Design of a Bioinspired Multi-fingered Soft Pneumatic Gripper with Embedded Suckers

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Abstract. Applications as robotic harvesting or pick and place in the agrifood domain require robotic grippers able to gently manipulate delicate products, while guaranteeing high gripping power and adhesion forces on smooth surfaces. Existing soft grippers are mainly based on pneumatic bending actuators which can guarantee a gentle manipulation, but they suffer from low gripping power and possibility of slip of the manipulated object. This paper describes a novel design concept of soft robotic pneumatic gripper with embedded suckers. The concept consists of four soft fingers, each one comprising an elastomeric structure with two separate air paths, one for pressurizing the finger for generating bending motion, one for vacuum–based adhesion to the object's surface via suction pads distributed along the surface of the finger. In this work we highlight the concept design of the mechanical system and the pneumatic control unit.

Keywords: Bioinspired design · Concept design · Soft grippers · Soft robotics

1 Introduction

Traditional robotic grippers consist of a discrete set of rigid links connected through rigid joints. Flexibility and dexterity in grasping and manipulation using rigid grippers can be achieved only through complex mechanical design and control strategies.

A different design approach involves the use of compliant elements embedded within their mechanical structure [1]. This results in simpler design concepts, where the control complexity is reduced by the "active" role of compliance in achieving effective grasping and manipulation. Robotic grippers made of compliant elements are called soft robotic grippers [2].

One of the most adopted approach for the design and development of soft grippers involves the use of fluid–driven actuators [3], namely elastomeric chambers which shape in a bending motion when inflated thanks to the adoption of embedded reinforcing layers. Many design architectures of robotic grippers make

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use of fluid–driven actuators, organized as multi–fingered systems or single–fingered, tentacles–like systems. The first typology allows soft grasping and manipulation of the object through multiple contact points. The second typology allows grasping and manipulation by enrolling the object through a bending or even helix motion; this is referred to as whole–arm manipulation. Gripping by pneumatic actuation of inflatable soft structures has many advantages as simplicity of realization, robustness and low cost. Despite fluid–driven actuators have been used for successful grasping of a large variety of objects, they suffer from low gripping power and low adhesion forces on smooth surfaces. These limitations can represent a problem for enabling applications, as in the agricultural sector, where a soft gripper can be used simultaneously for harvesting or pick and place applications. While most of design solutions, especially the multi–fingered concepts, have been successfully used for pick and place of fruits, no concepts have been provided for realizing, with the same systems, pick and place and harvesting of fruits [4]. This could be due to the fact that during the harvesting process, the gripper should guarantees, besides safe interaction with the fruit, also higher grasping power and adhesion to the surface. Furthermore, robotic grippers in the agrifood domain should also avoid the problem of potential slip of the product during the handling process.

One possible solution to this problem can by endowing the soft actuators with a biologically inspired mechanism of adhesion. Bioinspiration has always been present in soft robotics, aiming at transferring the working principles of biological soft–bodied living organisms to artifical machines [5]. Examples of living organisms which are source of inspiration for controllable adhesion mechanisms are the gecko and the octopus. Geckos are able to climb on vertical surfaces thanks to special microfibers, located on their foot, able to attract the object surface by the van der Waals force, resulting in the generation of shear forces [2]. The adhesion in robotic grippers exploiting this concept is guaranteed by the pressure of gecko–inspired microfibers in the direction normal to the object's surface [6]. Octopus is probably the most well–known biological source of inspiration for soft robotics [7]. Such incredible animals have impressive manipulation capabilities; as a matter of fact, their soft bodies produce complex motions which allow to easily conform to different objects, while the suckers–like structures distributed along their arms allow to attach to multiple surfaces [8]. This organism has been the source of inspiration of two examples of octopus–inspired grippers. The first example is the TentacleGripper by FESTO (https://www.festo.com/), a pneumatically actuated tentacle gripper with distributed suction cups that can produce 2D motion (inward bending), analysed in detail in recent research papers [9] and endowed with distributed sensors [10]. The second example is a tentacle gripper with distributed suction cups that can produce 3D motion, useful for grasping and manipulation of complex–shaped objects in confined environments as industrial pipes [11]. According to the literature, the combination of fluid–driven actuators and suckers for the development of soft grippers is reported only for tentacle–like structures.

In this paper we propose a novel architecture for bioinspired soft grippers, based on multi–fingered fluid–driven actuators, each one with bending motion capabilities endowed with distributed suction cups along their length. The integration of bending and suction in multi–fingered soft grippers is expected to provide improved gripping power and possibility to stick to multiple surfaces. This combination can allow to safely grasp and manipulate delicate objects which require high adhesion and gripping power. To the best of our knowledge, the synergistic combination of bending motion and vacuum–based adhesion via suction cups is proposed here for the first time in a multi–fingered soft gripper architecture. Indeed, so far the combined usage of pneumatic shaping and vacuum–based adhesion via suction cups is only reported for tentacle–like structures with a single finger [9,11]. As an application example, the implementation of this concept in the agrifood domain, can allow for combined harvesting and pick and place, without potential slip, of spherical–shaped fruits with smooth surface, as apples. As a matter of fact, while commercial solutions already exist for pick and place of fruits and food products (as the pneumatic grippers from Soft Robotics Inc. (https://www.softroboticsinc.com/), no commercial solutions exist for harvesting robot. In the rest of this paper, we present the concept of the gripper (Sect. 2) as well as the design description of the mechanical system (Sect. 2) and of the pneumatic control unit (Sect. 3). Conclusions are reported in Sect. 5.

2 Concept

The concept of the multi–fingered soft pneumatic gripper with embedded suckers in illustrated in Fig. 1. Here, we can appreciate the combined function of bending and suction in a simple example, i.e. safe grasping of an apple. Bending of the soft actuators, as generated by inflating compressed air within the pneumatic chambers, allows the gripper to conform to the apple's shape in a safe manner. Suction cups made of compliant materials are used indeed for enhanced adhesion to the apple's (usually smooth) surface, when vacuum is applied. The resulting adhesion forces, normal to the surface of the apple, might enable higher gripping power (useful, for example, in harvesting applications) and enhanced handling of the fruit (useful, for example, in pick and place with reduced possibility to slip).

3 The Mechanical System

The CAD model of the soft gripper is illustrated in Fig. 2. The system mainly comprises four soft fingers with embedded suckers and one gripper base. Each finger is composed by an elastomeric structure with two separate air paths, one for inflating the chambers on the back side to allow the bending motion, one for vacuumizing the channels on the front side for vacuum–based adhesion via the suction cups. In the isometric view of the finger (bottom right of Fig. 2), we can see that two air channels are dedicated to vacuum (one for each line of suction cups), while one channel is dedicated to compressed air for bending motion.

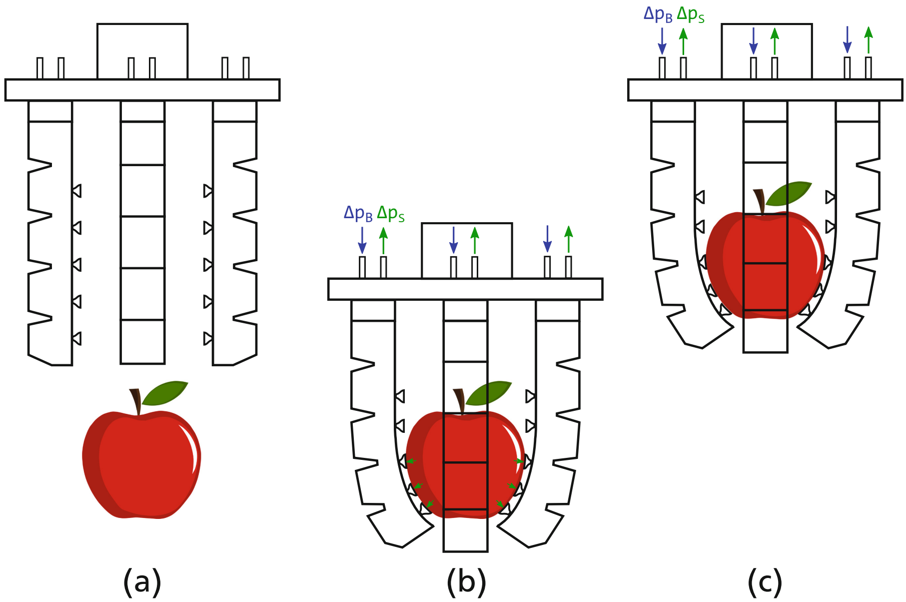

Fig. 1. Concept of multi–fingered soft pneumatic gripper with embedded suckers. Positive pressure generates bending of the actuators, allowing for shape adaptation to the object (Δp_B). Negative pressure generates suction, and thus better adhesion to the surface (Δp_S). (a) = soft gripper approaching the apple; (b) = soft gripper grasping the apple via bending motion and vacuum–based adhesion; (c) = soft gripper firmly handling the apple during its transportation.

To allow for grasping of objects with different sizes, we design a gripper base with three series of positioning holes; in this way the gripper has three opening distances. Furthermore, the gripper base has an internal opening for air tubes passage and it is equipped with a flange for coupling with robotic arms.

4 The Pneumatic Control Unit

The architecture of the pneumatic control unit is shown in Fig. 3. It comprises the control paths for vacuum and compressed air. For each finger, the architecture foresees: pressure regulator, solenoid valve, pressure sensor. It allows for independent control of the bending angles of the various fingers. For the vacuum path, we just consider one vacuum regulator and one solenoid valve for the simultaneous activation and deactivation of the suction cups. Indeed, in our concept, the suction cups are all activated simultaneously after the object to be grasped is enrolled by the bending motions of the fingers. The vacuum can be generated using a vacuum ejector downstream of the compressor or using a vacuum pump.

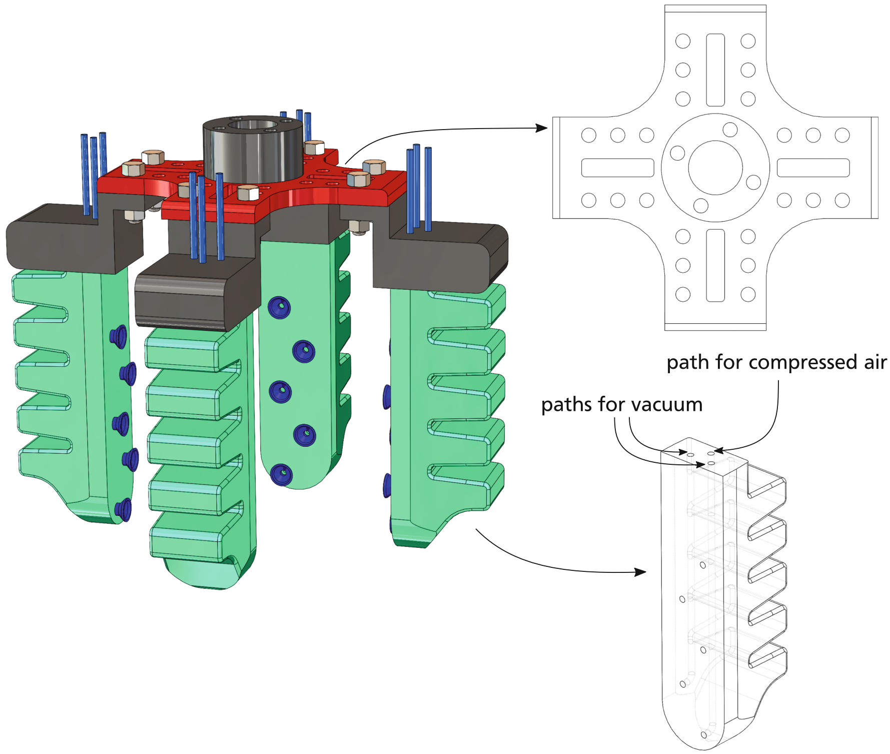

Fig. 2. CAD model of the multi–fingered soft pneumatic gripper with embedded suckers.

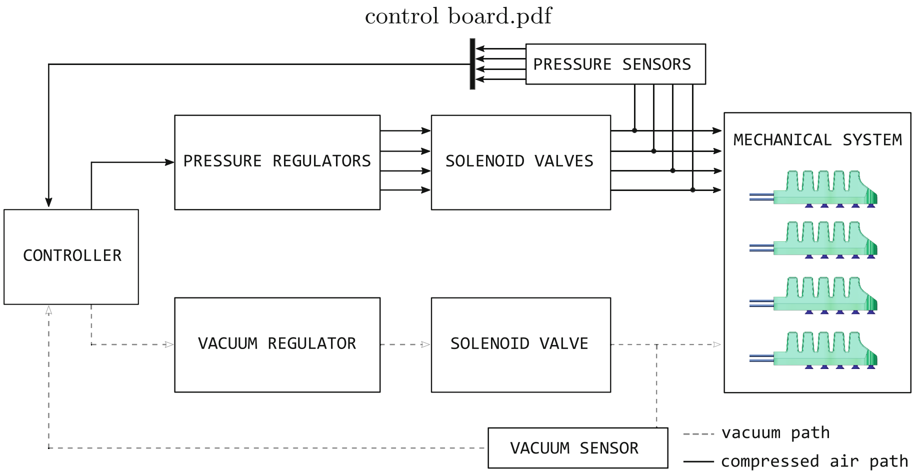

Fig. 3. Architecture of the pneumatic control unit.

5 Conclusions

A novel design concept of soft robotic gripper comprising a multi–fingered architecture with suction capabilities was presented in this paper. The design concept might improve the gripping power and reduce the objects' slip during trasport of existing solutions. These features are suitable for agrifood applications; more specifically, in the harvesting and pick and place of spherical–shaped fruits with smooth surface, as apples. However, the concept can also be valid for applications in different domains, which require soft grasping without slip and high gripping power. This is just a preliminary work dealing with the design of the gripper. Future works will be dedicated to fabrication and testing of the overall system.

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