Method for designing and controlling compliant gripper

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Abstract. The compliant grippers are useful for high accuracy grasping of small objects with adaptive control of contact points along the active surfaces of the fingers. The spatial trajectories of the elements become a must, due to the development of MEMS. The paper presents the solution for the compliant gripper designed by the authors, so the planar and spatial movements are discussed. At the beginning of the process, the gripper could work as passive one just for the moment when it has to reach out the object surface. The forces provided by the elements have to avoid the damage. As part of the system, the camera is taken picture of the object, in order to facilitate the positioning of the system. When the contact is established, the mechanism is acting as an active gripper by using an electrical stepper motor, which has controlled movement.

1. Introduction

The manipulation of small objects, such as electronic components, is a very challenging task due to some technical characteristics involving the accuracy, the grasping actuation control and the solutions for a stable or unstable process during the object movement. Moreover, the irregular shape of the object could have a great influence, because of the necessity of adaptive control.

The concept of compliant grippers provides the advantage of large flexural deflection of the finger nearby the challenging of predicting the contact points with the object. Consequently, one of the main objectives is to design a spatial shape of the active surface whose points may follow a well known trajectory [1]. Generally, these compliant grippers are divided into passive category and active one, depending on their actuation. The passive solution means that there is no external actuator, so the movement is provided only by internal forces developed by the mechanism. As a result, the displacement could be controlled easier and the accuracy is increased. The active grippers mean the external actuation of the fingers realized by electro-thermal, electrostatic or electromagnetic actuators, which has to provide the necessary forces and couples for an accurate positioning and grasping. They have to work in a feed-back system with position and force sensors for better results [2], [3].

Due to the recent development of MEMS a new research direction has been developed with the main goal of designing the grippers with spatial movement of the end – effector element. The problem of object dimensions that are very small is a challenging too, because of the imposed positional accuracy and force control in the meantime.

Another functional problem is regarding the contact force with the object that has to be analysed and optimized. If we work with passive grippers having large deflection fingers, there are only numerical methods for computing the necessary values of force for a stable contact. We have to take into account all types of friction acting on these points as well as the linear elasticity theory applied to
the mechanism elements, so that some optimization techniques were proposed in the literature. Finally, by using the FEM methods we may have a comparison between the results [5], [6].

The paper presents a compliant gripper designed by the authors that may be used for small objects grasping, comprising both the characteristics of passive and active grasping. At first, for establishing the contact with higher accuracy there are used only the elastic and kinetostatic properties of the mechanism for generating the trajectory and the forces affording the centring and the existence of the contact points.

The second working phase implies the electrical actuation with feed-back system, in order to assure the movement of the object following an imposed trajectory.

For improving the system accuracy, we have included the gripper in the assembly actuated with the second electrical motor that receives the processed signals taken by a camera placed inside the working space.

2. Mechanical Design

The proposed mechanism is presented in figure 1. As we may infer, it is designed with an active part actuated by an electrical stepper motor 1 that has to provide the linear movement of the base 3 by using a screw – nut mechanism 2. The actuation is controlled in an open loop system, based on the possibility of programming the step number as a speed function very accurately. The second part of the mechanism implies a planar mechanism with elastic components numbered 4 and 5 made of material with very well known elastic properties. This characteristic affords the displacement of two fingers numbered 6 having an imposed active surface.

There are the following working stages: at first the camera is identifying the object position within the working area, so we have to move the gripper until his symmetrical axis lies along the acceptable positioning error around the object. The movement is made using the stepper motor that is programmed with the known number of steps; the next stage implies the positional contact between the object and the fingers, based only on the elastic properties of the elements; the third one is governed by the electric stepper motor 1 that has to move the base 2, so that a grasping force is acting in the contact points along the active surface.

![Figure 1](image-url)
As we may infer from the figure above, the main technical characteristics of the proposed mechanism are regarding the narrow room of working space, so that it could be used for objects with small dimensions and the grasping force control as a result of electrical stepper motor actuation during the second working stage of the process.

3. The Mathematical Model
The theoretical approach has the aim of establishing the limits of working space of the fingers if the electrical stepper motor is controlled with an imposed number of steps. We know the angular step of the motor, \( \theta_p \), and the law of torque variation as frequency function. For instance, we have used the hybrid stepper motor, whose torque is given by the equation below:

\[
M_e = 0.197 - 5e - 0.4 \cdot (f - 220) + 3.78e - 0.6 \cdot (f - 220) \cdot (f - 240)
\]  

(1)

where \( f \) [step/sec] – the working frequency for the electrical stepper motor; \( M_e \) [Nm] – the torque of the electrical stepper motor.

The schematic of this mechanism is presented in figure 2.

![Figure 2. The schematics of the gripper mechanism.](image-url)

The screw – nut mechanism has the role of transforming the rotational movement into a translational one. The mechanism has the path \( p \), so we may compute the displacement of the mobile element \( x \) along the OX axis:

\[
x = \frac{\theta_p}{2 \cdot \pi} \cdot p
\]

(2)

The main goal of this mathematical model is to determine the angular displacement of the element BC, knowing the force acting along the OX direction if the electrical motor provides its electromagnetic torque (figure 2).

The displacement \( \Delta x \) of the element CD along the OX axis could be computing by using the following equation (3):

\[
\Delta x = \frac{1}{E \cdot I} \left( \int_0^{L_x} F \cdot x_1 \cdot x_1 \cdot dx + \int_0^{2\pi} F \cdot (L_1 + R \cdot \sin \alpha)^2 \cdot R \cdot d\alpha + \int_0^{L_2} F \cdot (L_1 - x_2)^2 \cdot dx \right)
\]

(3)
where: $E$ – the elasticity longitudinal modulus [N/m$^2$]; the inertial values $I = \frac{bh^3}{12}$ [m$^4$] if the cross section of the element has the $b$ and $h$ values [mm]; $F$[N] – the force acting along the OX axis on the CD curve of the mobile element, which is provided by the electrical motor; $x_1$ [mm] – the displacement of CD along the OX axis; $L_1$ [mm]– the length of CD; $R$ [mm] – the radius of BC; $a$ [grd] – the angular displacement of BC; $x_2$ [mm] – the displacement along the AB curve of the mobile element; $L_2$ [mm] – the length of AB.

As numerical setup, we have computed the angular variation for the BC curve as function of force acting on the mobile element and linear displacement of mobile element, by using the numerical method of Matlab functions. We have chosen the electrical motor with the couple $M_m = 0.2$ Nm. The mechanism dimensions are: $R = 16$ [mm]; $L_1 = 10$ [mm]; $L_2 = 30$ [mm]; $E = 21e-02$ [N/m$^2$]; $b = 3$ [mm]; $h = 0.6$ [mm].

The results are presented in figure 3 and figure 4. We may infer the maximum values for the angle of BC curve for computed force values for some working frequencies are enough for touching the object without damaging. The computation has been made for maximum torque of the motor, so we may work of high values for frequencies, meaning lower values for active force.

**Figure 3.** The variation of angular and linear displacement of BC. **Figure 4.** The variation of force acting curve on the element BC.

4. The solution for position improvement
The positional accuracy was improved by designing a supplementary positioning of the entire system presented above, meaning the electrical motor, the grounded and the mobile elements. In order to do this, the images taken by a camera are processed with Matlab software using some particular implemented functions. For instance, after we have taken the picture of the object, as it is presented in figure 5, we may observe that it should be processed because it has black holes, which is supposed to introduce fake information.

**Figure 5.** The picture taken by the camera and the resulting processed image.
By using functions of image processing in Matlab software, the boundaries are delimited and the holes and useless points have been left. Finally, the colored picture has the right shape, which gives the necessary details for the gripper system and its position. Based on these observations, we have identified the coordinates of some points along the object boundaries and considering the coordinate system for all the experimental setup as we may infer from figure 6. The origin of this system is on the OX axis of the camera and the entire system will be positioned according to these settings.

![Figure 6](image)

**Figure 6.** The point representation for the object boundaries.

Having the points coordinates established considering the coordinate system, we may move the gripper system using the second electrical stepper motor, so that the gripper axis will be aligned with the camera axis.

5. **The experimental setup**

The experimental setup comprises the electrical stepper motor 1 with the screw-nut mechanisms 5, the compliant gripper 3 and the object 4. According to the information from picture taken by the camera, the second electrical stepper motor provides the linear movement of the mechanism as we have described above. The main advantages are: the improvement of positional accuracy; the possibility of using the compliant gripper as passive one for the first working stage and as active one for the second working stage.

Better results could be obtained if we improve the active surfaces of the fingers, in order to increase the accuracy by the self–centering properties using.

As future work we aim to study the elastic properties of some materials the mechanism elements are made of and their influences on the grasping process. Another future goal of our activities could be the study of contact force acting on the active surface of the finger.

![Figure 7](image)

**Figure 7.** The experimental setup of the proposed system.
6. Conclusions
The paper presents compliant gripper with high accuracy positioning working as passive gripper at first, based on the material elastic properties and as active gripper for the end of the process. The information about object position is given with a camera. The gripper is actuated by an electrical stepper motor when it is working as active gripper and has active surfaces of the fingers that allow the contact with the object providing force values acting in these points. The entire system could be moved along the perpendicular direction too, by using the second electrical stepper motor due to the goal of position improvement.

As future work we will study the elasticity forces and internal tensions of the gripper elements and we will design affordable active surfaces of the fingers.

7. References
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