Simulation results of the grasping analysis of an underactuated finger

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Abstract. The results of a number of simulations concerning the grasping analysis is presented. The grasping device consist in an under-actuated finger driven by un-extendible tendon that is one of the fingers of a mechanical prosthesis that was principally conceived as human prosthesis. The results, however, are useful for any similar finger to be used in grasping devices for industrial and agricultural applications. Analysis maps of the grasping were obtained which show the “robustness” of the socket. The method seems to be a suitable tool for the optimum design of such under-actuated fingers for grasping devices.

1 Introduction

In the last decades, grasping devices based on the human hand were widely studied and developed (see e.g. [1-13]); this both for human prostheses and for industrial or agricultural purposes. Among these studies the authors conceived developed and patented a new mechanical hand (Federica mechanical hand) based on a self-adaptive patented scheme (patent n. 0001415546 and n. 102015000059873, the latter pending) based on a self-adaptive scheme and under-actuated fingers operated by un-extendible tendons.

The main results of these investigations were reported in some papers and conference proceedings [14-18].

In figure 1 a scheme of the self-adapting system of the hand tendons and of one of the fingers are shown.

In figure 2 an hand prototype showing a correct grasping of a rather complex object by all the fingers is reported.

The study, the testing and the prototyping of the fingers and of the whole hand were presented in previous paper (see e.g. [14-18]).

Being the 3 phalanxes of the finger operated by an extension tendon and just one flexion tendon, the finger itself is underactuated, hence it becomes crucial a correct design of the phalanxes, of the tendon guide and of the hinges positions, in order to obtain a correct grasping of almost any possible object.

The grasping of an object can be very different depending on the position of the object respect to the grasping device. In the case of the single finger the figures 2 and 3 show that the quality of the grasp may be deeply different. In both the figures the grasping of a sphere is shown.

In figure 3 an almost perfect grasping is shown: the inner surface of each of the phalanxes almost perfectly onto contact with the surface of the sphere. In figure 4, instead, the sphere is just roughly grasped since just the fingertip and the palm of the hand are onto contact with the surface of the sphere.

For the reasons above, it seemed to us interesting to propose and test a method to predict the grasping efficiency of each of the underactuated fingers that compose the mechanical hand we conceived.

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The method was presented in [19]; in the following some of the most significant results are presented.

Figure 2. An hand prototype correctly grasping an object.

Figure 3. Good grasping of a sphere

Figure 4. Instable grasping of a sphere

2 The contact between surfaces

The contact model was already described in [19] so we just briefly describe it.

The contact of the fingertip of each phalanx with the objects was simulated with an elastic damping reaction and a friction force between the bodies. In particular to analyze the contact of the finger with the object, each phalanx of the finger has been covered with a plain "skin", in this way the type of contact is always between a plane and a sphere. In figure 5 the model with the plain skin is shown.

Figure 5. The multibody finger mode with plain “skin” to simulate the contact with the object.

The contact between two bodies was simulated with a force applied only along the direction of penetration of the two bodies. In figure 6 this force is shown as $F_n$, and it acts on the plane and on the sphere in the opposite direction.

In the contact model, also the friction force is included; it acts as a tangential force in the contact point on both bodies. In figure 6 the friction force is shown as $F_t$.

Figure 6. Contact scheme with normal force $F_n$ and friction force $F_t$.

The normal force $F_n$ acts by opposing the penetration of the two bodies and the damping is zero when the penetration decreases.

$$
F_n = \begin{cases} 
0 & \forall Z_{\text{penetration}} < 0, \forall Z_{\text{penetration}} < 0 \\
-k Z_{\text{penetration}} + b v_{\text{penetration}} & \forall Z_{\text{penetration}} > 0, \forall Z_{\text{penetration}} > 0 \\
-k Z_{\text{penetration}} & \forall Z_{\text{penetration}} > 0, \forall Z_{\text{penetration}} < 0 \\
0 & \forall Z_{\text{penetration}} < 0 
\end{cases}
$$

(1)
Where $Z_{\text{penetration}}$ is the penetration between the two bodies, $v_{\text{penetration}}$ is the velocity of penetration, $k$ is the contact stiffness and $b$ is the contact damping.

The friction force $F_t$ is the product of normal force and a coefficient of friction that is a function of the relative velocity at the contact point.

$$F_t = F_n \cdot \mu, \quad \mu = f(v_{CP})$$

Where $\mu$ is the coefficient of friction and $v_{CP}$ is the relative velocity at the contact point.

In particular the coefficient $\mu$ has the following expression (3):

$$\mu = f(v_{CP}) = \begin{cases} v_{CP} \cdot \frac{\mu_s}{V_{thr}} & v_{CP} < v_{inh} \\ \mu_s - \frac{v_{CP} - v_{inh}}{0.5 \cdot V_{thr}} & v_{inh} \leq v_{CP} \leq 1.5 \cdot v_{inh} \\ \mu_k & v_{CP} > 1.5 \cdot v_{inh} \end{cases}$$

Where $\mu_s$ is the static friction coefficient, $\mu_k$ is the kinetic friction coefficient and $v_{inh}$ is a velocity threshold starting from which it is necessary to use the kinetic friction coefficient.

### 3 Simulation Results

The multibody model finger that was developed was used to analyze the grasping efficiency while the position of the object was changed. The result consists in maps in which while the position of the object is changed, the grasping quality is evaluated. In the following examples the grasped object is represented by a sphere.

The robustness of the grasp is measured by analyzing different parameters. In particular, using the model, the following parameters are analyzed:

- the object's speed respect to the phalanges,
- the velocity of the object respect to the palm,
- the object contact with the phalanges and palm.

All these parameters were used to define a function of grasping $G$ described by the expression (4):

$$G = \begin{cases} 0.50 & \text{if } v_{obj\text{distal}} \equiv 0 \cup v_{obj\text{medial}} \equiv 0 \cup v_{obj\text{proximal}} \equiv 0 \\ 0.75 & \text{if } v_{obj\text{palm}} \equiv 0 \\ 1.00 & \text{if the object is in contact with 2 surfaces} \\ 2.00 & \text{if the object is in contact with at least 3 surfaces} \end{cases}$$

Where:

- $v_{obj\text{distal}}, v_{obj\text{medial}}$ and $v_{obj\text{proximal}}$ are the velocity of the object respect to the distal, medial and proximal phalanx, respectively;
- $v_{obj\text{palm}}$ is the velocity of the object respect to the palm.

Naturally the function $G$ also assumes composite values when more conditions simultaneously occur.

#### 3.1 The grasping of the sphere by the finger

The grasping ability of a single finger of the Simulink model of Federica hand was tested; this was made both considering the object fixed and mobile. The simulations provide to move the ball in a plane orthogonal to the surface of the palm considering positions spaced of 2 mm. In the cases analyzed the ball center is situated in correspondence of the finger. Each simulation includes an analysis of approximately 300 positions and the result returns a graphic having different colored areas, depending on the contact. In figures 7 and 8 the cases of a fixed sphere of radius $r = 1$ cm and $r = 1.15$ cm are reported.

![Figure 7. Results with fixed sphere of radius 1.0 cm.](image1)

![Figure 8. Results with fixed sphere of radius 1.15 cm.](image2)
In figures 9, 10, 11 and 12 the cases with a ball of radius $r = 0.8 \text{ cm}$, $r = 1 \text{ cm}$, $r = 1.15 \text{ cm}$, and $r = 1.5 \text{ cm}$ are analyzed.

The higher the object's radius, the most "elusive" the grasping is; the finger often fails to stop the ball that rolls and falls from the palm of the hand. This occurrence is more evident in figure 12, where the ball radius is $r = 1.5 \text{ cm}$ and the area with a high value of $G$ is very small.

### 3.2 Finger with inclined surface

In the previous model the contact surfaces of the phalanxes are flat, and they have no inclination. A further investigation was carried on by tilting the contact surfaces of an angle of 5°.

In particular, it must be observed that referring to the distal and medial phalanxes the tilted surface promotes the slip off of the object towards the inside part of the finger; the inclination of the proximal phalanx, instead, acts in the opposite way since it facilitates the positioning of the object towards the medial phalanx. In figure 13 the arrangement of the surfaces is shown.

With this new configuration the grasping is improved especially in the case of a mobile object.

Figure 14 shows the results of the analysis with the mobile sphere of radius $r = 1.15 \text{ cm}$, and figure 15 shows the results with a mobile sphere of radius $r = 1.5 \text{ cm}$.
The area where the better grasping occurs (high values of $G$) is increased respect the one referred to the case with inclined contact surfaces, figures 11 and 12.

Figure 14. Results with moving ball of radius 1.15 cm and contact surfaces inclined.

Figure 15. Results with moving ball of radius 1.5 cm and contact surfaces inclined.

4 Conclusion

The developed finger model was used to obtain analysis maps of the grasping that permit to evaluate the "robustness" of the grasping.

The reported results it appears that the proposed tool is a suitable instrument to analyze the grasping; in fact it permits to highlight the different results obtained by changing the parameters of the finger.

From the latter point of view, hence, the tool is also useful for the optimum finger design.

The next applications will concern the study of the results obtained with different contact surfaces (for example, truncated-spherical).

The dynamical behavior of the finger during the grasp can be also analyzed as function of different laws of motion, [20], of the only one actuator, by means of this model.

The finger model will then be extended to the entire hand studying the grasping quality of the whole gripping device, and comparing the virtual results relative to some points of the model with real measures acquired with vision systems, [21-24].

Finally, the proposed method is also suitable to study several different topics (even very different from this one) the authors are investigating on. Among these, even the dynamics of the throwing machines (see e.g. [25-27]), as for the impact between their component is concerned, can be studied.

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References

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