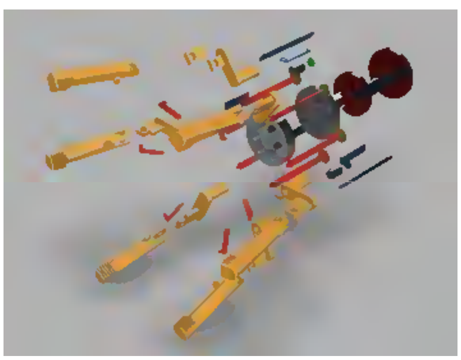

Figure 2. The exploded view of the newly designed gripper.

The new modular gripper design consists of a cylindrical-shaped finger arm and a base-link linked with the finger arm by one joint mechanism. As mentioned earlier, each finger assembly provides two degrees of freedom. The first degree of freedom originates from the first link (base-link), which rotates in the XZ plane by the finger's motor. The second degree of freedom comes from the second link. Figure 3 shows that the finger arm rotates in the YZ plane, and the rotation dawns from the conversion of translating linear piston movement. Furthermore, the finger assembly parts are shown in Figure 3 with their dimensions.

Furthermore, the finger parts assembled in the program to construct the design as shown in Figure 4. The joint holes will be bolted with proper screws and nuts after fabricating the design prototype using a 3D printing machine.

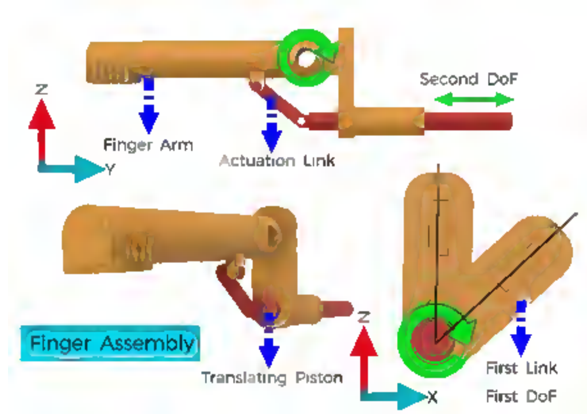

Figure 3. Finger Assembly and the two degrees of freedom.

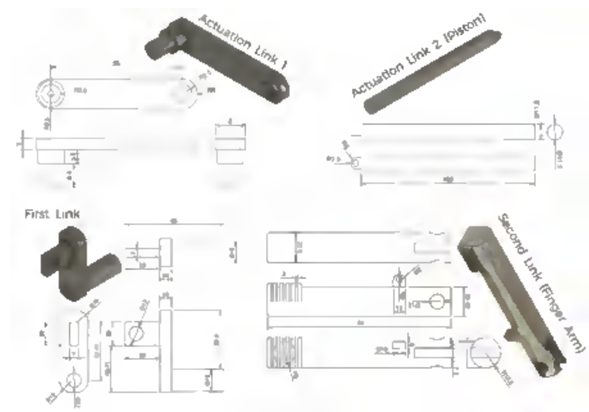

Figure 4. Finger Assembly dimensions in (mm).

The dimensions shown in Figure 4 are for the current design prototype, and once the fabrication process is decided, the dimensions will be adjusted accordingly. Also, the six fingers are mounted on the circular disk, which will be a fixed disk, and its function will be only holding the fingers for the gripper. The neck of the first link will be mounted on the first circular disk, as shown in Figure 5.

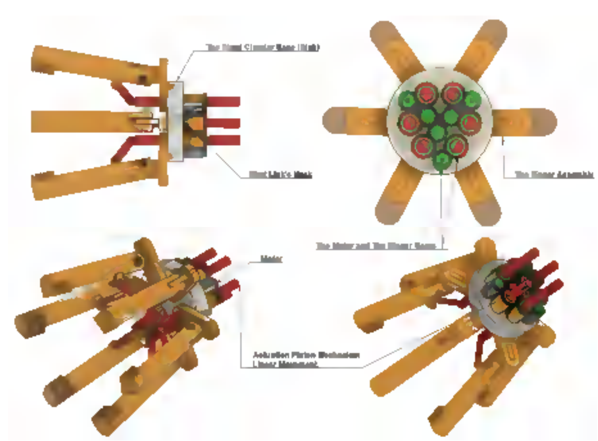

Figure 5. The Finger Assembly and the fixed circular disk.

At the end of each first link's neck, gear will be fixed to rotate the finger by coupling the gear with the motor gears. In addition, another disk was used to hold the gear mechanism and the motors. Also, the dimensions and the 2D model for the two disks are shown in Figure 6.

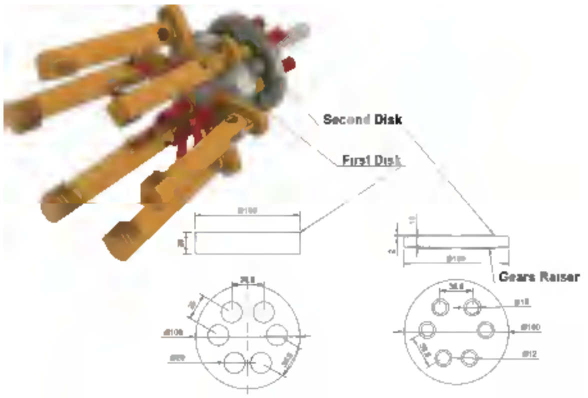

Figure 6. The first and Second Circular Disks.

The end of the pistons is connected to the third circular disk, which has a threaded hole at the center. The thread hole at the center is for the motor screw mechanism to provide clamping force for the finger assemblies. The disk will move along the screw mechanism when the motor rotates clockwise and anti-clockwise. Moreover, the third circular disk drags or pulls the pistons to create clamping force for the finger assemblies. Figure 7 shows the third circular disk and actuation mechanism for the gripper's fingers.

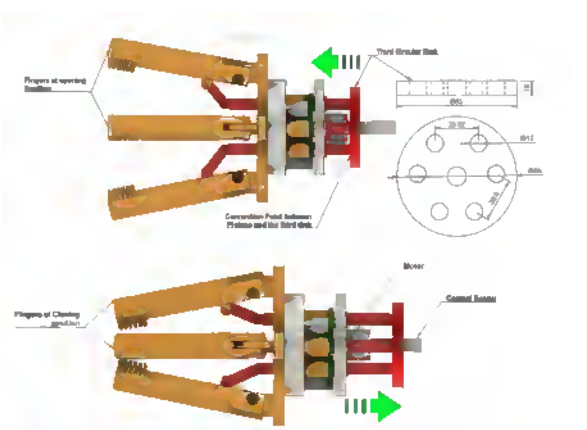

Figure 7. The third circular disk and the movement of the fingers.

The fourth circular disk connects the reconfigurable gripper with the manipulator end-effector. Also, the first circular disk, second circular disk, and fourth circular disk are joined together using disk connectors. The disk connector helps the design be more versatile and rigid. The fourth circular disk, the connectors, and their dimensions are shown in Figure 8. Two types of connectors are used, connector-1 and connector-2. Connector-1 is shorter in length than connector-2, and it connects the first circular disk to the second circular disk. Also, connector-2 connects the fourth circular disk to the first and second circular disks.

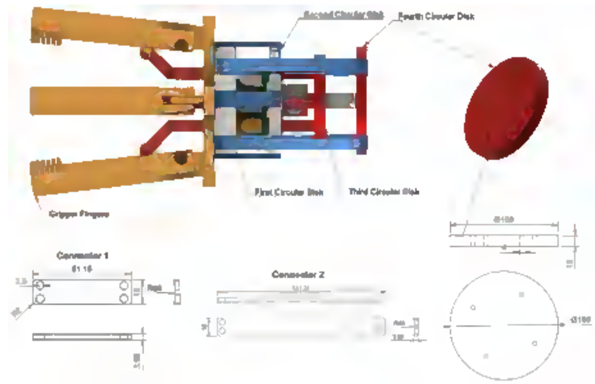

Figure 8. The fourth circular disk and the connectors.

3. Testing Modularity of the Gripper

The new reconfigurable gripper design is modular, and it can be tested for adaptability and reconfigure ability. The base-link part of the fingers can be adjusted to construct any number of fingers between three and six. The base-link neck's end is linked with spur gears, and it can rotate according to the desired position using motors. Each base-link is powered with one motor, so six motors are used to achieve the modularity of the gripper. Figure 9 demonstrates the modularity of the gripper design by constructing a different number of fingers. The gripper has one configuration for three-finger and six-finger, while it has three configurations for four and five fingers.

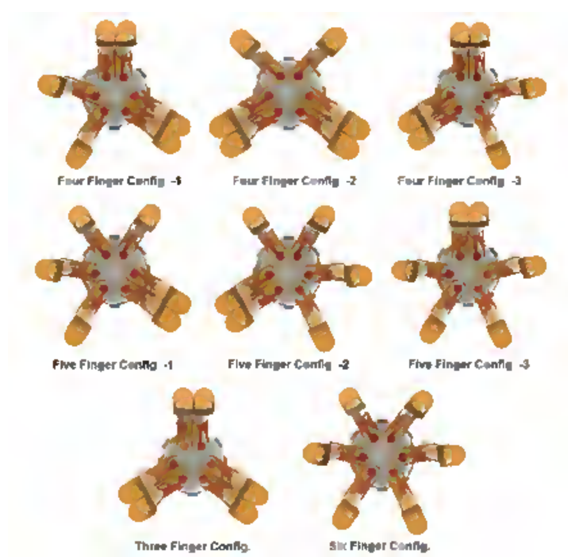

Figure 9, Gripper modularity testing by constructing a different number of fingers.

Further, when the two fingers of the gripper are touching each other side by side, it will be considered one finger. This case can be seen in Figure 10. The resulted finger will get more surface contact when the gripper is used to grasp objects. More surface contact means more gripping power than fewer surface contact cases.

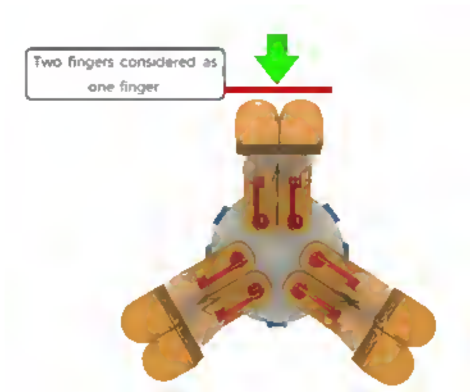

Figure 10. The construction of one finger from two fingers.

4. Grasping Scenarios

The newly designed gripper is supposed to have the ability to grasp different shapes of different geometries. In this section, the gripper will be tested for grasping different objects of different geometry. Firstly, the shapes planned to be grasped will be shown as illustrated in Figure 11, and secondly, the grasping scenarios will be demonstrated for each shape in Figure 11.

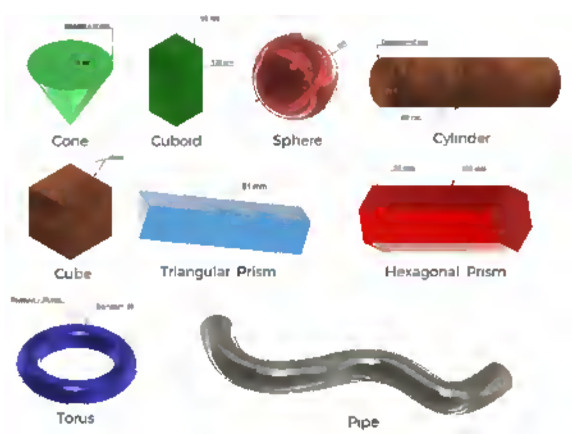

Figure 11. Some of the popular shape geometries.

4.1 Grasping a Spherical Object

For grasping a spherical object, two standard configurations will be demonstrated for successfully grasping the object. The first configuration is three finger configuration shown in Figure 12 (A). Two fingers can be combined to construct one finger in this configuration, so the total number of fingers will be three fingers. The fingers will be distributed to get 120° degrees between each other. Moreover, the grasping point will be shared between two fingers and equally in the touchline between the fingers.

The second configuration is the six-finger configuration. In this configuration, the fingers will be distributed to construct an angle of 60° degrees between each other. Also, the configuration provides more contact points between the fingers and the object's surface. For that reason, the grasping is expected to be more firm in this configuration as compared to the three-fingers. This grasping process is shown in Figure 12 (B).

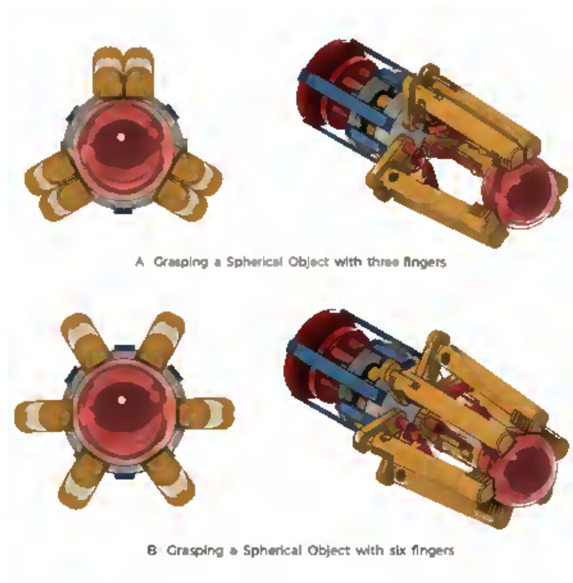

Figure 12. A- Grasping a Spherical Object with three fingers. B- Grasping a Spherical Object with six Fingers.

Furthermore, the spherical object geometry allows the gripper to grasp the object with three or six fingers, but it is possible to grasp it in other configurations, such as four and five fingers configurations.

4.2 Grasping a Cone Shape Object

The Cone shape geometry is fragile and unstable shape. Therefore, the grasp of this type of object is a challenging process. Further, the possibility of having more than two configurations for successful grasping is impossible. However, two configurations are possible to grasp the object successfully. The first configuration is to grasp the Cone from the smooth sides by distributing the three fingers at an angle of 120° degrees, as shown in Figure 13 (A). Moreover, the second configuration is to grasp it from the sharp edges, as shown in Figure 13 (B).

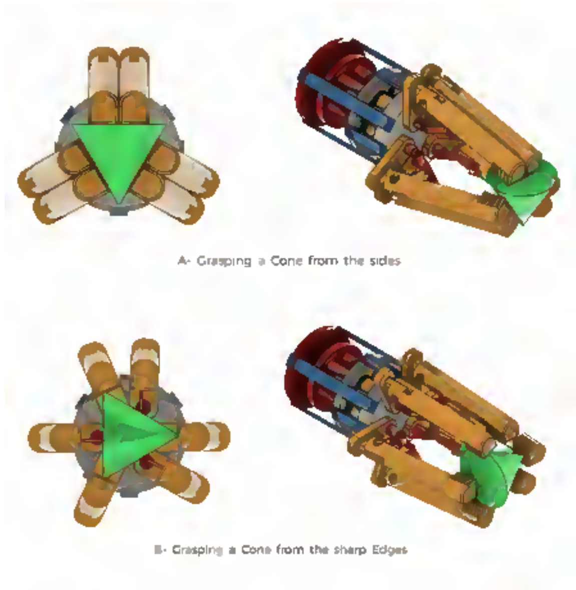

Figure 13. A – Grasping a Cone from the sides. B – Grasping a Cone from the sharp Edges.

4.3 Grasping Cuboid shape object

Three configurations can be tested to grasp a Cuboid-shaped object. The first configuration is shown in Figure 14 (A). This configuration uses three fingers, and the distribution of the fingers will be in a manner that one finger makes surface contact with the object, and the two other fingers create point contacts with the sharp edges of the Cuboid. In this configuration, the Cuboid will be grasped in the vertical position.

Figure 14 (B) shows the second grasping configuration, and in this case, the Cuboid is grasped horizontally. Again, two fingers will create surface contact with the object's surface. The other fingers will not be used in this case.

For the grasping to be improved in the second configuration, the four remaining fingers will support the grasping process by touching the sides of the Cuboid shape. Therefore, in Figure 14 (C), the grasping process uses six fingers, two fingers perform the grasping of the object, and the four other fingers will support the grasping process by touching the long side of the object.

4.4 Grasping Cylinder Shape Object

For grasping cylindrical-shaped objects, two configurations can be used for the fingers. The first configuration is shown in Figure 15 (A), and the second is shown in Figure 15 (B). Three fingers are used for the first configuration, one finger has surface contact, and two fingers have point contacts. Moreover, the fingers will be displaced by 120º degrees. The second configuration uses six fingers, as shown in Figure 3.15 (B). The grasping process will be performed by distributing the fingers so that each two-finger has 60º spacing, and the fingers will make surface contact with the Cylinder at the wrist of the object.

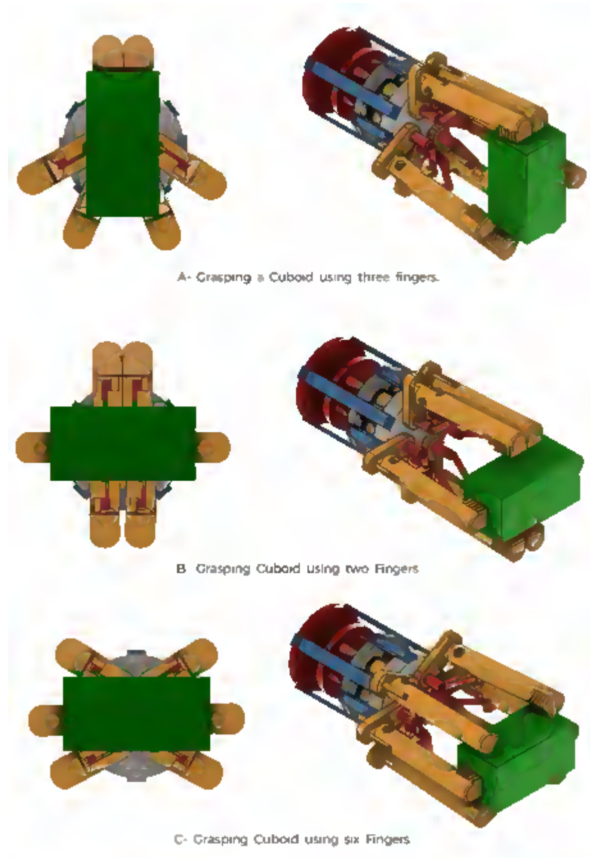

Figure 14. Grasping Cuboid shape object: (A)- Grasping Cuboid using Three-Fingers. (B) – Grasping Cuboid using two Fingers. (C)- Grasping Cuboid using six Fingers.

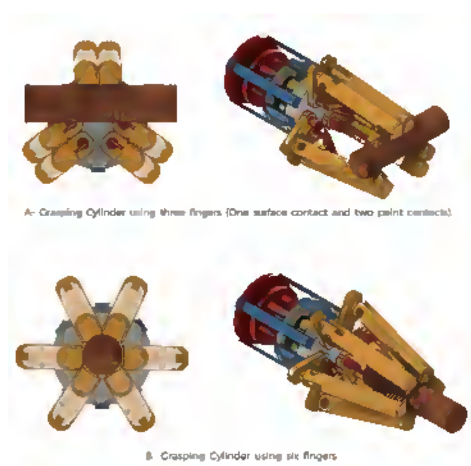

Figure 15. (A)- Grasping Cylinder using three fingers (one surface contact and two-point contacts) (B)- Grasping Cylinder using six fingers.

4.5 Grasping of Cube Shape object

The small cube shape shown in Figure 16 can be grasped using a three-finger configuration. Only one finger has surface contact with the object, and the two other fingers will make point contacts. The distribution of the fingers will be 120° degrees between the fingers. Larger Cube sizes can be grasped more efficiently and without any challenge. However, the fingers' workspace can limit the gripper's capability to grasp smaller objects as the fingers will slam into each other when the object's size is too small.

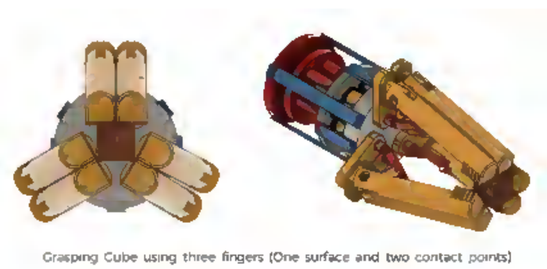

Figure 16. Grasping of Cube shape.

4.6 Grasping of Hexagonal Prism

The Hexagonal Prism shape shown in Figure 11 can be grasped using the new modular gripper by four different configurations. The first configuration is shown in Figure 17 (A), grasping the object vertically. In this configuration, the object will be grasped using three fingers having surface contact with the object surface. So, one finger will touch the top hexagonal face, and the other will touch the bottom hexagonal face.

The second configuration is to grasp the object with two fingers horizontally. This configuration is shown in Figure 17 (B). Further, the four remaining fingers can be used as support fingers for creating a firmer grasp in the second configuration, shown in Figure 17 (C). Finally, the last configuration is shown in Figure 17 (D). Each finger will have a surface contact with the object's rectangular face in this configuration. As a result, six fingers will be used to grasp the object in this configuration.

4.7 Grasping of Triangular Prism

The Triangular Prism shown in Figure 11 can be grasped in three different configurations, as shown in Figure 18 (A), (B), and (C). In addition, the shape can be grasped from its triangular faces using only two fingers, as shown in Figure 18 (A). Then, to support the grasping power in this configuration, the four remaining fingers can also touch the shapes' vertices on each side of the triangular faces. In this way, the grasping will be more tight and firm. This configuration is shown in Figure 18 (B). The third configuration is to grasp the object at its triangular faces using three fingers having surface contacts with the top and bottom triangular faces. The vertical grasp of Triangular Prism is shown in Figure 18 (C).

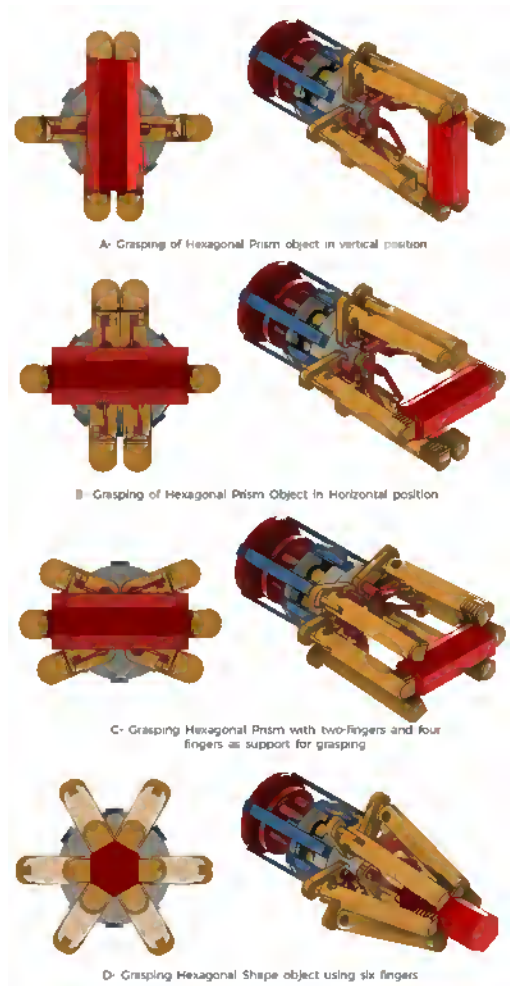

Figure 17. Grasping of Hexagonal shape objects in three different finger configurations.

4.8 Grasping of Torus

The Torus shape can be grasped through its equatorial plane, as shown in Figure 19 (A), (B), and (C). The first grasping configuration uses two fingers to grasp the object at the equatorial plane in its vertical position, and the second configuration uses three fingers to grasp the object vertically. Finally, the third configuration uses six fingers to grasp the shape through the outer pipe surface.

4.9 Grasping of Pipe

The pipe shape fragment shown in Figure 11 can be grasped using the configuration of the fingers as shown in Figure 20. Therefore, at one end of the pipe, the gripper fingers will be distributed so that each two-finger has 60° degrees apart. Then the grasping will be done by clamping the pipe's end with the fingers.

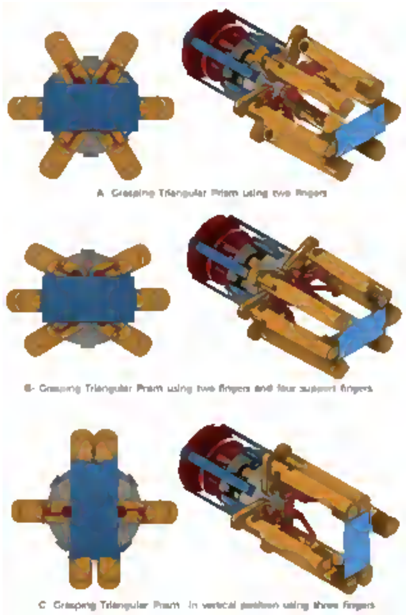

Figure 18. Grasping of Triangular Prism.

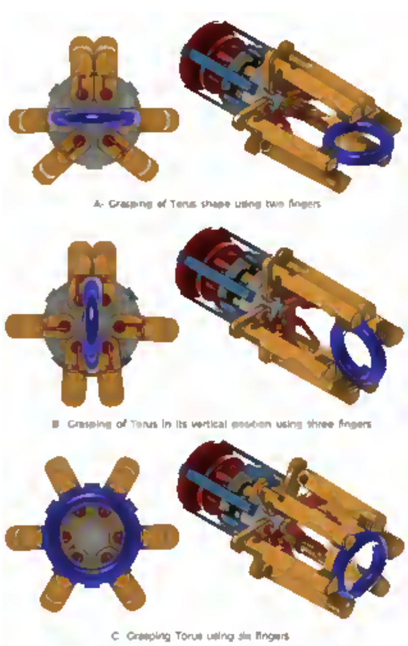

Figure 19. Grasping of Torus shape object.

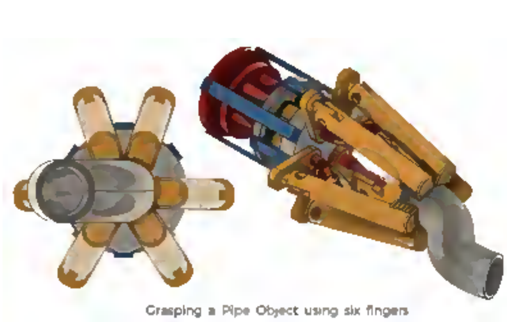

Figure 20. Grasping of pipe shape.

5. Conclusion

This paper has followed the design criteria proposed in our previous work. The new gripper in this paper has six fingers that can be rotated with motors and gear mechanisms. Moreover, each of the two fingers can be adapted to construct one finger when they touch each other side by side. Thus, the new gripper can be reconfigured to make three, four, five, and six finger grippers based on the shape geometry. Further, using Fusion 360 software, nine popular shapes were created, and grasping scenarios were presented to test the gripper's modularity. Consequently, the gripper can grasp shapes more than two ways, except for the small cube and pipe. Afterward, the gripper material will be decided based on the static stress, and the modal frequency analysis will determine which material is most appropriate for fabricating this new gripper.

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