

Flexible robotic strategy for the assembly of ring-shaped elastic objects

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Abstract—This paper addresses the challenge of the robotized insertion of ring-shaped elastic objects into parts' outer grooves, which is a key operation in several industrial processes. We propose a novel flexible strategy to insert ring-shaped elastic objects of different sizes and stiffnesses, exploiting a generic robot and a simple - yet effective - fixture. Despite the overall complexity of the procedure is entirely poured on the mentioned fixture, its simplicity of realization and implementation allows to equip the robot with a generic gripper, without the use of any additional sensor. The effectiveness of the proposed strategy is assessed via experimental tests.

Index Terms—Ring-shaped elastic object; robotics; flexible manufacturing; deformable object manipulation.

I. INTRODUCTION

The insertion of ring-shaped elastic objects into the outer grooves of a part is a task often requested in the manufacturing industry and it is fundamental in several industrial settings. The request for flexibility, high production mix and large number of product variants that characterize the current manufacturing industry calls for a robotized execution of this specific task. This paper presents a solution to make a robot manipulator insert ring-shaped elastic objects, of different sizes and/or materials, into parts' outer grooves. Particularly, the method allows to perform a common insertion operation in a flexible way, exploiting a cheaper and easily reprogrammable workstation. Indeed the operation is executed through a pneumatically actuated fixture, easy to implement, whose actions are synchronized with those of the robot, while sensors, ad-hoc grippers and specific kinds of robots are not required.

Robotic manipulation of deformable objects is a topic extensively studied in the literature since, as stated in [1], this ability is required in lots of different applications and could grant considerable economical benefits. However, the mentioned task requires high level of dexterity as explained in [2]: deformable objects are, indeed, described by an infinite number of degrees of freedom, resulting in huge uncertainties during manipulation. Ring-shaped elastic objects belong to this category and are analyzed as well: [3] presents a method, based on Finite Element, to plan the manipulation of this kind of objects. [4] discusses the assembly of a rubber belt on fixed pulleys, while motion planning for a dual arm cobot to perform the assembly of ring-shaped elastic objects, characterized by moderate stiffnesses, is investigated in [5], [6] and [7]. A force control method that exploits an ad-hoc tool is presented in [8]. Finally [9] states that, in the industrial framework, this

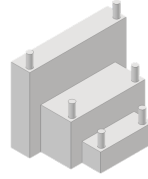


Fig. 1. Model of a custom fingertip with stair configuration.

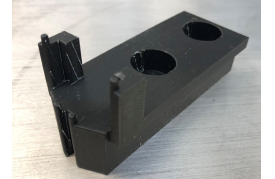


Fig. 2. 3D printed custom fingertip for the fixture.

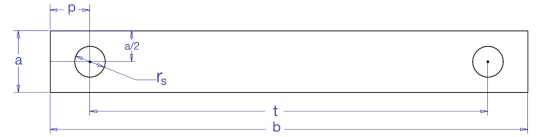


Fig. 3. Top view of the plate of a fingertip's step.

operation is usually carried out manually by human operators or thanks to specialized and complex grippers for robots. In contrast with the literature, our method does not require a specific robot, while a dual arm is necessary in [5], [6] and [7], and no additional sensors are needed, unlike [8]. Furthermore, previous strategies do not deal with the grasping phase of the elastic object. On the contrary, here the robot is equipped with a generic parallel gripper, unlike [9], enabling the grasping of the elastic components and of the parts, creating a flexible solution that is not influenced by the stiffness of the elastic object, in contrast with [5] and [8].

II. PROBLEM STATEMENT AND CONTRIBUTIONS

The task faced in this paper deals with the insertion of paired ring-shaped elastic objects into parts' outer grooves. The framework can be generalized considering all the tuples $(r_{ci}, r_{ni}, h_i), i \in \{1, \dots, I\} = \mathcal{R}$ where r_{ci} refers to the inner radius of the ring-shaped elastic object, while r_{ni} and h_i are, respectively, the nominal external radius and the insertion height (given by the distance between the beginning of the groove and the extreme edge) of the corresponding part where the elastic object has to be inserted. Finally, \mathcal{R} represents the set of paired objects. The goal is hence to design a fixture and create a routine to insert elastic objects of radii r_{ci} on the related parts of radii r_{ni} .

To complete the operation, we design custom fingertips that allow to enlarge in a hexagonal shape the elastic object, previously placed on their pins (Figures 1 and 2) without

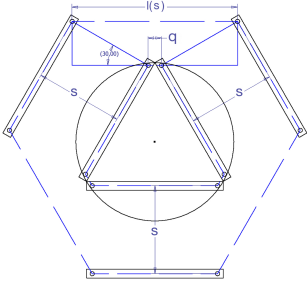


Fig. 4. Definition of $q, s, l(s)$.

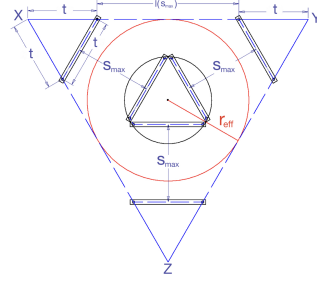


Fig. 5. Equilateral triangle and definition of the maximum r_{eff} .

stretching it. Controlling, by means of proportional regulators, the opening and the closing of the three jaws of a pneumatic gripper where the fingertips are mounted, it is possible to enlarge the elastic object of radius r_{ci} in a configuration that lets the robot insert from above the part with radius r_{ni} without any contact, bringing the groove at the same height of the elastic object. At this point the jaws close on the element without pressing against it, allowing the elastic object to partially enter the part's groove. Finally the robot lifts the part and the insertion is completed.

III. DESIGN OF THE FINGERTIPS

The proposed fingertips are designed according to a stair configuration, composed by different steps (Figure 1 and 2): a single step can be exploited to execute the considered operation on different tuples (r_{ci}, r_{ni}, h_i) and multiple steps are needed to perform all the required insertions.

The design of the fingertips can be split in two phases:

- Selection of the parameters to design a single step, starting from a given tuple (r_{ci}, r_{ni}, h_i) , aiming to place the elastic object with inner radius r_{ci} on the fixture without deforming it and to insert the highest number of subsequent pairs.
- Introduction of the physical realization constraints and computation of the needed number of steps.

Considering the variables reported in Figures 3, 4 and 5, it can be shown that the goal is to compute q to enlarge the elastic object in a configuration that brings to the identification of the circumference of maximum effective radius r_{eff} . This circumference is inscribed in the equilateral triangle XYZ , obtained by extending the biggest sides of the irregular hexagon created enlarging the elastic object, exploiting all the available stroke of the chosen pneumatic gripper, $s = s_{max}$. Since $\delta = p + \sqrt{3}a/2$ and $\gamma = -\sqrt{3}s_{max}/2 + \sqrt{4r_{ci}^2 - s_{max}^2}/2$, we can compute the value $q^* = \operatorname{argmax}(r_{eff})$ and conclude that:

$$r_{eff}|_{max} \begin{cases} q^* = \gamma & \text{if } r_{ci} \geq \sqrt{\delta^2 + s_{max}^2} + \sqrt{3}\delta s_{max} \\ q^* = \delta & \text{if } r_{ci} < \sqrt{\delta^2 + s_{max}^2} + \sqrt{3}\delta s_{max} \end{cases} \quad (1)$$

IV. EXPERIMENTAL RESULTS AND CONCLUSION

Custom fingertips with two steps have been produced to insert three o-rings on three different pistons' groove. The

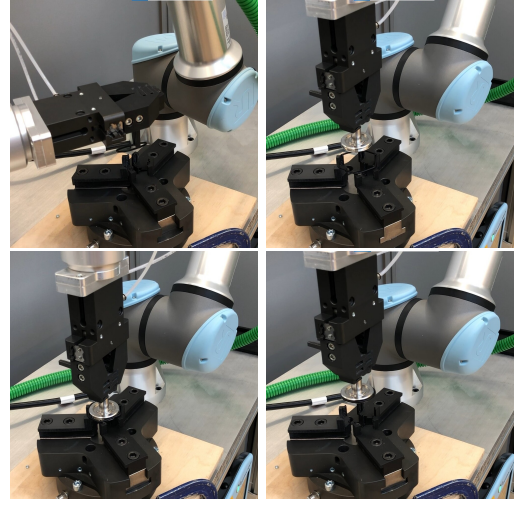


Fig. 6. Snapshots taken from one of the experiments of o-ring insertion.

experimental task consists in performing the insertion of two o-rings characterized by $r_{c1} = 8.57\text{mm}$ and $r_{c2} = 19.67\text{mm}$. Snapshots of one of this two insertion are shown in Figure 6.

Summing up, our method suggests a flexible solution to insert different kinds of ring-shaped elastic objects with various sizes and stiffnesses, using conventional and general purpose hardware: the proposed methodology lends itself to a straightforward use in a real industrial setup.

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