Design, Fabrication and Control of a Three-Finger Robotic Gripper

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Abstract— *In this article a robotic gripper with the ability of cylindrical object grasping is designed and fabricated. With the increasing use of robotic arms in industry, grasping and holding, as a part of industrial processes, are of great importance. Hence, proper design of grippers plays a key role in efficient performance of robotic arms. The main feature of this design is its reliability and efficiency while maintaining simplicity. This robotic gripper is designed for installing on a mobile robot with the task of holding and moving cylindrical object. One of the aspects of an efficient robotic gripper is its ability to satisfy the "Form-gripping" feature which is utilized for the presented design. Kinematic consideration is examined by Catia. Finally, control methods through Matlab and experimental test results are presented in this paper.*

Keywords-robotic manipulators; manipulation; robotic gripper; grasping closure properties

I. INTRODUCTION

With increasing capabilities of robotic systems, their applications have been promoted from industrial areas with simple and repetitive tasks to more unknown areas with more complicated applications. The usage of robots as nursing robots in hospitals [1], service robots in administrative areas [2], search and rescue robots in unknown areas [3], free flying robots in space [4], subsea robots for inspecting underwater oil transfer lines [5], medical robots for surgery [6], and many other applications are examples of extended applications of robots in vast areas.

Robot sub-systems like grippers and end-effectors [7] that can perform the defined task properly are of great importance. Grasping is one of the things that has been an important subject for many researches in the last three decades and has been studied with several point of views. Subjects like grasp planning [8, 9], grasp quality evaluation [10, 11], grasp in multiple task systems like cooperative robot manipulators [12], robot hands [13], specific features of grasp like stable grasp [14], form-closure grasp [15], and force-closure grasp [16,17] are important subjects in this context.

II. CONCEPTUAL DESIGN AND GRIPPER SPECIFICATIONS

Parallel-jaws grippers have the simplest design among grippers, and different designs of them are used in industrial purposes [18]. In grippers with two fingers, grasping with specific features like Force-Closure, needs great amount of force relative to the grasped object's weight, because the forces that should fulfill the stability status is friction forces. So, for stable grasping and reducing the exerted force while avoiding complexity, a three finger model is developed as it is shown in picture below:

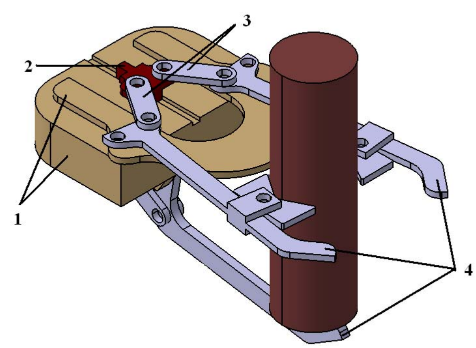

Figure 1. Designed gripper in isometric view: 1-Base. 2-Sliding motor. 3-Motor connecting link. 4-Main links

As it is shown in the above figure, two upper links that are in a same plane are used for primary grasp of the object (force-closure). Then, after detaching the object from its support base, third link is added and with inhibitors that are located in two upper links, the grasped object will be fully restrained(Form-closure).

According to the designed gripper dimensions, it is used for gripping cylindrical objects with a size near to human-hand size.

In below we discuss the primary gripper model in more details:

According to "Fig. 1", part 2 is a linear actuator. Two

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connecting links that are shown by number 3 in the figure are jointed to the actuator. Each distal links (number 4) has two joints that one of them is used for jointing to the base (part 1 in "Fig. 1"), and the other one is used to joint the link to the connecting links. So, as the linear actuator moves, the connecting links rotate around one of the joints until the distal links can easily surround the object. It is clear that backward motion of the linear actuator causes the distal links to close.

In lower links, a mechanism like the one that was described is used. Likewise, a linear actuator is used for the lower part of the gripper. The actuator is attached to the lower distal link 4 by means of two link bars. Also, the distal link is jointed to the base. So, with this mechanism the linear motion of the actuator causes the lower distal link to open and close.

The gripper's physical features are given in the table below:

TABLE I. PHYSICAL FEATURES OF GRIPPER

Feature	Value
Total Volume	6.158×10^{-4} m^3
Mass	0.308 kg
Density	500 kg/m^3
Maximum length	250 mm
Maximum Thickness	150 mm

The Working Space of this gripper is illustrated in figure below:

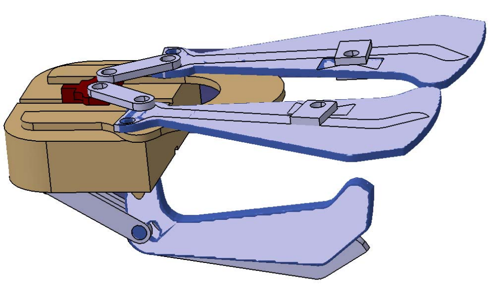


Figure 2. Working Space of the gripper

III. GRASP ABILITY USING FORM-CLOSURE

In order to retain the stability of the grasp during the duty performing, two characteristics are defined for the way to grasp objects: form-closure and force-closure. A grasp is called form-closure if the geometrical motion constraints (acting like a single direction force) restrain all degrees of freedom of the grasped object. Also, a grasp is force-closure if by exerting force in contact points; all degrees of freedom will be restrained [19]. It can be proven that each form-closure grasp is also a force-closure one, but the reverse is not always true [20]. Furthermore, it can be shown that for fully constraining an object in form-closure grasp m+1 contact point is needed where m indicates the dimension of the object configuration space [21].

With this introduction, for evaluating the features of form-closure a proposition is defined.

According to the Bicchi's proposition on *form-gripping* properties: Suppose an object is restrained in the working space with n grasp points. Position vector of each point is defined relative to the center of mass point and is introduced as c_i. Also grasp matrix G is defined as below:

$$G = \begin{bmatrix} I & \dots & I \\ S(c_1) & \dots & S(c_n) \end{bmatrix} \quad (1)$$

In which I is a unit matrix and $S(c_i)$ is the cross-product matrix for c_i [22]. Matrix G is used to form the below equation:

$$\vec{\dot{c}} = G^T \vec{\dot{u}} \quad (2)$$

Where

$$\dot{u} = (v^T, \omega^T)^T \in R^6 \quad (3)$$

$$, \dot{c} = (\dot{c}_1^T, \dots, \dot{c}_n^T)^T \in R^{3n} \quad (4)$$

Also, constraint matrix N is defined as below:

$$N = diag(n_1, \dots, n_n)$$

In which n_i is a unit vector in the direction where object motion is constrained and is exerted into the surface at c_i.

In this way:

A necessary and enough condition for a grasp to be form-closure is that the constraint matrix GN should be full row rank [21].

In the continuance, it will be illustrated that the designed gripper for grasping cylindrical objects, satisfies the form-closure proposition.

Considering the designed gripper configuration and the way it grasps a cylindrical object, grasp points and direction of the motion constraints are demonstrated in "Fig. 3". Constraints with white triangle indicate the virtual constraints of the directions that are not needed to be restrained in reality; however they are used so that the form-closure proposition can be applied for the gripper. In reality the cylindrical object can move along z direction and can rotate around z direction and remains stable provided that the motion of the object in the z direction is restrained with the lower constraint (constraint 1) during the whole task performing. The coordinates of the contact points and the direction of constraints are depicted in table.1

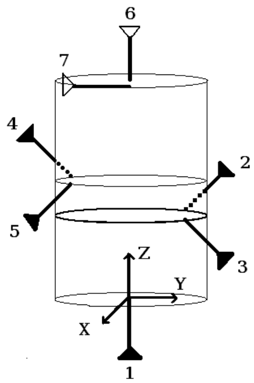


Figure 3. Motion constraints in grasped cylinder

TABLE II. GRASP POINTS AND MOTION CONSTRAINT DIRECTION

No.	Grasp Point Position Vector	Motion Constraint Direction
1	$[0,0,0]^T$	[0,0,1]
2	$[-10,17.3,50]^T$	[0.5,-0.86,0]
3	$[10,17.3,50]^T$	[-0.5,-0.86,0]
4	$[-10.3,-17.3,55]^T$	[0.5,0.86,0]
5	$[10,-17.3,55]^T$	[-0.5,0.86,0]
6	$[0,0,100]^T$	[0,0,-1]
7	$[20,0,100]^T$	[0,1,0]

Accordingly, the constraint matrix GN for the presented model is as follows:

$$GN = \left[\begin{array}{c|c|c|c|c|c|c} 0 & 0.5 & -0.5 & 0.5 & -0.5 & 0 & 0 \\ 0 & -0.86 & -0.86 & 0.086 & 0.86 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & -1 & 0 \\ \hline 0 & 43.3 & 43.3 & -4.763 & -47.63 & 0 & -100 \\ 0 & 25 & -25 & 27.5 & -27.5 & 0 & 0 \\ 0 & 0.01 & -0.01 & 7.784 & 0.01 & 0 & 20 \end{array}\right] \quad (5)$$

With these set of constraints the grasp matrix GN is full row rank and its rank is 6. So, according to the proposition, the grasp is form-closure and stability of the grasp is ensured.

IV. CONTROL

In this part of the paper, at first, the system response without using a controller is studied. Then, by trying out different feedback controllers, an appropriate controller for creating desired response is chosen.

Km and Rf and the values in the plant in "Fig. 4" are motor structural properties.

The open of the gripping system is simulated with Matlab-Simulink ("Fig. 4") and the step response of the system is illustrated in "Fig. 5":

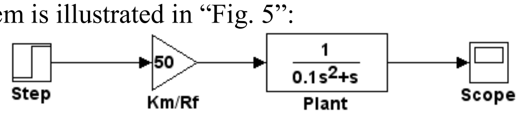


Figure 4. Open loop system without using controller

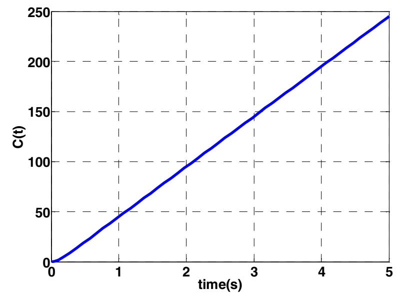


Figure 5. Step response of the open-loop system without using controller

As it is obvious from "Fig. 5" open loop step system response is not stable.

Using a PD-action controller with parameters $K = 0.08$ and $T_d = 0.1$, the system response is as follows:

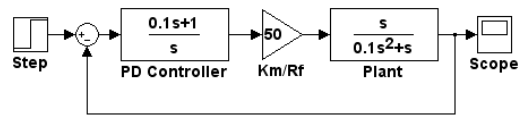


Figure 6. Closed loop system with PD-action controller

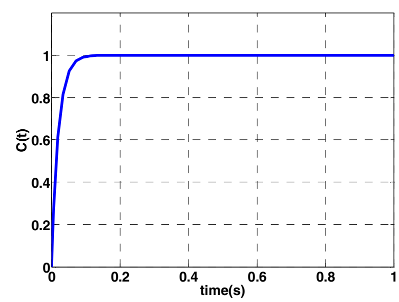


Figure 7. Step response of the closed-loop system with PD-action controller

According to "Fig. 7", it is obvious that the system response to the unit step input by using a PD-action controller is stable. It can be understood that by using PD-action controller, the system reaches to the stable state in a short period, and the overshoot of the response with PD-action controller is 0% which is desired for the position control of the gripper links.

V. EXPERIMENT

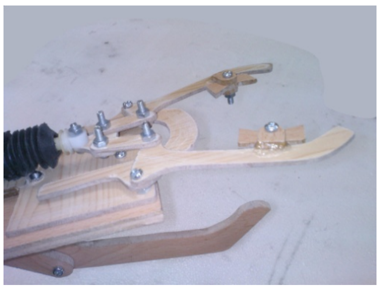
The first wooden prototype of the gripper is build to verify the results obtained in the simulation. In this model two linear actuators are used. By exerting different voltages, the output force of the end-effectors can be controlled. The maximums voltage that these actuators perform properly in is 12V.

The fabricated gripper under experiment is demonstrated in "Fig. 14". In this experiment the cylindrical object has the following properties:

Mass=1kg, Height=10cm, Diameter=7cm

This Gripper can easily perform the desired task and grasp the object according to form-closure proposition. Also, the object is stable during the displacement.

This gripper is designed to be used on a mobile robot, and since the position control of the links is by using a camera, it is necessary to use some data compression methods [23] in order to decrease the size of the transferred data from mobile robot to the base controller.



1

2

3

Figure 8. An experiment conducted in the primary model of the gripper carrying a short cylindrical object

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