Development of a Three-DOF Underactuated Finger

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Abstract

Existing underactuated fingers have only two dofs. Better performance can be obtained if three-dof underactuated fingers are used. Therefore, a new three-dof mechanism is developed. The finger is designed using the criteria presented in [1] for two-dof fingers and a new design methodology. The performance is also improved by the addition of a parallel precision grasp mechanism.

1. Introduction

The design of versatile but simple to control hands which are capable of grasping a wide variety of objects with large forces is of great interest for several industrial applications. To this end, the principle of underactuation is used in order to mimic the grasping behavior of complex articulated hands while reducing the number of actuators and the complexity of the control. When applied to mechanical fingers, the concept of underactuation leads to *shape adaptation*, i.e., underactuated fingers will envelope the objects to be grasped and adapt to their shape although each of the fingers is controlled by a reduced number of actuators.

The existing underactuated fingers based on linkages have two phalanges or three coupled phalanges with two degrees of freedom. However, it is desirable to design an underactuated finger with three phalanges and three degrees of freedom since this would lead to more stable, more flexible and more uniform grasps. Therefore, this paper presents the design of a three-dof underactuated finger.

2. Shape adaptation mechanism

In order to obtain a three-dof finger with three phalanges, a four-bar mechanism is added to the five-bar mechanism of a two-dof finger. The resulting mechanism is illustrated in Figure 1. It is important to notice that the behaviour of the finger is determined by the design parameters since the different degrees of freedom cannot be controlled independently. Hence, the choice of the design parameters is a crucial issue. The finger is designed using the criteria presented in [1] for two-dof fingers and a new design methodology.

The different parameters involved in the design, illustrated in Figure 1, are now discussed. The length of phalanges, i.e., l, k, j are fixed from comparison with other existing fingers and experimentation with a finger model on objects to be grasped. The studied variables are a_i, b_i, c_i and ψ_i. The large number of parameters can make the design a very complex task. In order to simplify the study, some relationships between these parameters will be imposed in order to reduce the number of variables to two. In [1], it has been shown that the behaviour of the fingers is mainly dictated by

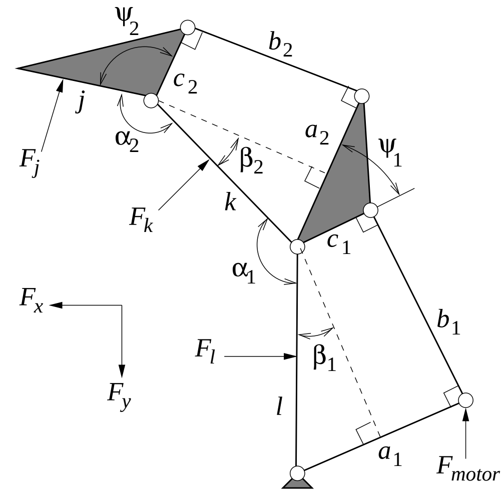

Figure 1: Three-dof shape adaptation mechanism.

the ratios $R_i = a_i/c_i$. In order to minimize the thickness of the finger, the length c_i should be as small as possible but is limited by mechanical interference considerations. Therefore, c_i is fixed, then a_i is fixed for a given ratio. The performance of the finger regarding the stability of behaviour, the mechanical interferences and the internal forces is correct if the transmission angle is close to 90 degrees when the finger is in an average configuration, as illustrated in Figure 1. The parameters b_i and ψ_i can be computed from this criterion.

First, the average configuration of the finger is defined as the configuration in which angles α_1 and α_2 are given by

$$\alpha_i = \frac{\alpha_{i,min} + \alpha_{i,max}}{2}, \qquad i = 1, 2 \tag{1}$$

where $\alpha_{i,min}$ is the minimum value of angle α_i and $\alpha_{i,max}$ is the maximum value. Then, the average angles β_1 and β_2, as defined in Figure 1, are given by

$$\beta_1 = \arcsin(\frac{a_1 - c_1}{l}), \qquad \beta_2 = \arcsin(\frac{a_2 - c_2}{k}) \tag{2}$$

which leads to values of b_i given by

$$b_1 = l\cos(\beta_1), \qquad b_2 = k\cos(\beta_2) \tag{3}$$

and to the values of ψ_i given by

$$\psi_1 = \pi - \alpha_1 + \beta_2 - \beta_1, \qquad \psi_2 = \frac{3\pi}{2} - \alpha_2 - \beta_2 \tag{4}$$

Using the above equations as design constraints, the parameters can be computed as functions of ratios R_1 and R_2.

To perform the tests, a series of grasps are performed on cylinders of different sizes and at different positions, in a simulation tool discussed in [1]. The tests are performed on fingers with different combinations of ratios R_i, giving an overview of possible fingers. The main criteria used to estimate the performance of the fingers are:

a) The sum of the forces applied by each finger on the object must be directed towards the palm (F_y) and the opposite finger (F_x) in order to obtain a stable grasp. Also, the forces F_x should be larger than the forces F_y in order to obtain balanced grasps, since the forces F_y work in cooperation (towards the palm) and the forces F_x work in opposition (against each other). That is, $F_x = EF_y$, where the value of E depends on the type of grasp and is generally around 2. The performance index associated with the resulting forces is given by the sum of the smallest force for each of the m objects grasped.

$$I_{xy} = \frac{\sum_{i=1}^{m} \min(F_{x,i}, EF_{y,i})}{m} \quad (5)$$

b) The forces should be well distributed among the phalanges in order to avoid large local forces on the object. The corresponding index is defined as the ratio of the total force on the three phalanges divided by the largest force.

$$I_{lkj} = \frac{\sum_{i=1}^{m} \frac{F_{l,i}+F_{k,i}+F_{j,i}}{\max(F_{l,i},F_{k,i},F_{j,i})}}{m} \quad (6)$$

c) An *equilibrium point* should exist on the last phalanx in all configurations in order to ensure feasible grasps. The equilibrium point is defined as *the point of contact on a phalanx which leads to static equilibrium, for a given configuration, when no contact occurs at the preceding phalanx (see [1] for details)*. If the equilibrium point is not located on the last physical phalanx, then the grasp is not possible and the object will be ejected. If the equilibrium point is on the last physical phalanx, the index $I_{ep} = 1$; if it is not, the index $I_{ep} = 0$.

d) The finger mechanism should be as compact as possible. If the finger is sufficiently compact, the index $I_c = 1$. Otherwise, the index is between 0 and 1.

The performance indices are combined in order to obtain a global index $I_G = I_{xy}^2 I_{lkj} I_{ep} I_c$ for each of the fingers. The index I_{xy} is squared since it is a more important criterion. A graph of I_G as a function of R_1 and R_2 is presented in Figure 2. A correct finger can then be chosen among the best values of I_G. For example, $R_1 = 2$ and $R_2 = 2.5$.

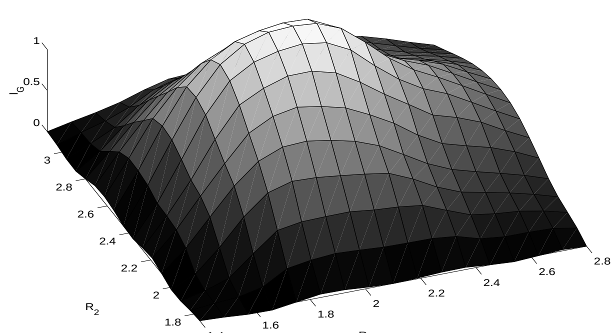

Figure 2: Global performance index.

3. Parallel precision grasp mechanism

Underactuated fingers cannot perform precision grasps while maintaining the distal phalanges parallel to each other, for objects of different sizes. However, this feature is very useful and very often feasible with simple grippers. A mechanism has been proposed in order to achieve this behaviour for a two-dof underactuated finger [2]. A mechanism achieving a similar behaviour with the third phalanx of a three-dof underactuated finger has been developed here [3] and is shown in Figure 3. It is composed of two parallelograms mounted in series. This mechanism is coupled to the phalanges of the finger but not to the other links of the shape adaptation mechanism (it is moving on a parallel plane). Two mechanical limits with springs at the top and bottom ends of the mechanism allow to perform precision grasps and adapt to power grasp if necessary. This is illustrated in Figure 3. In configurations *left*, from dashed lines to full lines, a parallel motion of the distal phalanx is accomplished, by maintaining the parallelogram mechanism on its mechanical limits. In *right*, a power grasp is performed, with contacts on all phalanges. In this case, the parallelogram mechanism is moved away from its mechanical limits and the distal phalanx is no longer maintained parallel.

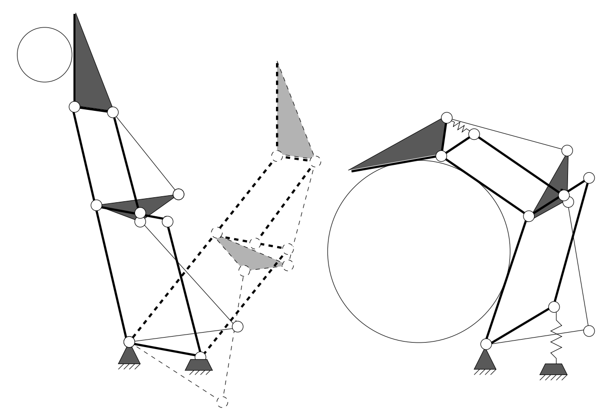

Figure 3: The parallel precision grasp mechanism (dark lines). Left: parallel precision grasps. Right: power grasp.

4. Conclusion

This paper presented the development of a three-dof underactuated finger. It is a complement of the paper [1] which discussed in detail the design of two-dof fingers. The resulting finger is used in a three fingered hand [3].

References

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[2] S.J. Bartholet: "Reconfigurable End Effector", US Patent 5108140, 1992.

[3] C.M. Gosselin and T. Laliberté: "Underactuated mechanical finger with return actuation", US Patent 5762390, 1998