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3D printing aimed at the fabrication of an airtight, assembly free, pneumatically actuated soft gripper

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Abstract

In this paper, the most common and inexpensive Additive Manufacturing (AM) technology, i.e. Fused Filament Fabrication (FFF), was exploited to manufacture a soft gripper able to grasp and manipulate several objects with different weight and shape. Generally, soft pneumatic grippers fabricated through FFF technology consist of more soft elements (soft flexible fingers) separately 3D printed and subsequently assembled each other, and a commercial air-connector usually glued to the soft structure. Here, a new soft gripper made up of 4 fingers has been manufactured in a single-step printing cycle without resorting to any assembly tasks. No commercial air connector has been used: a novel soft air-connector has been manufactured in the same printing cycle of the gripper making it fully assembly-free. Two different thermoplastic polyurethane filaments have been used, the rigid one for the air-connector and the inextensible elements and the soft one for the extensible fingers. Taking particular care to process parameters, a printing strategy ensuring the total air-tightness of the soft gripper was developed: the additive manufacturing of air-tight soft structure with complex geometries is very challenging in soft robotic field because it could lead the replacement of the traditional moulding manufacturing technology. After the gripper fabrication and the air-tightness test, it has been used to grasp and manipulate several objects, such as a bottle of water, a laptop mouse, an alarm clock etc. From this phase stands out that objects with different shape, geometry and weight (from 15 g up to over 1000 g) can be successfully handled thanks to soft material used because the soft fingers of the gripper passively adapt themselves to unknow objects.

Additive manufacturing; soft robotic; soft gripper; fused filament fabrication; pneumatic manipulator

1. Introduction

In recent years, a growing interest in the field of the soft robotics has emerged: several bio-inspired soft robots[1], [2][3][4] were designed, fabricated and characterized showing the potential of this new robotic wave, based on soft matter[5]. A promising application field of soft robotics concerns the world of grippers; at the state of the art, soft grippers can be classified into three main classes: actuation, controlled stiffness and controlled adhesion[6]. The main advantages of using soft grippers is the possibility to manipulate objects with several and un-conventional shapes and geometries and different weights, because the gripper can passively adapt to the shape of the object. Additive manufacturing (AM), also known as 3D printing, technologies well fit with soft robotics requirements; recently a huge exploitation of these technologies for soft robotics arose. In particular, it is possible to draw up three AM-based approaches as a function of AM role in the whole soft robot manufacturing cycle: rapid mold fabrication approach, hybrid approach and total additive manufacturing approach [7].

In the present paper, the approach named total additive manufacturing has been used to produce a soft pneumatic gripper. Two different elastomeric materials have been used to manufacture, in a single-step printing cycle a 4-finger soft pneumatic gripper: it consists of 4 PneuNets connected each other by means of a junction and an embedded air-connector. This research lays the foundation for a deep exploitation of fused filament fabrication (FFF) technology, well known for being inexpensive and very widespread, in the field of the soft robotics: in fact, the possibility to manufacture structures with embedded elements (such as air connectors), and a reduction of fabrication and assembly steps has been proved.

2. Design, manufacturing and preliminary tets

In a previous work [8], the authors: i) provided a methodology to manufacture soft actuators with embedded air connector, ii) defined the best shapes of actuators (rectangular and sinusoidal-shape) in terms of bending angle and iii) studied the relationship between process parameters and air-tightness of the whole actuator. With this in mind, a novel soft gripper actuated by means of compressed air has been designed, manufactured and characterized. The soft gripper consists of the following main elements: i) 4 extensible fingers: each finger is characterized by an overall lenght of 95 mm, height of 19.4 mm, width of 18 mm. Also, a sinusoidal shape and a wall thickness of 1.6 mm have been set; ii) 4 inextensible layers needed to obtain the bending of the four fingers instead that a lengthening; iii) a central junction to direct the air flow throught the four etensible fingers; and iv) the air-connector described in detail in [8]. All the elements are illustrated in Figure 1. FFF technology was employed: the 3D printer Ultimaker 3 (Ultimaker, Utrecht, the Netherlands), a bowden dual extruder machine, was used. Two different thermoplastic polyurethane materials have been employed: the rigid one named TPU 95 A was used for inextensible layers and air connector while the flexible one named TPU 80A was used for the extensible fingers and the junction. Two nozzles with the same diameters of 0.4 mm were used. It is important to point out that all the elements of the soft grippers have been manufactured in the same, no-stop printing cycle: in this way no assembly tasks between 3D printed elements or external parts (i.e. steel air connectors) are required.

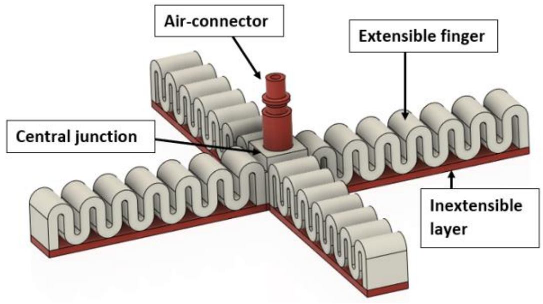

Figure 1- Design of the soft gripper

The open-source slicing software Ultimaker Cura 4.6 was used to set the process parameters: the most significant are listed in Table 1. The proposed gripper was manufactured with the longitudinal axis of the connector perpendicular to the 3D printer working platform and without recurring to the usage of supports. The total manufacturing time was 22 hours and 28 minutes, while the total cost estimated by the software was 10.83 €. As a matter of fact, the total time and cost can be reduced by increasing the layer height (in this case, it was set as 0.1 mm) and reducing infill density of the central junction (in this case, it was set as 100%).

Table 1- process parameters vs gripper elements

Element / Parameter	Extensible finger	Inestensible layer	Central junction	Air-connector
Material	TPU 80A	TPU 95A	TPU 80A	TPU 95A
Line width [mm]	0.4	0.5	0.5	0.4
Printing temperature [°C]	243	223	240	228
Printing speed [mm/s]	15	35	25	25
Infill pattern	lines	Zig-zag	lines	circular

Afterwards, the gripper was tested to understand its behavior when objects with different shape and weight were grasped. Three different objects were employed: a common funnel (weight: 15 g), a wireless mouse (weight: 70 g) and a plastic rectangular box filled with several elements (weight: more than 1000 g). The procedure used is the same for each object: an air-pressure of 4 bar is provided, the object is kept for 2 minutes by the gripper and finally decreasing the pressure up to 0 bar the object is dropped. These preliminary tests show a promising gripper behavior: it is able to manipulate several objects with different weights but more characterization steps to better classify the cathegories of objects that can be manipulated are needful; also, the integration between industrial robotic arms and the proposed soft gripper will be studied to provide a soft gripper which could be employed in real industrial scenarios. Further details about single finger actuator (i.e. pressure vs bending angle) can be found in [8]

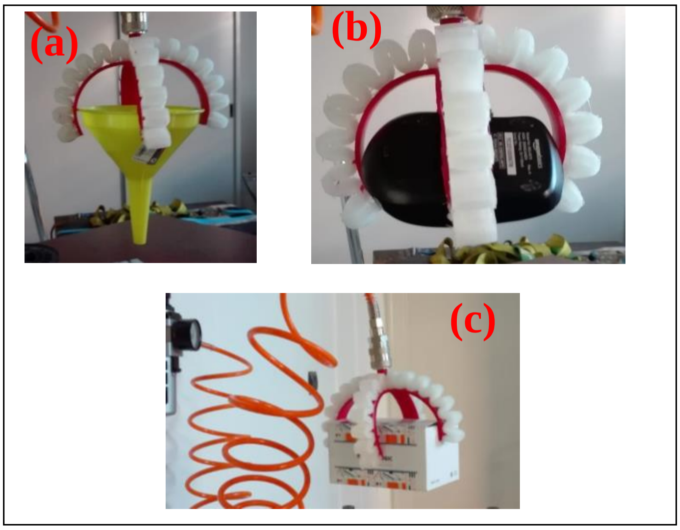

Figure 2- soft pneumatic gripper tested with: (a) 15g funnel, (b) 70g wireless mouse and (c) 1000g rectangular box

3. Conclusions

In this paper, a preliminry design of a soft pneumatic gripper has been fabricated and tested: the novelty of this work is the possibility to fabricate the gripper in a monholitic way, using FFF technology in order to avoid assembly tasks. The working principle of the proposed soft gripper is the same underlying PneuNets actuators: the usage of pressurized air to obtain the bending of patterned soft structures. Preliminary tests were carried out to show the ability of the gripper to manipulate different kinds of objects. Future works will be focused on i) a deeply characterization of the gripper in order to improve its performance under different point of views (i.e. a new design to improve the grip with the objects, improved wall thickness to increase the life-cycle of the gripper and the performances); and ii) the integration of the gripper with industrial systems to be effectively employed in industrial automation context.

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