Design And Fabrication Of A Gripper For Grasping Irregular Objects

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ABSTRACT

This paper deals with design and fabrication of a multi-fingered gripper. The research is motivated by the requirement for grasping of objects of arbitrary shape and size. The key issues consider here are: the gripper should be able to grasp the object of any shape, size and weight (with a maximum limit); stability of the object held during manipulations; should not dependent of frictional forces between gripper and object; synchronization in fingers motion; and employment of minimum number of actuators to manipulate the gripper. Kinematic and dynamic analysis of gripper is made to support this novel design. The gripper is successfully designed, fabricated and tested and hence can find many applications, e.g., as a robot end-effector, prosthetic hands etc.

INTRODUCTION

Several mechanical grippers and articulated hands have been made over the past years, a few examples are the MIT hand [1, 2], the UPenn hand [3, 4] the GRASAPAR hand [5]. The description of many other can be found in [6,7]Which falls mainly in two categories i.e., industrial and anthropomorphic designs. The design of industrial manipulators is governed by a specific manufacturing task to be executed. Anthropomorphic manipulators are characterized by their similarity to a human hand, both in appearance and potential functionality.

A lot of discussion is going on to finalize the number of fingers in a gripper. Harmon [8, 9] suggests that only three fingers are required to reproduce the most frequent and common human grasps. Brown [10] and Hazelton et al. [11] found that the middle, ring, and little finger provide the strength needed for a firm grip. Although not heavily loaded themselves, the thumb and index finger serve as a retainers to make the grip more precise. Choa [12] suggested that in fingertip pretensions, stability is usually achieved with the index finger and thumb. The literature suggests that the thumb, index, and middle finger will provide sufficient dexterity during manipulation. The thumb and index finger will ensure a precise and stable grip, while the middle finger will provide the necessary strength.

Most studies of gripper design have proceeded under the assumption that the frictional force will be large enough to keep the object from sliding in the fingers [], however in practice it is very difficult to ensure that the frictional forces between the finger tips and the object are sufficiently high to hold the object.

Most of the grippers used now days are simply two-fingered gripper. However a two fingered configuration would not ensure a safe grasp as sideway slip can easily occur if any irregularities are present on the object's surface [13] or the object is hold in the way that the centre of gravity does not become collinear with the forces applied by the gripper's fingers. Other grippers, which have more than two fingers use motors on each joint of the finger, which decreases the load holding capacity of the gripper due to self-weight of the motors. Moreover they have some gear arrangements to provide interlocking at the joints which not only decreases the load holding capacity but also increases the probability of mechanical failure at any joint. Some grippers use wire and belt arrangement (where the full load is directly applied to the wires and pulleys) which make them less reliable in comparison to gear arrangements due to chances of slipping. In case of wire and pulley, precision motion is not possible.

Considering the above literature, in this work a novel gripper is designed, fabricated and tested to hold irregular objects of different shape, size and weight. The conceptual and actual design, kinematic and dynamic analysis, fabrication and testing are described in the following sections.

CONCEPTUAL DESIGN OF THE GRIPPER

- It should be able to grasp irregular objects of different shape and size.
- It should be able to take different loads (of course with upper limit)
- There should be stability during manipulations.
- It should be independent of friction coefficient between object and gripper.
- Synchronization in finger motion.
- Employment of minimum number of actuators.
- It should not slip, so there should be provision of interlocking.
- It should simulate the human hand.
- It should be precisely control (through computer or manually).
- It should be of lightweight.
- It should be easily fabricated with readily available resources.
- It should be of low cost.

DESIGN OF THE GRIPPER

It is well known that minimum three points are required to hold any object. In this work, a three-fingered gripper each with two limbs have been designed and fabricated to hold irregular objects as this can be used for both force and form closure purpose. In comparison to gripper with single limb (Figure 1 a) where it may fail if the friction force is not sufficient, here the presence of the second limb (Figure 1 b) will augment the friction force and will help in firmly gripping the object.

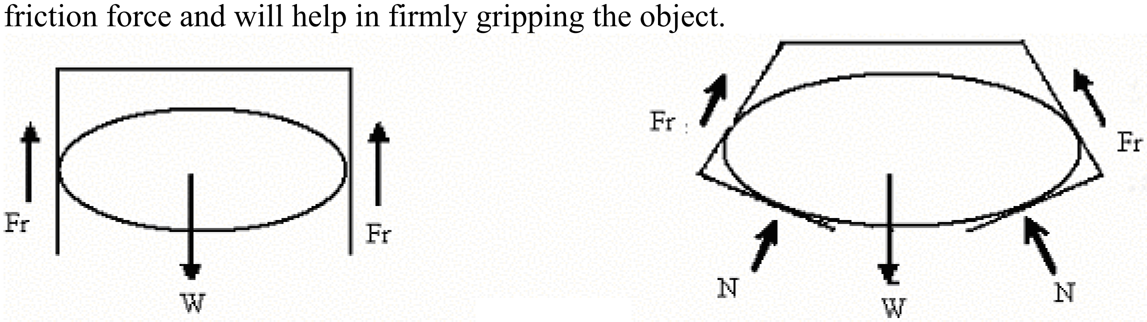


Figure 1 (a) Fingers with single limb (b) Fingers with two limbs; F_r : frictional force, N: normal reaction force, W: weight of object

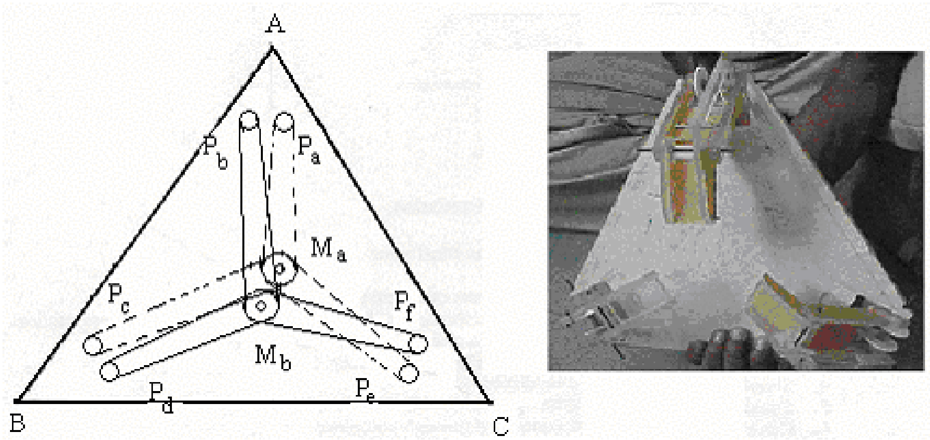


Figure 2: (a) Back side of the horizontal base with pulley and belt arrangement.
(b) Front side of the horizontal base with three fingers.

The gripper consists of a base, three fingers with two limbs each and two motors placed centrally. In order to control the two limbs of each finger, two independent actuators are required. Hence, in this case with three fingers one may require six actuators. Synchronizing the motion of three fingers, only two motors have been used to grasp the object. This design can be modified with six motors for independent motion of three fingers. Here belt drive is used to connect the motors with the pulleys of the fingers (Figure 2). This arrangement is made on the top of the horizontal base, by employing six pulleys (two for each finger) Pa, Pc, Pe connected to center motor Ma with three belts and Pb, Pd, Pf connected to the center motor Mb with three different belts. Each pulley in turn rotates six different worm gears of three fingers (two in each finger).

DESCRIPTION OF THE FINGER

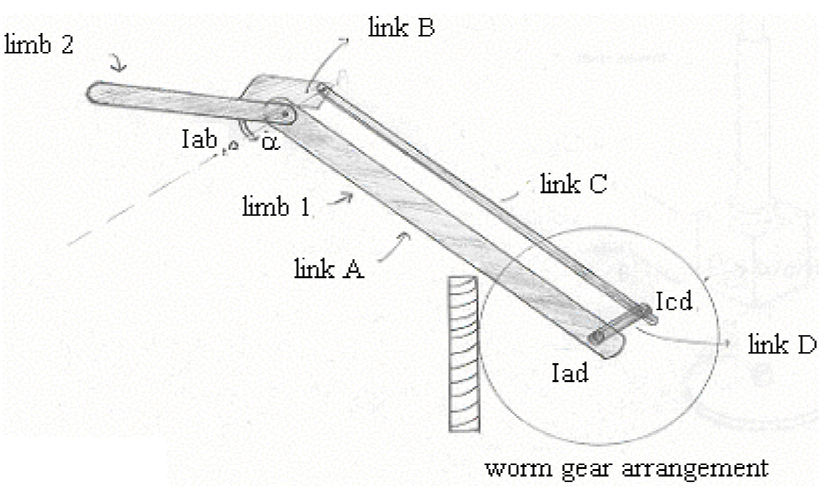


Figure 3: A typical finger with two limbs

Each finger is a simple parallelogram four bar mechanism with link A as the first limb and the extension of the link B as the second limb. At a particular position of link A if link D is rotated about I_{ad} (the instantaneous center of rotation between link A and link D) as an input then rotation of link B about I_{ab} (the instantaneous center of rotation between link A and link B) is obtained as an output of the four bar mechanism. At any instant the angular velocity ω_b of the link B will be same as the angular velocity ω_d of the link D, since links A, B, C and D constitute a parallelogram. Second limb being an extension of link B will have same angular velocity ω_b of link B

$$\omega_{(limb\ 2)} = \omega_b = \omega_d \qquad \text{for all time (t).}$$

Now at any instant $\theta_{ab} = \theta_{ad}$

θ_{ab} is the angle between link A and link B. θ_{ad} is the angle between link A and link D.

So at any instant the angle between the second limb and the horizontal $\psi_{(limb\ 2)}$ can be known by simply subtracting α from the angle that link D makes with the horizontal, i.e., ψ_d.

$$\psi_{(limb\ 2)} = \psi_d - \alpha$$

If the angle between Link D and the horizontal is fixed say θ then the angle of link B with the horizontal is simply θ and it do not depend on the orientation of link A (figure4)

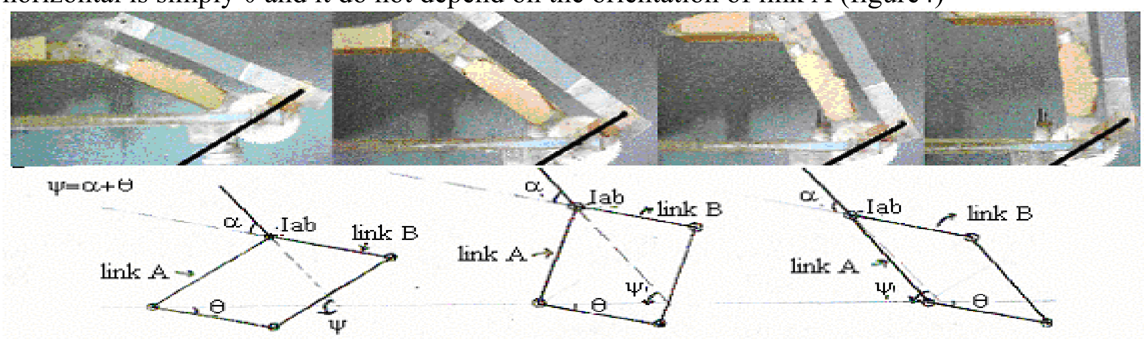


Figure 4: Different orientations of link A when the inclination of link D (θ) is fixed and therefore the inclination of the second limb (ψ) is fixed

To drive first limb (link A) and the second limb (link B) of the finger, a pair of worm gears have been used. The first worm gear is directly attached to link A (Worm gear wheel being an integrated part of link A), and the second is attached to link D (Worm gear wheel being an integrated part of link D). Link D in turn operates the second limb i.e. link B of four bar mechanism. For such an arrangement in this design, two independent actuators have been used to control the two links of the four bars. In order to give mobility to a four bar mechanism one actuator is sufficient, but in this case one has to change the orientation of the four bar mechanism, therefore additional actuator is required for each finger. With this actuator user can change the orientation of the first limb i.e. link A.

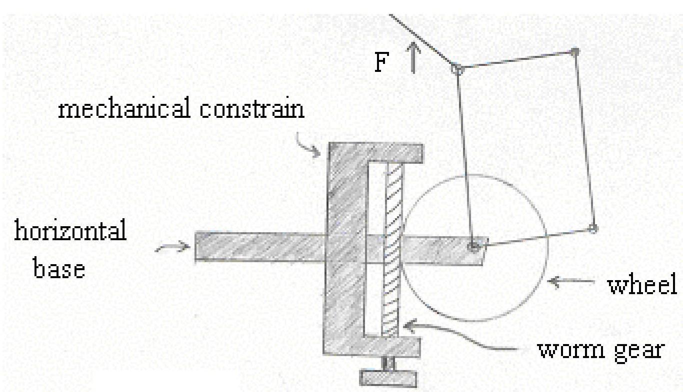


Figure 5: Interlocking of finger limbs with the horizontal base due to worm gears

In this design worm gears have been used to provide interlocking of the limbs with the horizontal base. Once the driving motors have been stopped at a particular position of the limbs, the limbs will not move by the forces applied on it by the load. The mechanical constrain will provide necessary force to the warm gear to lock the system (Figure 5).

As mentioned earlier each finger is made of rigid links and worm gears. When the gripper will hold the load, all the forces will be transferred to the horizontal base through these rigid links and worm gears. It is assumed that the material chosen for the links and the gear have sufficient strength and there is no breakage of the link and the gears. Possibility of failure is only if there is slipping of worm gear and the wheel. This is possible if the transmitted force between the gears exceeds the critical value (beyond which the gear teeth get damage). Therefore the maximum load that the gripper can take will depend on this critical value.

CALCULATION FOR THE MAXIMUM LOAD

As the maximum load that the gripper can take will depend on the critical transmitting force, this critical value should be determined. The maximum vertical force (*F-max*) that finger can sustain (which depend on critical force F_c) is determined below.

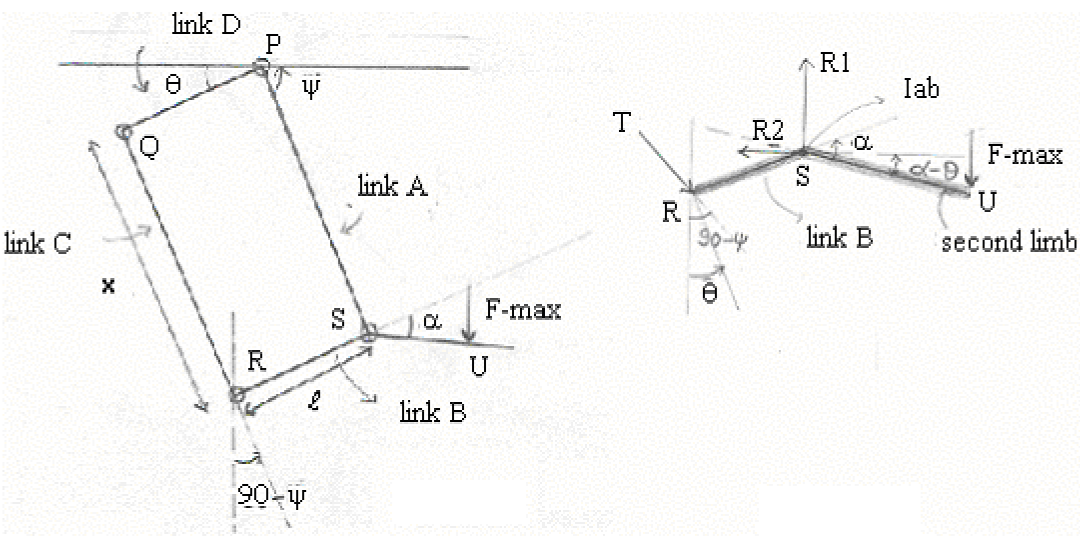


Figure 6 (a) External Force acting on the finger (b) Free body diagram of Limb 2

Figure 6(a) and Figure 6(b) shows: *(F-max)* – Maximum vertical force

L	– Length of second limb S-U
l	– Length of Link B = Length of Link D
X	– Length of Link A = Length of Link C
T	– Tension in Link C
R_1	– Vertical reaction at I_{ab} of second limb by Link A
R_2	– Horizontal reaction at I_{ab} of second limb by Link A

From the free body diagram (Figure 7) moment about I_{ab} must be zero.

$$(F\text{-}max)\ L \cos(\alpha - \theta) = T\ l \cos(90 - \psi - \theta)$$
$$T = \quad (F\text{-}max)\ L \cos(\alpha - \theta) / [l \sin(\psi + \theta)]$$

Equating forces in vertical direction

$$R_1 = (F\text{-}max) + T \cos(90 - \psi)$$
$$R_1 = (F\text{-}max)\ [1 + (L / l)(\cos(\alpha - \theta) \sin \psi) / \sin(\psi + \theta)]$$

Equating forces in horizontal direction

$$R_2 = T \sin(90 - \psi) = \quad (F\text{-}max)\ [(L / l)(\cos(\alpha - \theta) \cos \psi) / \sin(\psi + \theta)]$$

Now there are two worm gears in each finger one attached to link A and the other attached to link D. R_1 and R_2 will get transferred to the base through link A and the corresponding worm gear. Tension in link C will get transferred to the base through link D and the corresponding worm gear.

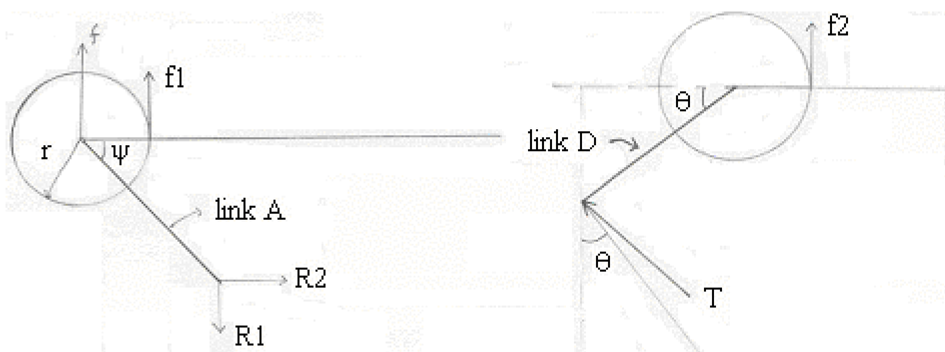


Figure 7 (a) link A and the first worm gear (b) link D and the second worm gear.

From figure 7(a)

$$(f_1)\ r + X R_2 \sin \psi = X R_1 \cos \psi$$
$$(f_1) = (X / r)(F\text{-}max) \cos \psi$$

From figure 7(b)

$$(f_2)\ r = l\ T \sin(\psi + \theta)$$
$$(f_2) = (l / r)(F\text{-}max)(L / l)\ [\cos(\alpha - \theta) / \sin(\psi + \theta)] \sin(\psi + \theta)$$
$$(f_2) = (L / r)(F\text{-}max) \cos(\alpha - \theta)$$

So $(f_1\text{-}max) = (X / r)\ F\text{-}max$ at $\psi = 0$

And $(f_2\text{-}max) = (L / r)\ F\text{-}max$ at $\theta = \alpha$

Here $L < X$, therefore $f_2\text{-}max < f_1\text{-}max$. So the gear attached to limb 1 will fail first. Now if the maximum possible breaking force between worm gear and wheel is F_c then

$$F_c = f_1\text{-}max = (X / r)\ F\text{-}max$$
$$F\text{-}max = F_c\ (r / X)$$

So we conclude that the force that load applies on the finger should be less then *F-max*. In the above derivation it has been found out that at *F-max* failure will occur if $\theta = \alpha$ and $\varphi = 0$ at this position finger is completely horizontal, and force acting on it is perpendicular to the finger. Therefore at any value of θ , φ if *F-max* is acting perpendicular to the finger the gear will slip.

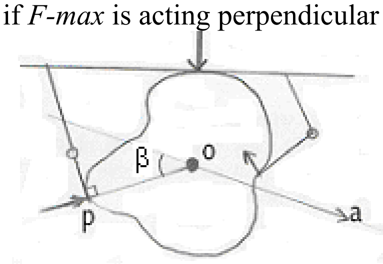


Figure 8: Gripper under accelerated manipulation

For any arbitrary position of three fingers with any load, say the gripper is manipulating with an acceleration (a), and the direction of a is at angel β with the line (op) (Figure 8) dropped perpendicular from center of mass to one of the finger.

$$F\ (normal) = M\ a\ (\cos\beta)$$

F (normal) will be maximum at $\beta = 0$ and will be (M a). Maximum value of F(normal) should be less then F-max (calculated in previous derivation).

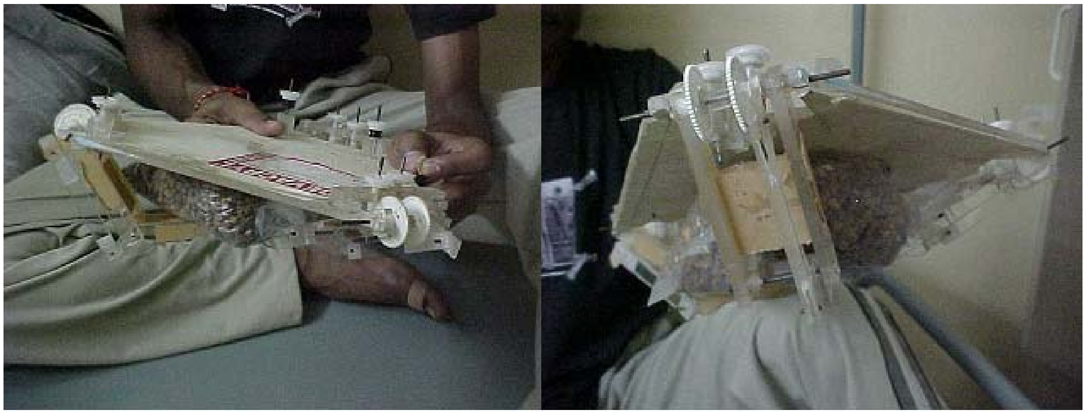
$$F\ (normal) = M\ a \quad < \quad F\text{-}max = Fc\ (r / X)$$
$$M < (Fc\ r)/(X\ a)$$

CONCLUSIONS

A new dexterous robotic gripper has been designed, fabricated and tested successfully. Through the use of three fingers with two limbs in each finger, the gripper is able to grasp objects of various shapes, sizes and weights. The use of a two remotely located actuator reduces the inertia of the manipulator. , size, complexity and cost of the gripper while increasing the holding capacity. This gripper can be used in hostile environment such as nuclear power plant, chemical industries, laboratories, hospitals etc. Even the idea can be used for a humanoid robot.

FABRICATION AND TESTING

The gripper has been fabricated in the institute's workshop with the following specifications.
Material use: Acrylic sheet,
Limb 1(link A) = 9 cm, Link B = 2.5 cm, Limb 2 =6cm, Link C=9 cm, Link D=2.5, Gear Wheel Radius =1.4 cm, Worm Gear diameter =0.8 cm, Finger Width 4.5 cm, length of the equilateral base=25 cm .The testing has been done successfully with a load of 0.5 kg.



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