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A planar underactuated grasper with adjustable compliance

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ABSTRACT

Underactuated graspers are known for their self-adaptability. The configuration in which it obtains a stable grasp relies on static force equilibrium. Any external or inertial forces acting on the seized object disturb this static equilibrium and tend to change the configuration of the grasper. Self-adaptability therefore challenges the robustness against external perturbations. This paper introduces the concept design of an underactuated grasper with the ability to adjust its level of self-adaptability by changing the rotational stiffness of its differential mechanism. To avoid an additional actuator for this adjustment, a bi-stable mechanism was implemented which changes the actuation type of the differential from a point force in the compliant state to an antagonistic couple in the stiff state once the actuator force overcomes a threshold value. Experimental validation of the concept design shows that the lateral compliance of the grasper in the stiff state reduced by a factor 7 compared to the compliant state. Also, the lateral pullout force in the stiff state increased by a factor 1.9. Thus a grasper was designed which uses the benefits of self-adaptability to grasp an object and increases its robustness once a stable grasp is obtained.

1. Introduction

Underactuated grasping is a research topic that is widely studied. Many grasper designs have been proposed, such as the SARAH hands [1], SDM hand [2], TWIX hand [3], Delft Hand III [4], SRI hand [5] and others as can be found in [6]. Underactuated graspers distribute an actuation force between the phalanges of its fingers. When an actuator force is applied and the fingers enclose an object this results in a number of contact forces. Because of the self-adaptability of the grasper these contact forces change the configuration of the grasper until a configuration is found in which the contact forces are in static equilibrium with each other. The general advantage of this working principle is that a large variety of objects can be grasped without sophisticated control algorithms. In the case that an external force is applied to the object the static equilibrium is perturbed. As a response to this force perturbation the configuration of the grasper is adjusted and a new static equilibrium position can be found as long as the object position stays within the stable region of the grasper. One could say that instead of resisting external forces the grasper adjusts to them due to its self-adaptability.

This behavior can be troublesome, for example during a pick and place task in which the grasper undergoes high accelerations. The inertial forces that act on the object can change the configuration of the grasper which could lead to instability. It may therefore be beneficial if the grasper could use the self-adaptability while grasping and to increase its robustness once a stable grasp is obtained.

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In the literature previous works can be found that have focused on improving the stability and the robustness of underactuated graspers. Stability can be improved by optimizing the dimensional design of a grasper [7] or by adding a second actuator [8]. Other works have focused on improving the robustness of an underactuated finger during a precision grasp by varying the transmission ratio between proximal and distal phalanx [9]. This variable transmission ratio is obtained by actively changing the pulley radius of the proximal joint. Another way to increase the robustness of a grasper is to remove degrees of freedom (DOF) of the grasper using joint locks such as electrostatic brakes as applied in [5] or friction based brakes as applied in [10,11]. Still another possibility is to implement a friction based coupling mechanism as in [12]. This design increases the robustness by restricting the rotation of a pulley that connects two tendon driven fingers.

Instead of removing DOF to increase the robustness of a grasper another approach is to mechanically adjust the rotational stiffness of the available DOF. This method is widely applied in the designs of variable stiffness actuators such as the MACCEPA 2.0 [13], AwAS II [14], DLR FSJ [15] and others as can be found in [16]. The rotational stiffness of this type of actuators can be adjusted continuously within a certain range by using passive elements and a secondary mechanism to adjust the characteristics. A similar method has been applied in underactuated grasping to obtain the ability of adjusting grasp styles by varying spring preloads of the fingers of the grasper [17]. Implementing a secondary mechanism can also be used to adjust the robustness of a grasper.

This paper proposes the design of an underactuated grasper which increases its robustness against external force perturbations in enveloping grasps by adjusting the rotational stiffness of an internal differential mechanism. By changing the actuation type of the differential from a point force to an antagonistic couple the rotational stiffness of the differential is adjusted. Using a preloaded bi-stable mechanism the grasper requires only a single actuator and transfers between a compliant and a stiff state once the actuator force overcomes a threshold value. Analytical and experimental validation of the design was done to quantify the robustness of the grasper.

This paper is structured as follows: Section 2 describes the design method which led to the final concept and the methods used to analytically and experimentally validate the concept. Section 3 shows the analytical and experimental results, which will be discussed in Section 4. Conclusions are presented in Section 5.

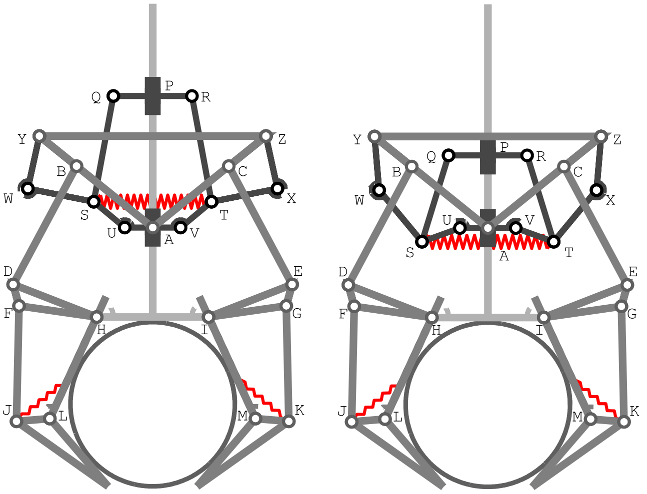
2. Methods

2.1. Design framework

In order to restrict the solution space of this research a number of limitations were applied. The actuation force was set at a constant value of 4 N and no mass or inertia of the links and seized objects was considered. It was also considered not to model the spring that connects the proximal and distal phalanx. The robustness of the grasper was defined as the ability of the grasper to resist lateral forces that are applied to the center of the object in the direction parallel to the palm (indicated as link HI in Fig. 1). The lateral compliance of the grasper was used as a metric to quantify the robustness and was defined as follows:

$$\frac{1}{k_{lat}} = \frac{\Delta X_{obj,lat}}{\Delta F_{obj,lat}} \tag{1}$$

where the lateral compliance of the grasper is denoted by $\frac{1}{k_{lat}}$ in which k_{lat} represents the lateral stiffness of the grasper. The term $\Delta X_{obj,lat}$ represents the change in lateral displacement of the object in meters and $\Delta F_{obj,lat}$ represents the change in the resultant



(a) (b)

Fig. 1. Schematic representation of the final concept in its compliant (a) and stiff (b) state. In the text, link HI is denoted as the palm, ternary link AYZ is the differential, P is the actuation site. SU and VT are the toggle links of the bistable spring mechanism. All links are rigid, the springs provide the compliance.

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