Determination of Loss Factor and Contact Forces in Underactuated Gripper

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Abstract - **In this paper, an approach is proposed to calculate the un-predictable losses of grasping force that occur at the fingers of an under actuated robotic arm. The optimum grasping force which is needed to firmly grasp an object is calculated using "Genetic Optimization Algorithm" in MATLAB software. The actual force which is applied on the grasping fingers is measured with the help of strain gauge sensors and LABVIEW software. The difference in these two force values gives the "Loss-Factor". This paper also presents the trend in which the grasping force changes with the varying diameter of the object that is grasped. The results give the mathematical relation between a) Object size and the Loss-Factor, b) Object size and the Grasping Force.**

Keywords - Robotic gripper, grasping force, Optimization, Genetic Algorithm, mathematical model

I. INTRODUCTION

An increasing research interest in the field of robot end effectors particularly grippers are growing tremendously and are beyond the boundary of applications [1]. Grippers are required easy to control and to obtain large grasping forces as output. Grippers are designed in such a way that adapt itself on the grasped object whatever its shape [2, 3]. The better shape adaptation is required more number of contact points between the gripper and the object. Increasing the number of contact points provides a better repartition of contact forces, which ensures a better stability of grasp and prevents from deterioration of the grasped object. However, their grasping dexterity and compliance are limited. Lionel Birglen et al [4] designed and analysed geometric design of underactuated grippers. Under actuation is the concept of manipulating a robotic system with lesser number of actuators than the Degree of Freedom (DOF) of the system. A fully actuated robot has an equal number of actuators to its number of DOF. It denotes number of independent coordinates or parameters that are required to represent the position and orientation of an object in space. Nicolas Rojas et al [5] analysed planner mechanisms. Most of the researchers designed and analysed link mechanisms of underactuated grippers [6-9]. This type of systems are used when the robotic arm needs to traverse a complex trajectory and in the situations which demands more number of actuators. The increase in complexity increases the number of sub-systems needed to achieve the trajectory. V. Begoc et al [10] developed pneumatically driven underactuated grippers. The robotic gripper arm that is analyzed in this work has 3 degrees of freedom and is actuated by a single hydraulic actuator.

Dynamics of robotic gripper is important to control it [11-14]. There are several types of under-actuation mechanism, like tendon actuated mechanism, linkage mechanism, differential mechanism and hybrid mechanism. Ha XV et al [15] calculated contact forces to apply grasping force [16]. The optimum grasping force which is needed to firmly grasp an object is calculated using different intelligent algorithms for optimization [17, 18]. The forces that are to be taken into account are the actuating force at the input, grasping force at the grasping end and the reaction force exerted by the object gripped. The number of linkages varies with the DOF of the under-actuated system. Moreover, it saves some power by using lower number of actuators. In this work, a gripper with two four bar linkages corresponding to three DOF is used.

II. ROBOTIC GRIPPER DESCRIPTION

An under actuation mechanism is defined as a system whose number of control inputs is lesser than their DOFs. The concept of under actuation is applied to mechanical fingers leads to self adaptability. Self adaptive fingers will envelope the objects to be grasped automatically and adapt to their shape without complex control strategies. When the object is fully grasped, the force applied at the actuator is distributed among the phalanges.

The under actuated mechanism allows the grasping of objects in a more natural and more similar to the movement obtained by human hand. The geometric configuration of the finger is automatically determined by external constraints related with the shape of the object and coordinated activities. The whole grasping sequence can be obtained with a continuous motion by a single actuator as shown in Fig.1.

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Fig.1 Under actuated arm designed using CREO

III. DESIGN OF UNDERACTUATED FINGER MECHANISM

The design of the finger mechanism proposed here uses the concept of under actuation applied to mechanical hands. These actuators do not require an active coordination of the phalanges through simple stable grasping sequences.

Table 1 Dimensions of various links of the under actuated arm

S.No	Link	Dimension in cm
1	A	11
2	B	10
3	C	5
4	D	15.5
5	E	14
6	F	15
7	G	16
8	H	14
9	I	10

Fig.2 shows the dimensions, arrangements and position of the links of the grippers. Three phalanx under actuated finger is composed by three links which corresponds to the proximal, median and distal phalanges. In the kinematic scheme, two for-bar linkages are connected in series through the rigid body for transmitting the motion to the median and distal phalanges, respectively, where the rigid body represents the distal phalange. Hydraulic actuator is used to drive the first four bar linkage to move which stands for the transmission mechanism then moves the second four bar linkage and finally the distal phalanx which represent the output link of the second four bar linkage.

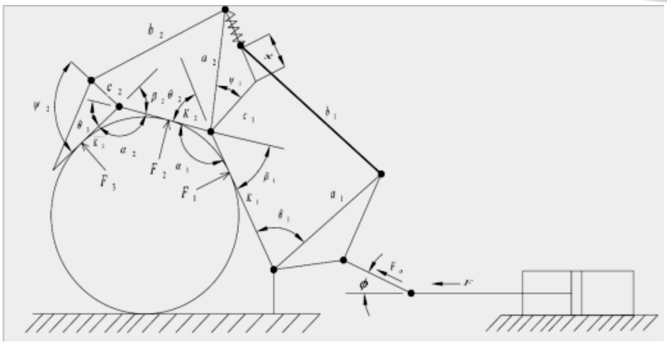

Fig.2 Three DOF shape adaptation finger mechanism in an average configuration

The three phalanges of grippers are formed as shown in Fig.2. The position and orientation of the links with respect to the reference frame are given by a free body diagram. The lengths of the links and positions are tabulated in the table 1.

Grasping forces that are calculated using the following equations,

$$F_1 = \left(\frac{x_1 - 5.9171}{16.25\, x_1 x_2}\right)$$

$$F_2 = \left(\frac{6.8325}{16.25\, x_2}\right)$$

$$F_3 = \left(\frac{x_2 - 5.9171}{15.09\, x_2 x_3}\right)$$

$$F_{Total} = F_1 + F_2 + F_3$$

IV. OPTIMIZATION USING MATLAB

Recent advances in robotics and machine intelligence have led to the application of modern optimization method such as genetic algorithm to solve the path planning problem and motion control. The genetic algorithm is applied to generate the trajectory and choosing the control parameters for the desired behaviour. The generation of optimal contact positions is essential for the efficient operation of a gripper. In the optimization, the control parameters contact positions and contact forces are evaluated. The most difficult problem in motion control is to find such parameters which could match up fast and precise grasping. A suitable fitness function can be expressed with constraint function. The contact force expression is derived from a static analysis. Here our aim is to maximize the number of contacts between the fingers and the object and total contact force for the grasping process. A contact force at each phalanx is assumed to be a pure force normal to the phalanx. In the analysis of the contact forces of the gripper, we have the gripper contact force as the dependent variable and that dependent variable is the one to be maximized. Here the total contact force is maximized in order to obtain the maximum grip force while gripping the object.

Then, these variables are input into the GA to find optimum contact force for the contact points. The objective of the gripper design is to minimize the actuation force and maximize the grasping force. Fitness function is the objective function that is to be maximized. The equation that was obtained from the calculations for the contact forces of the gripper is to be described as the Fitness function as shown in Fig.3. The fitness function is defined in MATLAB as follows,

```
function y = myfitness19(x)
y = (118.20 * x(1) * x(3) + 16.25 * x(1) * x (2) - 89.29 * x(3)
- 96.15 * x(1)) / 245.213 * x(1) * x(2) * x(3);
end
```


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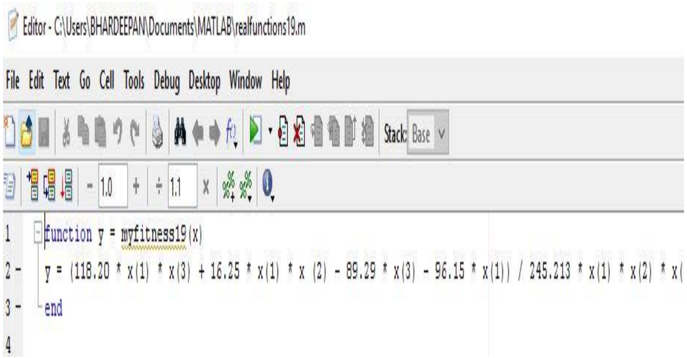

Fig.3 Objective function used in GA

Constraint function is the function that gives the boundary for the control variables that drives the Fitness function. The constraint function was calculated for the contact forces considering the limits of the contact arm lengths as shown in Fig.4. The constraint function is defined in MATLAB as follows,

function [c,c_eq] = realconstraints19(x)
c = [8.3656 - x(2)-x(3)* x(1)+ 28.56];
c_eq = [];
end

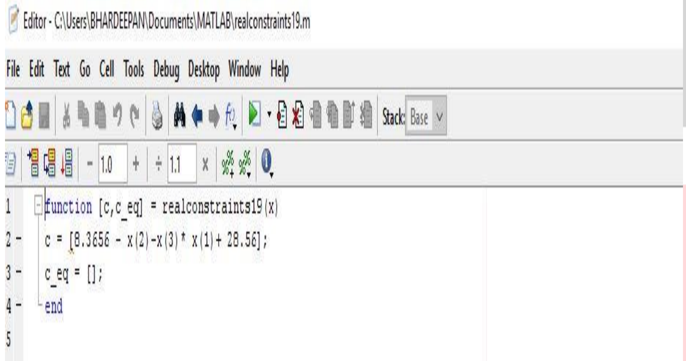

Fig.4 Constraint function used in GA

The GA used in the analysis is given below,
ObjFcn = @realfunctions19;
nvars = 3;
LB = [0 0 0];
UB = [11 10 15.5];
ConsFcn = @realconstraints19;
[x,fval]=
ga(ObjFcn,nvars,[],[],[],[],LB,UB,ConsFcn);

- ObjFcn = @realfunctions19; calls the predefined function that is to be maximized from the working directory.
- nvars = 3; defines the number of variables that control the objective function, here 'three'.
- LB= [0 0 0]; gives the lower limit of the control variables.
- UB = [11 10 15.5]; gives the upper limit of the control variables
- ConsFcn = @realconstraints19; calls the predefined function that is to be maximized from the working directory.
- [x,fval]=ga(ObjFcn,nvars,[],[],[],[],LB,UB,ConsFcn); gives the local maximum x of the objective function to give the maximized value of the function as shown in Fig.5.

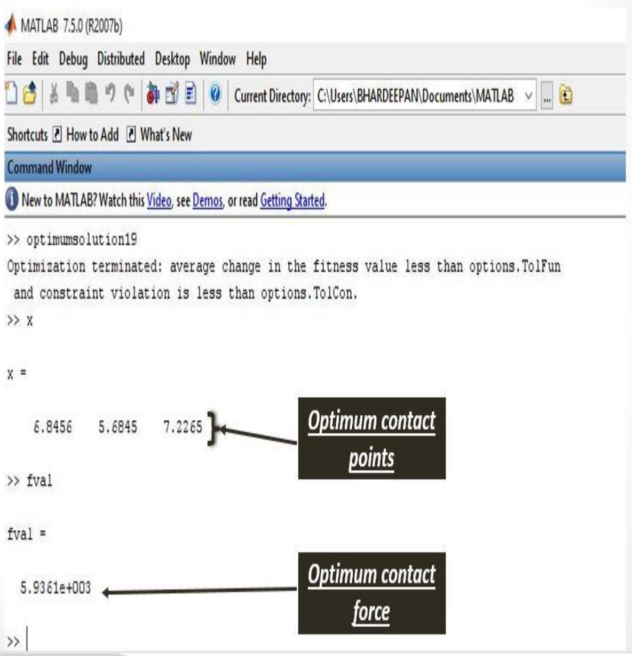

Fig.5 Result obtained while executing the GA for Diameter 19 cm object

The optimal force is maximized by the number of contacts between the fingers and the object and total contact force for the grasping process. Thus, the fitness function is responsible in finding optimal results.

V. EXPERIMENTAL SETUP

In this experiment, the contact is made on the gripper and the contact forces are measured in order to test the optimum force of the gripper, a wide range of contact position were selected and found the exact position. It is very important and necessary to measure these contact forces in every phalange. The contact sensors are pasted into the phalanges plane to measure the contact force as shown in Fig.6. The sensors are interfaced with Labview software for measuring contact force. Hydraulic actuator is used to drive the fingers and to make contact to acquire grasping force.

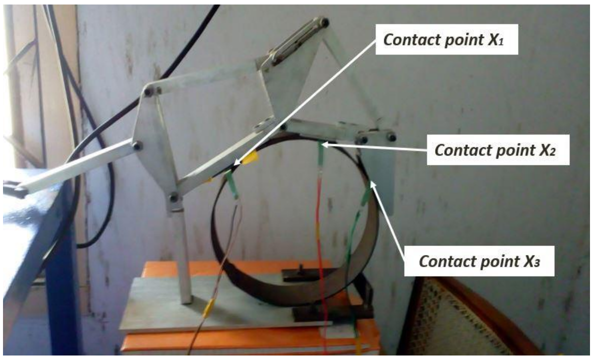

Fig.6 Experimental setup

Labview is a graphical programming language that allows instrument control, data acquisition and pre/post processing of acquired data. It relies on graphical symbols rather than

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textual language to describe programming actions. The principle of dataflow, in which functions execute only after receiving the necessary data, governs execution in a straight forward manner. First labview program is written for acquisition of data and the contact forces are analysed as shown in Fig.7.

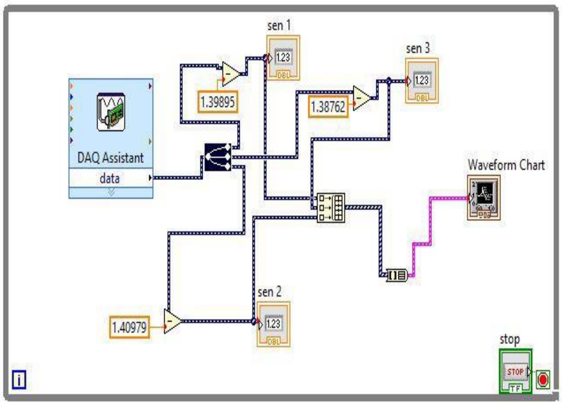

Fig.7 LabVIEW program used to measure contact forces

Double acting cylinder is actuated in forward direction to make the gripper to grasp the object. The sensors are fixed at the optimum contact positions in the three fingers of the under actuated grippers. The sensors are interfaced with the DAQ acquisition card. The object is gripped and the sensor readings are obtained in the Labview as shown in Fig.8. The data is exported from Labview to Excel. The voltage is converted into force using the equation,

$$y = -16.89ln(x) + 137.12$$

VI. RESULTS AND DISCUSSION

On executing GA for the three different diameters of 19 cm, 21 cm and 23 cm gave the following values of optimum contact points and maximized contact forces and are tabulated in the Table 2 and Table 3.

Table 2 Relating diameters with optimum contact points

Diameter in cm	X(1) cm	X(2) cm	X(3) cm
19	6.8456	5.6845	7.2265
21	5.8756	5.3872	7.8645
23	5.502	4.9532	6.1346

Table 3 Relating diameters with optimum contact forces

Diameter in cm	Contact Forces in N
19	593.61
21	465.78
23	527.88

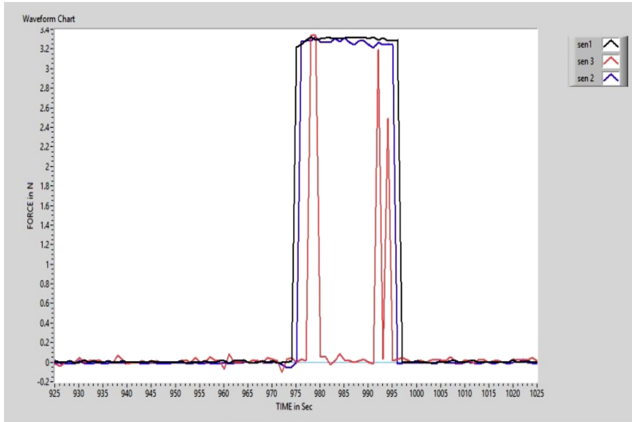

Fig.8 Reading obtained for diameter = 23 cm

Table 4 Comparison of results

S.No	Diameter, cm	Actual Force, N	Optimum Force, N	Loss Factor, N
1	19	652.62	593.61	59.01
3	21	639.76	465.78	173.98
5	23	641.26	527.8	113.46

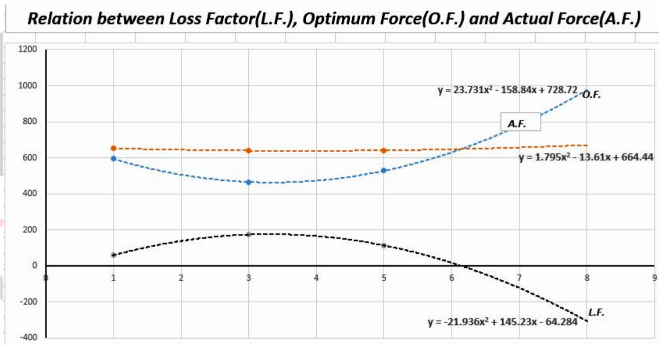

Fig.9 Relation between Loss Factor(L.F.), Optimum Force(O.F.) and Actual Force(A.F.)

From results, Optimum force varies with the diameter following the relation,

$$y = 23.731x^2 - 158.84x + 728.72$$

Actual Grasping force varies with the diameter following the relation,

$$y = 1.795x^2 - 13.61x + 664.44$$

The comparison gives us the final relation between the Loss Factor and the Grasping force as,

$$y = -21.936x^2 + 145.23x - 64.284$$

VII. CONCLUSION

A new relation to calculate the unpredictable losses that occur in the grasping force of under actuated robotic arms is obtained in this work. Also, this paper gives the trend in which the grasping force changes with the varying diameter of the object that is grasped. The optimum force needed to firmly grasp an object is calculated using Genetic Algorithm. Further it provides the relation of Loss Factor with the grasped object dimensions. Thus, the proposed objectives were achieved successfully.

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