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OBJECT GRASPING AND LIFTING BY PASSIVE COMPLIANT GRIPPER

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Abstract

The development of universal grippers able to pick up unfamiliar objects of widely varying shapes and surfaces is a very challenging task. Passively compliant underactuated mechanisms are one way to obtain the gripper which could accommodate any irregular and sensitive grasping object. The purpose of the underactuation is to use the power of one actuator to drive the opening and closing motion of the gripper. The fully compliant mechanism has multiple degrees of freedom and can be considered as an underactuated mechanism. This paper presents a new design of the adaptive underactuated compliant gripper. The optimal topology of the gripper structure was obtained by two different methods simultaneously: iterative FEM optimization procedure and optimal criteria method using mathematical programming. The main points of this paper are the explanation of the new compliant gripper structure and presentation of the gripper behavior during grasping and lifting the gripping objects.

1. Introduction

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 gripper 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. The strategy for reducing the number of actuators while preserving the hand capability to adapt its shape to the grasped object is referred to as underactuation. Papers [1,2,3] show that underactuation allows reproducing most of the grasping behaviors of the human hand, without augmenting the mechanical and control complexity.

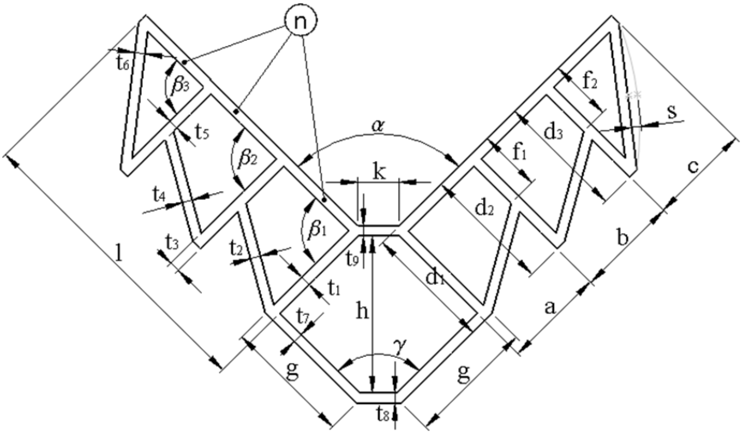
A mechanism is said to be underactuated when it has fewer actuators than degrees of freedom. In order to achieve this goal, passive elastic elements are used.

Due to the multiple degrees of freedom of a single compliant joint, any compliant mechanism [4,5,6] can be considered as an underactuated mechanism, i.e. with fewer actuators than degrees of mobility. Compliant underactuated grippers [7,8,9] show particular promise for use in unstructured environments, where object properties are not known *a priori* and sensing is prone to error. 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.

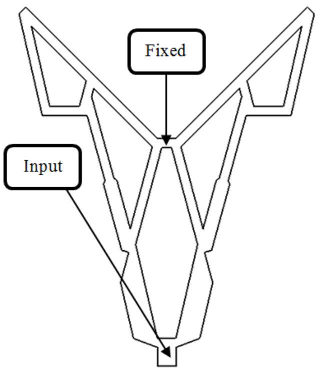
2. Gripper Structure Topology

Compliant mechanisms attain their mobility from flexibility of their constituents as opposed to their rigid body counterparts that attain their mobility from hinges, bearings and sliders. The main advantages of compliant mechanisms are that they can be built using fewer parts, require fewer assembly processes and need no lubrication. Special care must be taken, however, in designing compliant mechanisms in order to obtain sufficient mobility and safety against failure due to fatigue.

Only the fully compliant mechanism could establish the adaptable behavior of the gripper. To determine the optimal design of the fully compliant underactuated adaptive gripper, many FEM simulations of the gripper designs were performed [7] for every changing design parameter (Figure 1(a)). The optimized design of the gripper is shown in Figure 1(b). The FEM simulations were made to verify the design for two target functions of the gripper, accommodation to concave and convex shapes of a grasping objects. The accommodation of the gripper to many other shapes of a grasping object was verified as well (Figure 2) and it was proven that the gripper could accommodate different shapes and sizes of the grasping objects. The FEM analysis was performed in ABAQUS software with the following parameters and characteristics:



(a)



(b)

Fig. 1: Initial (a) and the optimized (b) gripper design

- grasping object as explicit discrete rigid element,
- finite element type for the object R3D4: a 4-node 3-D bilinear rigid quadrilateral, 1mm size,
- gripper material: silicone rubber (Yeoh hyperelastic model),
- 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.

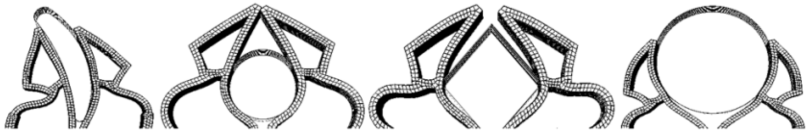


Fig. 2: Verification of the gripper functions for different shapes of grasping objects

Figure 3 shows the main gripper features. These are:

- the whole gripper structure represents one passive elastic structure (Figure 3(a));
- one active input actuator (Figure 3(b));
- for one active input, the gripper has multi-output contact points (Figure 3(b)).

The gripper accommodation to the cylindrical object with the radius r=25 mm is shown in Figure 3(b)). The gripper part which is fixed during gripping and holding of a grasped object is shown as well.

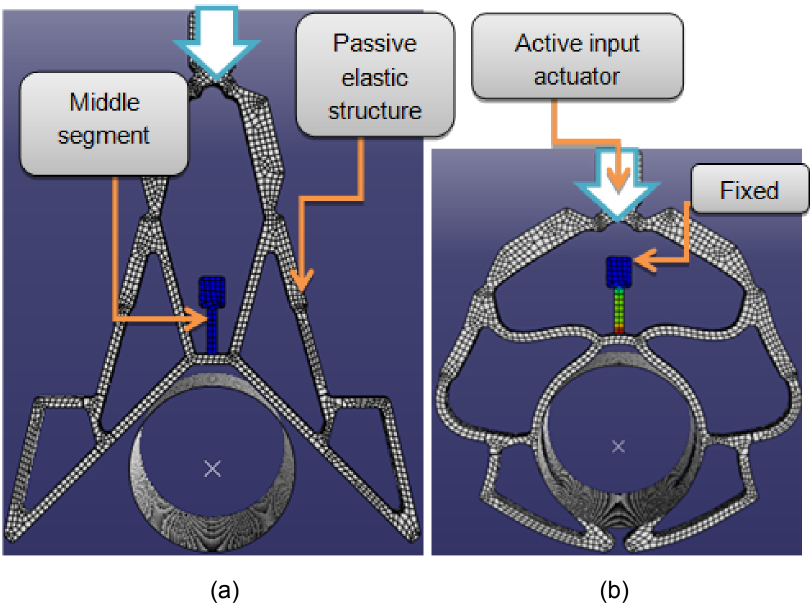


Fig. 3: The main features of the adaptive gripper

3. Gripper Mannufacturing

The designed gripper model was made by press-curring from silicone rubber. The moulding tool for the gripper manufacturing and one extracted gripper from the tool are shown in Figure 4. The production of the gripper was executed in the Laboratory of Mechanism Technology Department, Faculty of Mechanical Engineering at Ilmenau University of Technology, Germany. In the beginning silicone rubber with different shore hardness was used i.e. 60, 70 and 80. According to experimental test, the best silicone shore was 70 and therefore Elastosil R420/70 was used for the gripper manufacturing.

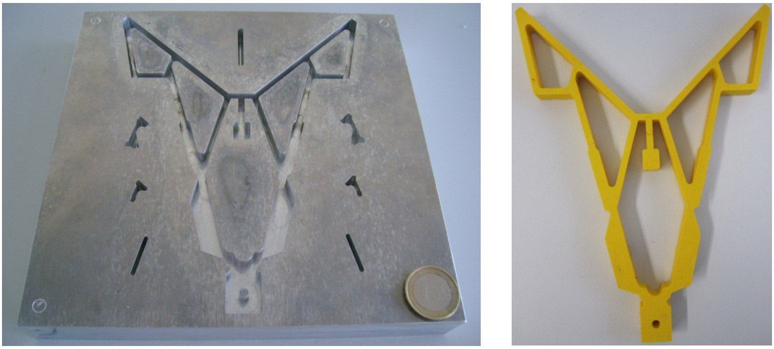


Fig. 4: The gripper manufacturing process; a) the moulding tool, b) produced gripper

4. Object Grasping and Lifting

The combination of underactuation and compliant mechanism leads to a gripper with high adaptability and the elasticity of the silicon rubber ensures a soft contact between the gripper and the grasped object. The only drawback for this designed gripper lies in its very high flexibility, i.e. it is not able to hold heavy objects. Therefore, the next analysis was the behavior estimation of the designed gripper model during the object grasping and lifting.

The emphasis was on the determination of the change in the middle segment stress while the grasping object weight increased (Figure 5), since the middle segment could be used for sensing purposes like detection of the exceeding weight of the grasping object. It was observed that for the designed gripper model the maximum weight of the grasping object for stable object grasping and lifting was 0.3 kg.

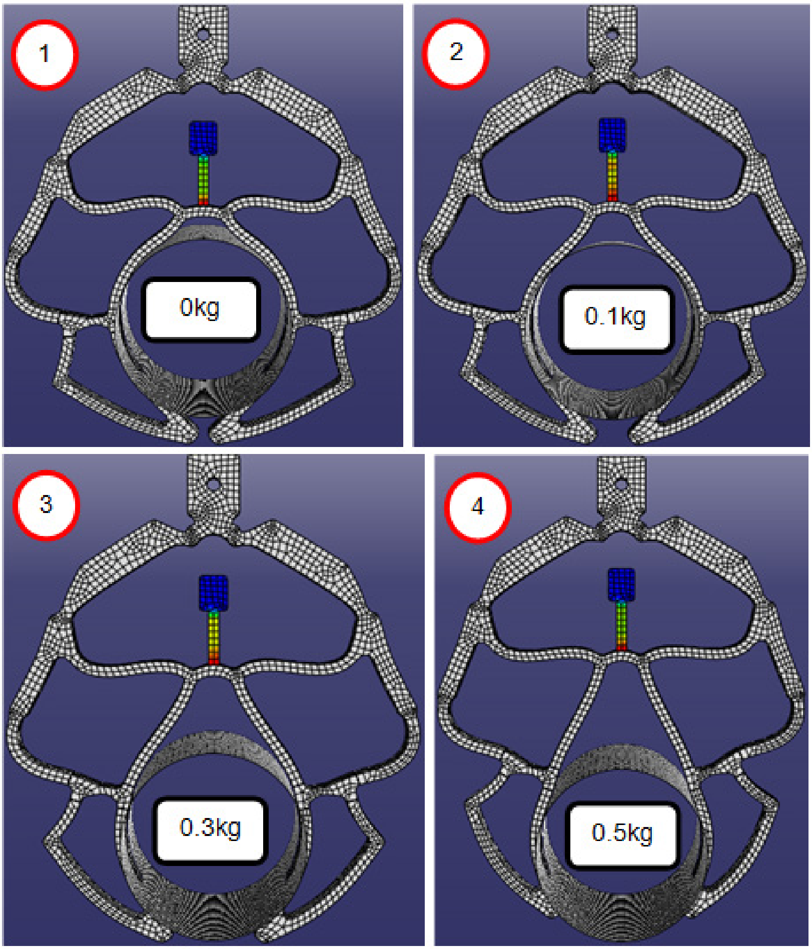


Fig. 5: Grasping and lifting the objects of different weight (in kilograms)

As already noted, the main emphasis was on the determination of the change in the middle segment stress during the object grasping and lifting. This features of the middle segment could be usefull for determining the maximum weight of the grasping object for the stable grasping. Figure 6 shows the change in the middle segment stress for these two steps in relation to gripper input displacement. Dotted blue line labels the middle sensor stress limit for the stable grasping and lifting of the object. Based on this analysis it is possible to develop a controller unit which would cancel the gripper lifting process if the middle sensor detects electrical and mechanical characteristics of the exceeding of the stable grasping and lifting.

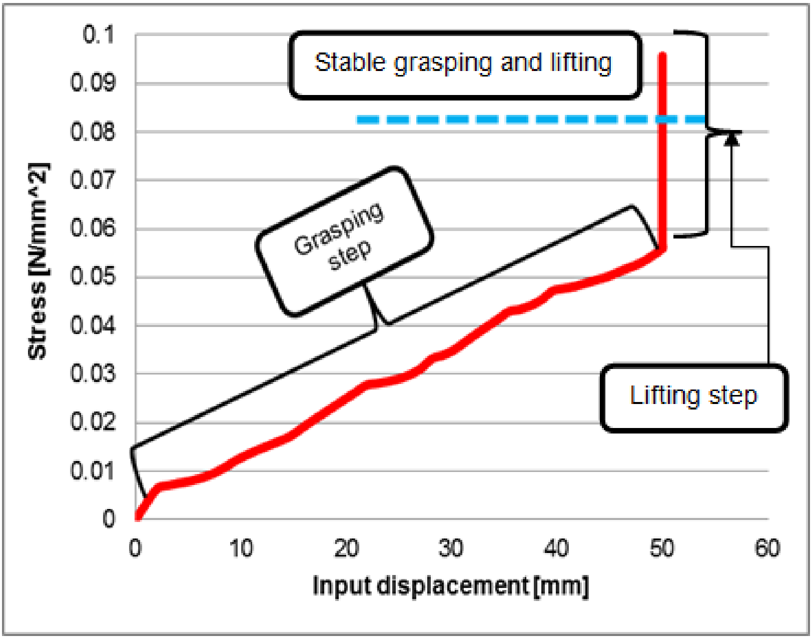


Fig. 6: Change in the middle segment stress for grasping and lifting the object

One of the solutions to handle the problem of the gripper high flexibility is to change the gripper material, e.g. use stiffer silicone rubber, but it has to be carefully performed since too stiff a material leads away from a compliant mechanism with distributed compliance.

Figure 7 shows the middle segment stress of the designed gripper for incremental increasing of grasping object weight. At stable object grasping and lifting, the middle segment stress was 0.083 N/mm^2.

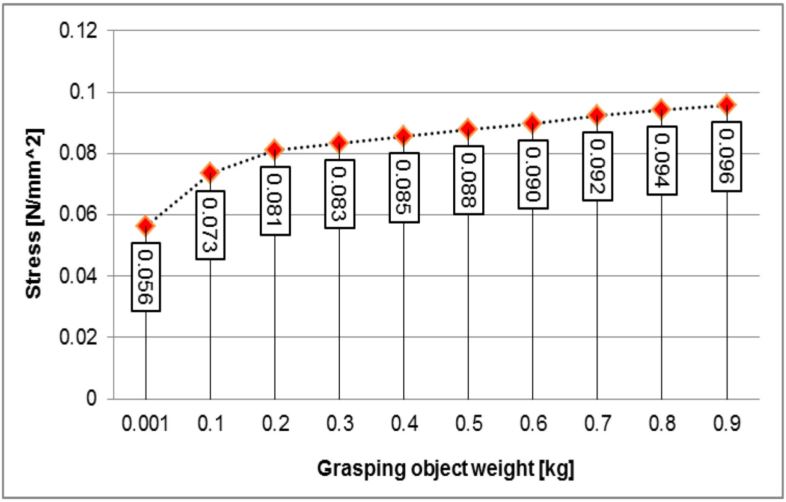


Fig. 7: Middle segment stress for incremental increasing of grasping object weight

5. Conclusion

The handling of irregular, unpredictably shaped and sensitive objects introduces demands on gripper flexibility and dexterity. Reaching the desired dexterity and adaptation capabilities requires 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 underactuation and compliant mechanisms leads to a gripper with high adaptability and sensibility. Another characteristic of compliant underactuated grippers is the elasticity of the silicon rubber which ensures a soft contact between the gripper and the grasped object, e.g. sensitive grasping.

According to our knowledge, the gripper principle utilized here is new and original. The main advantages of the compliant underactuated gripper are in its distributed compliance, simple manufacturing process, low cost and easy adaptation to any irregular object. The only drawback for this gripper lies in its very high flexibility, i.e. it is not able to hold heavy objects. One of the solutions to handle this problem is to change the gripper material, e.g. use stiffer silicone rubber, but it has to be carefully performed since too stiff a material leads away from a compliant mechanism with distributed compliance.

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