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Design and construction of a variable-aperture gripper for flexible automated assembly

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ABSTRACT

The growing market demand for a wide variety of product models and small batch production makes flexible robotized production systems an emerging need in industry. Today, in manufacturing applications, general purpose grippers are not very considered, and robot end effectors are properly designed for the specific task with a strongly limited versatility. Flexibility is thus usually obtained by using a different tool for each family of parts: a tool changing system allows the robot to rapidly replace the tool on the end effector; tools are stored in a tool magazine allocated in the workcell. However, such systems are expensive and their use can affect the working cycle-time. This paper presents the design and testing of a variable-aperture, cost-effective gripper, capable of adapting its aperture (grasp width) to different handling demands, without affecting the working-cycle time of the production system. The solution proposed consists of (1) an electrically-actuated mechanism, which allows it to satisfy flexibility requirements, by regulating the aperture in hidden time; (2) a pneumatically-actuated mechanism to achieve high performance in open/close operations. Simulations and preliminary tests showed that this type of design can be a suitable solution to increase flexibility in robotized workcells without increasing the cycle time.

1. Introduction

Today's fast changing market situation is characterized by reducing product life cycles and increasing the number of product variants. Flexibility in production is the key issue that industries increasingly requires to handle a wide variety of products, perform quickly and easily frequent model changeovers, process multiple parts and models simultaneously, and be quickly responsive to part design changes [1]. The flexible automation and robotics are a viable investment strategy to compete economically in the global market, evidenced by sales of industrial robots increased by 9% every year since 2008 to 12% in 2013 [2,3].

When automated by means of a robot, traditional flexible assembly systems (FAS) are typically composed of a programmable manipulator fed by traditional hoppers and vibratory feeders that requires, in case of product variations, new bowl feeder tooling, additional bowl feeder tops and expensive time-consuming set-up activities. Rosati et al. [4,5] and Finetto et al. [6] introduced a new concept in the field of automated FAS: the fully-flexible assembly system (F-FAS). This kind of assembly system consists of: a fully flexible feeding subsystems, which replaces a dedicated feeder for each component and uses a vibratory bulk, containing all parts needed to fill the production order, to pour a random set of components onto a vibrating plane; a vision system that recognizes the parts on the vibrating plane; a programmable robotic manipulator used to pick the parts on the plane in an online defined sequence, and place them on one or more flexible assembly stations [6]. This single robotized workcell is able to guarantee a higher level of flexibility than traditional automated FAS, and eliminate many of the problems experienced by manual operators such as accuracy and lower productivity [7]. However, it can suffer of low efficiency [8,6]. A way to achieve high productivity for a F-FAS is maximizing the number of graspable components with respect to those recognized by the vision system. For this reason, a manipulator in a F-FAS requires a compact gripper, able to pick single parts while avoiding collisions or undesirable movements of near components. Another issue is that parts of significantly different sizes must be picked to ensure flexibility, however tool change may heavily affect productivity [9]. Ideally, the robot of a F-FAS workcell should be equipped with a gripper having short stroke (for compactness) but variable aperture (for flexibility).

Today, in manufacturing applications, general purpose grippers are not very diffuse and, on the contrary, end effectors are designed for very specific and focused task with a strongly limited versatility [10]. On the other hand, flexibility is one of the biggest differentiators and the common denominator in the latest EOAT (End-Of-Arm Tooling) trends [11]. In fact, lately, research has shown wide interest in the development of innovative and adaptive grippers in many area of use. Udupa et al [12] have designed an

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innovative asymmetric bellow flexible pneumatic actuator (AFPA) and a miniature soft gripper consisting of three AFPAs developed to pick and place small parts with the capacity to adapt to the form of the object. Sam et al. [13] proposed a flexible, multi-functional gripper for handling unpacked food products with variable size, shape and weight. Based on Bernoulli principle, this gripper is able to generate a high-speed flow between the gripper plate and the product surface thereby creating a vacuum which lifts the product. Takavoli et al. [14] have introduced Flexirigid, a grasping mechanism that combines caging and force closure approaches in order to grasp an object. The main advantage of this gripper is its adaptability to various object shapes and sizes with low degrees of freedom (d.o.f.). Canali et al. [10] have proposed a high reconfigurable robotic gripper which is designed to be able to grasp objects of various shape, material, weight and dimension, based on a two-d.o.f. finger.

For more specific fields, such as micro-assembly line, other types of adaptive grippers have been investigated. Bruzzone et al. [15] have developed a modular gripper with metamorphic fingertips, capable of adapting their shape to different micro-objects. Qingsong et al. [16] have designed an asymmetric flexible micro-gripper mechanism based on flexure hinges that is able to perform micro-assembly tasks.

This paper presents the design of a variable-aperture, cost-effective gripper, capable of adapting its aperture to different handling demands in such a short time as to be masked by the robot handling time in order to minimize the working-cycle time of a flexible robotized production system. The solution proposed consists of a gripper with two different parts: an electrically-actuated mechanism to satisfy adaptability requirements, by allowing the regulation of the aperture (grasp width) in hidden time; a pneumatically-actuated mechanism to achieve high performance in open/close operations. The electrical actuation of the mechanism allows for continuous regulation of gripper aperture, whereas pneumatic on/off actuation of jaws assures high speed opening and closing. The regulation of gripper aperture, instead of using a simpler gripper with a single pneumatic actuator, is fundamental for achieving a correct, accurate, and effective grasp of objects. In fact, if both small (e.g., width of 10 mm) and large (e.g., width of 100 mm) objects were grasped by using a gripper actuated by a single pneumatic cylinder (e.g., with an aperture of 105 mm and a stroke per jaw of 50 mm), either grasping time would result much longer for smaller objects (due to longer stroke), or an extremely higher velocity of the jaws would be needed. However, in this way, the impact between jaws and grasped object would lead to damage of the object, vibrations, significant re-orientation or movement of the object during grasping. This would compromise repeatability of grasping, which is a fundamental requirement in every industrial application. Secondly, the use of a large aperture gripper to grasp small objects would require large clearance around the object, which is usually unavailable in real applications (part picking from vibratory feeders or pallets, loading/ unloading of machining center or die, etc.). On the contrary, the solution proposed in this paper allows to adapt aperture to object size, while keeping at the same time stroke length and grasping time independent of object size.

In the following, after the definition of system specifications (Section 2), we illustrate the mechanism synthesis (Section 3) and the mechanical design (Section 4) of the gripper. Section 5 describes the prototype construction, whereas Section 6 shows some results from preliminary tests. Finally, conclusions are drawn in Section 7.

2. Specifications

The gripper consists of a mechanism that is actuated by an electrical motor for the regulation of the aperture, and a pneumatic cylinder in order to rapidly open and close the gripper jaws. The first important design aspect for such a system is the path type of the gripper jaws when they are moved by the two different actuators. In the presented solution, we opted for: a parallel gripper [17] with short transverse stroke of the jaws; a continuous regulation of the aperture that allows

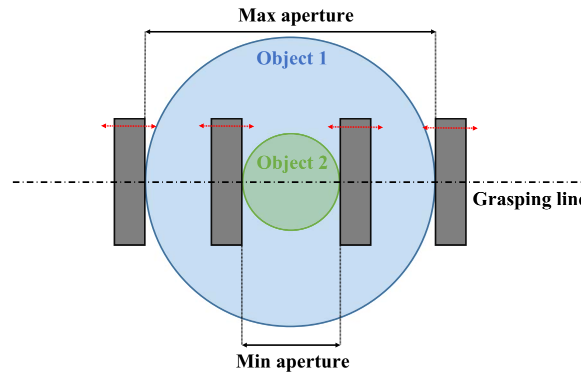

Fig. 1. Regulation of the aperture to grasp different objects with a parallel gripper. The arrows indicate the opening-closing movement of the jaws to grasp objects.

the jaws to be closed along the same grasping line for any aperture selected (see Fig. 1). Other desirable features are low mass and inertia, and compactness.

More precisely, the system specifications that we used are listed below.

Aperture regulation:

- regulation of the aperture with repetition accuracy of ≤ 0.1 mm;
- simple control system and affordable electrical equipment;
- maximum variation in part widths to handle of 100 mm (e.g., 5 ÷ 105 mm);
- regulation time of ≤ 1.0 s.

Grasping movement (opening-closing):

- parallel jaws with negligible transverse velocity with respect to the grasping line;
- closing time of ≤ 0.1 s;
- grasping force of ≥ 50 N;

Additional specifications:

- mass of $\leq 1,\ 5$ kg;
- inertia at the robot axis of $\leq 0,\ 045$ kgm^2;
- maximum volume $h \times l \times p \leq 150 \times 200 \times 100$ mm.

3. Mechanism synthesis

By following the traditional procedure of planar mechanisms design [18], the selection of the mechanism topology is the first crucial point. In the literature, several advanced methodologies exist to carry out the mechanism type synthesis [19]. In this study, with the aim of maximizing the simplicity of the system, we used a single-criterion method, that is to minimize the number of joints and links, also minimizing mechanical plays and maximizing accuracy. Another import aspect of topology regards symmetry. We chose a symmetrical design in order to enhance the impact of the jaws on the grasped parts. In the following, we will consider half of the mechanism only.

3.1. Mechanism topology

The topology considered is based on a four-bar linkage, as shown in Fig. 2 (*ABCD*). Link *DC* works as the crank whilst the connecting rod consists of a ternary link, in which the end point *P* represents the revolute joint of the coupling to the jaw (*PGQ*). By acting on the crank (first d.o.f., electrical actuation), the end point *P* can be moved in order to regulate the aperture (regulation movement).

For grasping movements, a second d.o.f. (pneumatic actuation) is added by introducing a slider (either horizontal or vertical) in *A*. By