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Kinematic Design & Analysis of a Three Finger Gripper

Archita Singh[1], Vivek Chawla[2]

archita.singh@yahoo.com, vchawla24@gmail.com

Abstract

This thesis work focuses on the three finger gripper. The main aim is to develop a three finger gripper for picking up specific hazardous objects by the gripper and placing it in the desired position.The system is under actuated. Therefore, to develop these three fingered, a solid model is prepared in Solid works.Kinematic analysis is carried out to find position, orientation and joint values of the gripper by forward and inverse kinematic equation. Grasping mechanism is also discussed in the thesis for gripping an object precisely.

Keywords

Gripper, Solid works, Ansys, Roboanalyzer

Introduction

In order to replicate the movements of a human hand smoothly and more efficiently by a machine in terms of dexterity, the robotic gripper is used. Service robots are used in various applications in industries because of their adaptive capabilities such as fine manipulation skills and stable grasping of objects, various personal applications as per the requirement. This is surely human excellence in terms of anatomy and intelligence which enables to perform tasks like humans and a safe co-operation between humans and robots. The multi-finger gripper has three articulated fingers with each finger having three joints, thus three phalanxes per finger according to human anatomy. Thus gripper can engage with three points of contact with objects three on each of the phalanges and the palm. The fingers have less number of motors attached than the total number of joints in a finger, thus they are known as under-actuated. This adaptation helps fingers to take the shape of the object it holds and hence ensures tight grip and also due to this it can hold, pick and handle a variety of objects of different shapes and sizes.

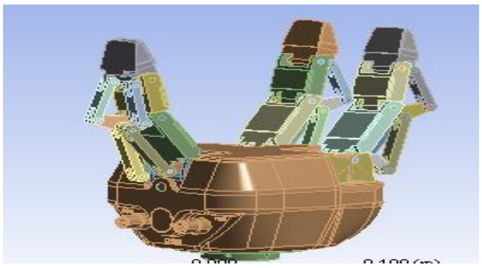


Figure 1: Three Finger Gripper Model

The main functional requirement is to develop a gripper which can pick up a payload of 10 kg safely without any slippage. A kinematic analysis has been carried out for the same. A solid 3D model on solid works has been prepared.The mechanical specification of the gripper is: the opening of the gripper is 0-155mm. The weight of the gripper is around 2.5 kg to pick 10 kg of objects. For encompassing gripping, the payload is 10 kg, while for the fingertip payload is about 2.5 kg. Maximum force fingertip can bear is 60N. And maximum break away force at the fingertips is about 100N. Material used is structural steel.

Gripper

"It is a subsystem of handling mechanisms which provide temporary contact with the object to be grasped and ensure the position and orientation when carrying and mating the object to the handling equipment.Types of grippers -vacuum grippers, pneumatic grippers,hydraulic grippers, servo electric gripper, magnetic grippers, soft grippers. The Gripper Considerations are such as Gripping force, weight, supply of services, environmental capabilities, sensor capabilities, Speed of gripper, Range of sizes of objects to be held, Mechanism maintenance, Behavior under power failure.

Design and Methodology

Design is the creation of a convention of an object or a system. Designing often requires aesthetic, functional, economic and sociopolitical dimensions of both the design and the object. It requires considerable research, modeling, re-design of the desired object for functionality. A mock model is a replica of the model that is desired to be made, we can also say as rapid prototype.

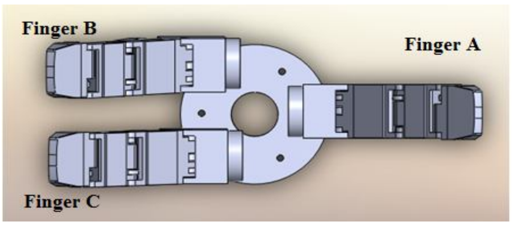


Figure 2 Solid Model of 3 Finger Gripper

A. Gripper structure

The multi-finger adaptive gripper finger consists of the three main links and supported by other links for supporting the main body and to impart motion forward to the next link joined with the help of revolute joints at points A, B, C, D, E, F, G, H, I in all the three fingers of the grippers. The lengths of the links are: for link1 length =57.12 mm, link2=38.12 mm , and link 3=22.12mm , while it has a range of ± 90°, ± 75° and ± 60° The model is designed in solid works and analysis is carried out in Ansys workbench software.

B. Gripper Kinematic Modeling:

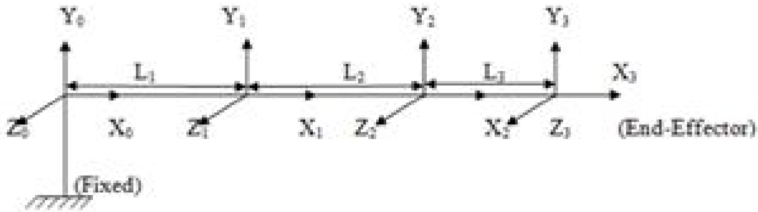


Figure 3 Gripper link coordinate system of one finger

C. Transformation matrices

Putting values of each of the links from the D-H table,

$$A_1 = \begin{bmatrix} cos\theta_1 & -sin\theta_1 & 0 & l_1 cos\theta_1 \\ sin\theta_1 & cos\theta_1 & 0 & l_1 sin\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} cos\theta_2 & -sin\theta_2 & 0 & l_2 cos\theta_2 \\ sin\theta_2 & cos\theta_2 & 0 & l_2 sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} -sin\theta_3 & -cos\theta_3 & 0 & l_3 cos\theta_3 \\ cos\theta_3 & -sin\theta_3 & 0 & l_3 sin\theta_3 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Since, $T_0^3 = A_1 A_2 A_3$. The position vector of the finger is given as:

$$\begin{bmatrix} P_x \\ P_y \\ P_z \\ 1 \end{bmatrix} = \begin{bmatrix} l_3 \cos(\theta_1+\theta_2+\theta_3) + l_2 \cos(\theta_1+\theta_2) + l_1 cos\theta_1 \\ l_3 \sin(\theta_1+\theta_2+\theta_3) + l_2 \sin(\theta_1+\theta_2) + l_1 sin\theta_1 \\ 0 \\ 1 \end{bmatrix}$$

Now, let $\theta_p=(\theta_1+\theta_2+\theta_3)$ ….

And,

P_x=[l_1 $cos\theta_1$+$l_2$cos(θ_1+θ_2)+$l_3$cos(θ_1+θ_2+θ_3)]
P_y=[$l_1$sinθ_1+$l_2$sin(θ_1+θ_2)) + $l_3$sin (θ_1+θ_2+θ_3)]

Let, (P_x- $l_3$cosθ_p) =a_x and (P_y - $l_3$sinθ_p) =a_y
Therefore,

$$\text{Sin}\ (\theta_1 + \theta_\alpha) = (a_x^2 + a_y^2 + l_1^2 - l_2^2) / [2l_1\ (a_x^2 + a_y^2)^{1/2}]$$

Now, let (a_x^2 + a_y^2 + l_1^2 -l_2^2)) / [2l_1 (a_x^2 + a_y^2)$^{1/2}$] = G.

$$\theta_1 = (\text{G}-\theta_\alpha))$$

$$\theta_2 = \{(\text{G}-\theta_\alpha)) - \text{atan2}\ [(a_y - l_1\sin\theta_2)/\ (a_x - l_2\cos\theta_1)]\}$$

Since, θ_p =(θ_1+θ_2+θ_3). Therefore,

$$\theta_3 = \{\theta_p - 2\text{G} + 2\ \theta_\alpha) + \text{atan2}\ [(a_y - l_1\sin\theta_2)/\ (a_x - l_2\cos\theta_1)]\}$$

Table 1 DH Parameters of Finger

S.no.	a_i	d_i	α_i	θ_i^*
1	l_1	0	0	θ_1^*
2	l_2	0	0	θ_2^*
3	l_3	0	0	θ_3^* = (θ_3+90)

From Forward Kinematic, the position and orientation of the gripper is calculated from the above equations and based on these equations, InverseKinematics is evaluated to find out joint values of the finger. From inverse kinematics we get, range of θ_1 , θ_2 and $\theta_3$such as:

θ_1(Min) = 0 degree; θ_1(Max) = 90 degrees
θ_2(Min) = 0 degrees; θ_2 (Max) = 75 degrees
θ_3(Min) = 0 degrees; θ_3 (Max) = 60 degrees

From the above values of θ_1, θ_2 and θ_3, we get values of P_x and P_y as given below:
i) P_x and $P_y$for θ_1 is given as:

Table 2 values of P_x and $P_y$coordinates for varyingθ_1 & θ_3

S. No	θ_1/θ_3	P_x(mm)	P_y(mm)
1	0	115.3600	0
2	0	79.7029	54.9958
3	0	14.9437	44.8856
4	0	-2.2534	-18.3618

ii) P_x and $P_y$for θ_2 is given as:

Table 3 values of P_x and $P_y$coordinated for varying θ_2

S. No	θ_2(degrees)	P_x(mm)	P_y(mm)
1	0	115.36	0
2	20	79.7029	54.9958
3	40	14.9437	44.8856
4	60	-2.2534	-18.3618

D. Finger Design

The fingers are designed so that they are able to hold objects up to 10 kg weight. The coefficient of friction between the object and the finger will be in the range of 0.25-0.3. We have choosen the friction to be 0.3 (Assumed). This is done to underestimate the force required to lift the object. F is the force applied by each finger on the object.

F = Mg =10*9.81 N = 98.1 N

The force required to grip any object, F=µ*W*n*g' [32]. Therefore,

F=0.3*10*9.81*3=88.29N

Grasping

A grasp is commonly defined as a set of contacts on the surface of the object, which purpose is to constrain the potential movements of the object in the event of external disturbances [13]. Grasping process has three main principles under which it works are Grasping Principle, Releasing Principle, Monitoring Principle.

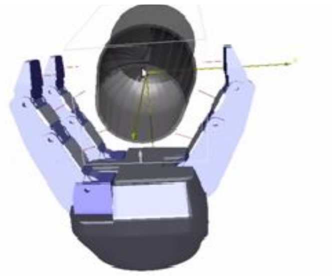


Figure 4 Grasping of a cylindrical Object

The principles of Grasping can be given in the above figure 17 showing the gripper principle for picking an object, grasping it and placing it. The steps involved are: Approaching the object, Coming into contact with the object surface, Increasing the grasping force, Securing the object, Lifting the object, Releasing the object. Monitoring the grasp: direct or indirect control of force, torque, stick slip sensors, contact.The number of contact points defines the grasp capability of a gripper. More the number of contact points on the object, greater will be the grasp stability.

The basic function of a multi finger (in our case three fingers) grippers is to grasp objects and manipulate them with the help of fingers. Each finger of a three finger gripper is considered to be an independent manipulator with its base fixed to the wrist in a particular manner [13] [19].

There are numerous advantages of multi-finger grasping in comparison with parallel jaw gripper, a few are as

1)Higher grip stability due to multi contact point between gripper and object.

2) Can adapt to any shape and sizes of objects.

A. Force closure

Force the closure is defined as a grasp developed with all the possible wrenches at the contact points of the object such that any external forces and torques acting on the object can counterbalance by those wrenches. Therefore, the notion of the Convex-Hull (CH) is introduced. The Convex Hull of set W of wrench vectors is the set of all convex combinations of the subsets of vectors from W. In other words, the CH is the minimal convex set containing W. With system W of wrenches $w_{1,.....}w_n$, the CH (W) is defined as:

$$CH (W) = \{\sum n_{i-1}(a_i^+ w_i^+ + a_i^- w_i^-): w_i^+, w_i^- \in W, \sum n_{i-1}(a_i^+ + a_i^-) = 1, a_i^+, a_i^- \geq 0\}$$

$$O \in \text{interior} (CH (W)$$

B. Gripping force at the finger tip

Consider a free body diagram of the object to be grasped.The weight mg of the object acts in a downward direction, parallel to the surfaces of the finger and thumb. Let R_f and R_t , be the reactions of the finger and thumb respectively on the surface of the object.

$$R_f = R_t$$

Let μ be the coefficient of friction between the gripper surface and the object surface. Then,

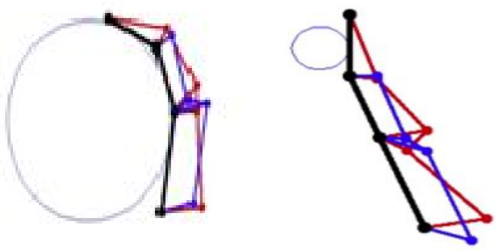
$$\mu . R_f + \mu . R_t = mg.... (1)$$

$$2 \mu . R_f = mg \text{ (since } R_f = R_t \text{)}$$

$$R_f = mg / 2 \mu .... (2)$$

Thus, the grasping force (*P*30 *F*) required on the finger tip of the gripper is

$$P30\ F = mg / 2 \mu ....(3)$$



a)Encompassing Grip b)Finger Tip Grip

Figure 5 Grips

It means the distal phalange should exert this force on the object in the x-z plane. The position of the finger while gripping the object is as shown in fig. 6. Let $Ø_1$, $Ø_2$ and $Ø_3$ be the angles made by links 1, 2 and 3 respectively, with x axis and L_1, L_2 and L_3 be their lengths. Let q_1, q_2 and q_3 be the angle made by the proximal, middle and distal phalanges respectively, with x axis respectively and P_1, P_2 and P_3 are their lengths. 3 $P\ F\ P_2$ stands for the force exerted on distal phalange (P_3) by middle phalange (P_2) and α $P_3\ P_2$ stands in the angle between distal phalange (P_3) and middle phalange (P_2). Subscript B stands for base, N stands for nut and O stand for the object.

Results

The roboanalyzer software is used for simulation of the finger. With this software with the help of DH parameters of the fingers, we can visualize the movement of the gripper and we get simulation results from it. A finger consists of 3 links and 3 revolute jointsBased on the roboanalyzer software visualization and simulation of one finger of the gripper is shown as:

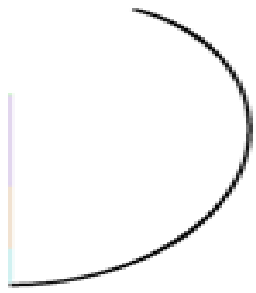
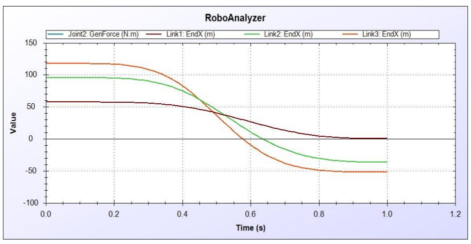


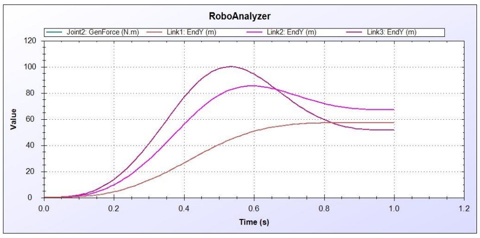
Figure 6 Workspace of the Finger (Roboanalyzer Software)

The curve showing the workspace covered in forward movement of the finger. Likewise, other two fingers to show similar results.We get the following results for the finger for velocity, acceleration, force and torque. A comparative simulation for every link for each parameter is shown below:

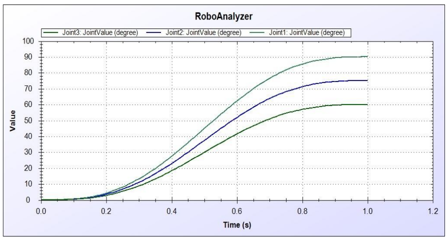
1. Graph Plot shown below for X coordinates of Link1-link2-link3 (Nm) and Time (Sec):



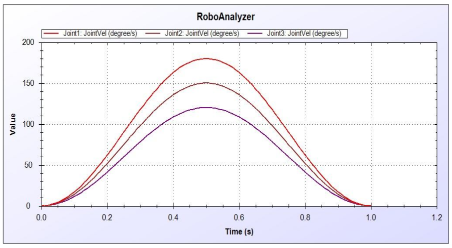
2. Graph Plot shown below for Y coordinates of link1-link2-link3 (N m) and Time (sec):



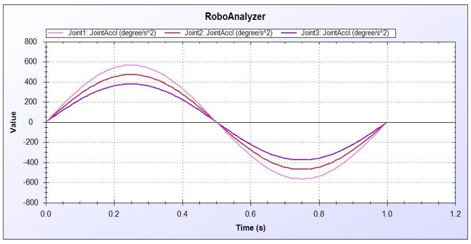
3. Graph shown for Joint value for link1-link2-link3 (degrees) and Time (sec):



4. Graph Plot shown below for Joint velocity for link1-link2-link3 (degrees) and Time (sec):



5. The graph shown Joint Acceleration of link1-link2-link3 (degrees) and Time (sec):



Conclusion

Multi finger grippers are now-a days, very popular because of its efficiency and hand movements same as humans, that is capable to perform many tasks. Based on this 2, and 3, 4 and 5 fingers are being designed and developed to carry out some specific set of tasks.Multi finger gripper is used by the industries for various applications in industries for material handling, etc. The results and simulations are based on the Roboanalyzer software for kinematic analysis designing. The robotic gripper gives surety of 100% efficiency and reliable operations.The gripper is solely an example of automation; it is somewhat human dependent, for the input, we can make it fully automated systems by using sensors and artificial intelligence.

Future Work

There is a wide scope in the future work of three finger grippers. In this multi-finger gripper work, the dynamic analysis can be further carry out to finger more parameters. The multi finger gripper can be manufactured and then tested for various desired performances to be use in several operations. The control of this three finger gripper can be designed to control the working of the gripper in the environment for the desired operation to perform from the user by designing PID controllers. The grasp synthesis algorithm has to be designed based on the requirement of the task to pick, hold and place operation.

Since the work is in the research phase, there is a wide scope of this work to explore and to take this work to an advance level.

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