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# COMPLIANT MULTI-FINGERED ADAPTIVE ROBOTIC GRIPPER

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## Abstract

Passively compliant underactuated mechanisms are one way to obtain the finger which could accommodate to any irregular shaped and sensitive grasping object. The purpose of the underactuation is to use the power of one actuator to drive the open and close motion of the gripper. The fully compliant mechanism has multiple degrees of freedom and can be considered as an underactuated mechanism. This paper presents design of the adaptive underactuated compliant multi-fingered gripper with distributed compliance. The optimal topology of the finger structure was obtained by an iterative optimization procedure. It was proven that for real robotic applications multi-fingered grippers with three or more fingers were more suitable for stable and safe grasping.

Passiven nachgiebigen unteraktuierten Mechanismen bieten die Möglichkeit solche Robotergreifer zu entwerfen die anpassfähig an irgendeine unregelmäßig geformte und empfindliche Greifobjekt sind. Der Zweck der Unteraktuierung ist nur ein Aktor für die Greifer-öffnen/schließen-Funktionen zu benutzen. Völlig nachgiebige Mechanismus hat grosse Anzahl der Freiheitsgrade und man kann als unteraktuierte Mechanismus betrachtet werden. In diesem Beitrag wird ein adaptive unteraktuierte nachgiebige Multifinger-Greifer mit verteilten Nachgiebigkeit entworfen. Die optimale Topologie der Fingerstruktur wurde durch ein iteratives Optimisation-verfahren bekommen. Es wurde bewährt dass für die realen Anwendungen

der Multifinger-Greifer mit drei und mehr Fingern für stabile und sichere Greifen besser geeignet ist.

# 1 Introduction

Multi-fingered robotic grippers offer great advantages compared with traditional tools mounted at the end of a robot arm. Like human hands they are capable of handling both parts and tools. With a minimum of three contact points they offer a greater stability and mobility of the grasp [1,2]. Dexterous, multi-fingered grippers have been the subject of considerable research [3,4,5], with the kinematics and force control issues being investigated in [6,7].

Significant efforts have been made to find gripper designs simple enough to be easily built and controlled, in order to obtain practical systems. To overcome the limited success of the early designs due to the cost of the control architecture a special emphasis has been placed on the reduction of the number of degrees of freedom, thereby decreasing the number of actuators [8,9]. The strategy for reducing the number of actuators while keeping the hand capability to adapt its shape to the grasped object is referred to as underactuation [10,11]. Papers [12,13] show that underactuation allows reproducing most of the grasping behaviors of the human hand, without augmenting the mechanical and control complexity.

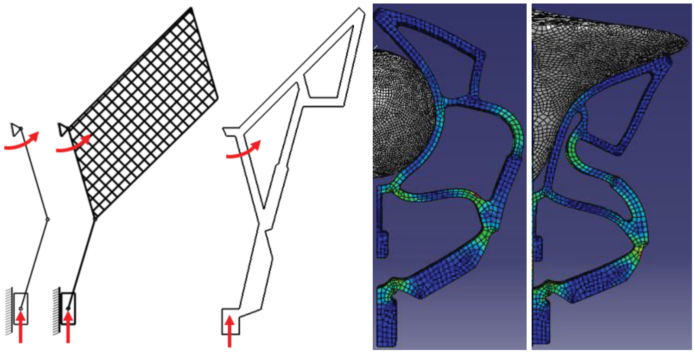
A mechanism is said to be underactuated when it has fewer actuators than degrees of freedom. In order to achieve this goal, passive elastic elements are used. The transmission mechanism used to achieve such a property must be adaptive, i.e. when one or more fingers are blocked, the remaining finger(s) should continue to move. When all the fingers are blocked, the force should be well-distributed among the fingers and it should be possible to apply large grasping forces while maintaining a stable grasp.

Due to the multiple degrees of freedom of a single compliant joint, any compliant mechanism [14,15,16,17] can be considered as an underactuated mechanism. Finger compliance allows the gripper to passively conform to a wide range of objects while minimizing contact forces. Passive compliance offers additional benefits, particularly in impacts, where control loop delays may lead to poor control of contact forces. Compliance allows lower implementation costs by reducing the sensing and actuation required for the gripper.

The proposed design of the finger in this article is able to flex inwards and outwards while closing around the grasping object. It means the gripper can accommodate to convex and concave grasping shapes. The optimal topology structure of the finger is obtained by iterative FEM optimization procedure. The obtained finger structure is also verified by optimality criteria method [18,19,20,21]. In this article, design and analysis of a multi-fingered robotic gripper is presented too; the single-actuated two-, three- and four-fingered grippers are analyzed.

## 2 Finger structure topology

Finger structure topology was obtained by FEM iterative optimization procedure [22,23]. The main target grasping curvatures were concave and convex grasping shape.



(a) (b) (c) (d) (e)

**Fig. 1:** (a) Slider crank mechanism, (b) finger design domain, (c) optimized finger topology, (e) convex grasping shape and (d) concave grasping shape [22]

Figure 1 shows the input mechanism principle for one finger. As it is shown in Figure 1(a) the basic input mechanism for the finger can be presented as an slider crank mechanism. Figure 1(b) shows the slider crank mechanism with addition of the finger design domain. Finally, Figure 1(c) shows the optimized structure of the compliant adaptive finger. Figure 1(d) and 1(e) show the finger accomodation to convex and concave grasping shape.

## 3 Two-fingered gripper

To investigate the behavior of the fully compliant underactuated adaptive finger, many FEM simulations of the different gripper designs with two fingers were performed. By the way, the two-fingered gripper design is not practicle for real grasping applications especially for cylindrical grasping objects (Figure 2).

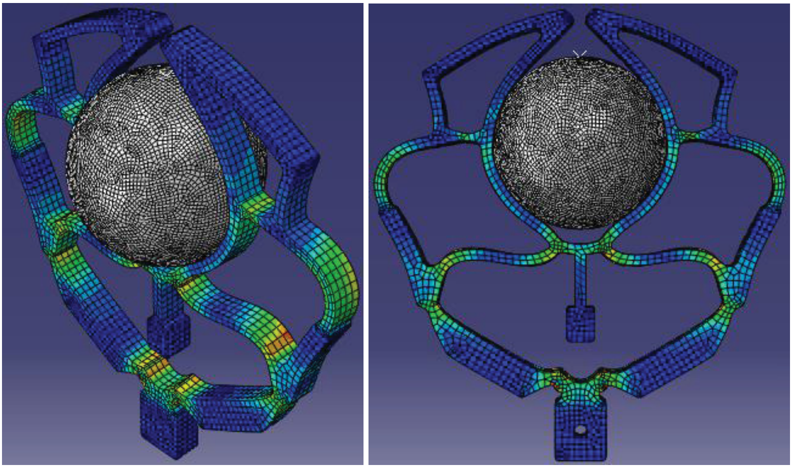


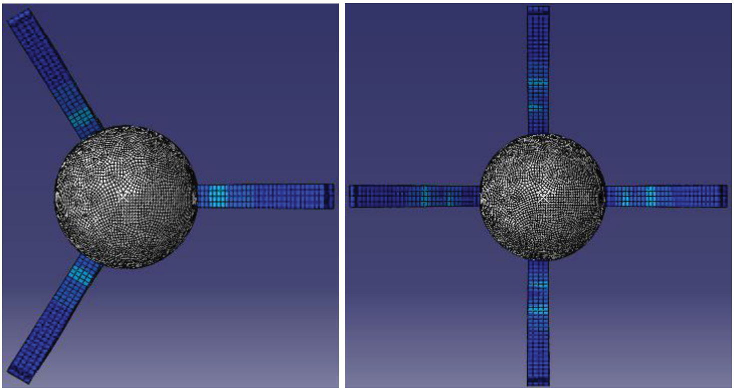
**Fig. 2:** Two-figered gripper desing

The entire FEM analysis was performed in ABAQUS software with following parameters and characteristics:

- grasping object as explicit discrete rigid element,
- finite element type for grasping object R3D4: a 4-node 3-D bilinear rigid quadrilateral, 1mm size,
- gripper material: ABS plastic (mass density 1250g/mm$^3$, Young's modulus: 2.3GPa, Poisson's ratio: 0.37),
- solid and homogeneous section for the gripper,
- gripper as explicit 3D stress element,
- finite element type for the gripper C3D8R: an 8-node linear brick, reduced integration, hourglass control, 1mm size.

## 4 Multi-fingered gripper

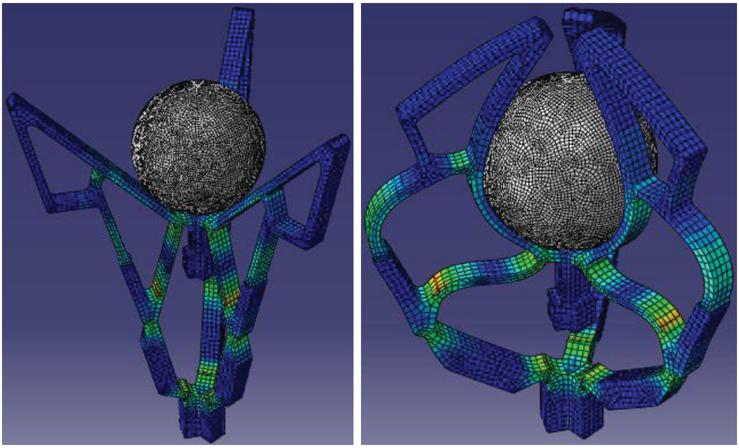
Although two-fingered gripper structure can be useful for experimental analysis, for real grasping applications in robotics (especially for cylindrical grasping objects (Figure 2)) it is useful to model multi-fingered grippers with three or more fingers. Figure 3(a) shows the three-fingered gripper design principle. The fingers of the gripper are positioned 120 degrees relate to each other. Afterwards the four-fingered gripper was designed (Figure 3(b)). It can be noticed that the fingers of the gripper are positioned 90 degrees relate to each other.



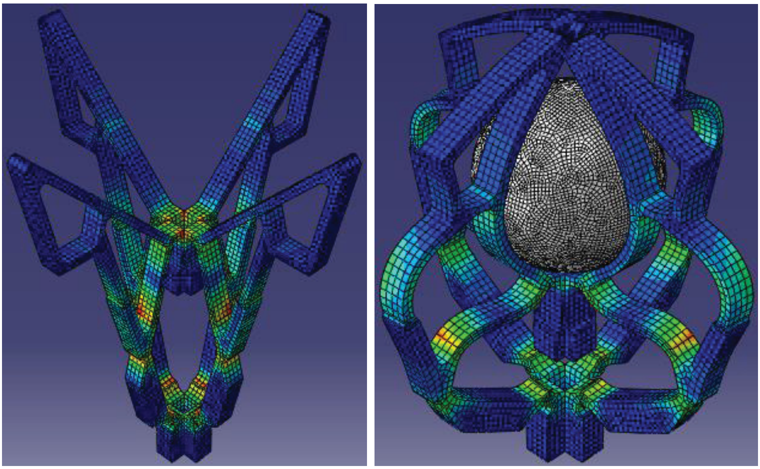
(a) (b)

**Fig. 3:** Multi-fingered gripper designs principles: (a) three-fingered and (b) four-fingered gripper

Figure 4(a) shows three-fingered gripper accommodation to the cylindrical object (convex grasping shape). Figure 4(b) shows four-fingered gripper accommodation to the cylindrical grasping object. In both cases, single actuation principle was used. It means that with one actuator and without any control procedure the gripper should provide safe and fully accommodation to the object. This is the main advantage of the passive mechanisms with underactuation.



(a)



(b)

**Fig. 4:** (a) Three-fingered and (b) four-fingered gripper design

Figure 5 shows four-fingered gripper behaviour for three different grasping objects: (a) cylindrical, (b) convex and (c) parallepopipedical grasping object. It can be noticed fully adaptation of the gripper in the all three cases.

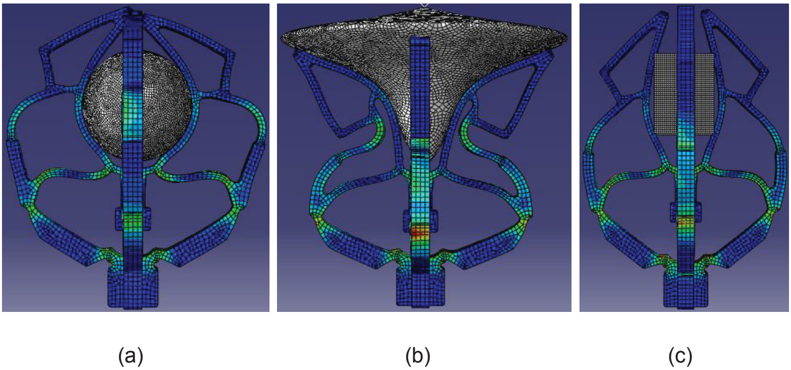



**Fig. 5:** Four-fingered gripper grasping of cylindrical object (a), concave object (b) and parallepopipedical object (c)

## 5 Conclusion

The handling of irregular, unpredictably shaped and sensitive objects introduces demands on gripper flexibility and dexterity. Reaching the dexterity and adaptation capabilities require the control of a lot of actuators and sensors. The dexterity can also be obtained by underactuation, which consists in equipping the finger with fewer actuators than the number of degrees of freedom. The flexibility can be reached by introducing compliant mechanisms with distributed compliance, i.e. fully compliant mechanisms. The combination of the underactuation and the compliant mechanisms leads to a gripper with high adaptability and sensibility. Another characteristic of compliant underactuated grippers is the elasticity of the gripper structure which ensures a soft contact between the gripper and the grasped object, e.g. sensitive grasping. The main advantages of the compliant underactuated gripper are in its distributed compliance, simple manufacturing process, low cost and easy to adaptation to any irregular object.

The design and behavior of a novel multi-fingered compliant passive adaptive gripper was introduced. The adaptability of the proposed gripper in this article is passive and each finger of the gripper has many degrees of freedom. There are no sensors, or computers within this design to actively coordinate finger motion. Instead, the adaptive mechanism adaptive function relies on the physical contact force of the fingers with an object, to adjust the position of the fingers relative to each other. This allows simple design that can fit within a small space and is low in weight.

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