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 vibratory 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
innovative asymmetric bellow flexible pneumatic actuator (AFPA) and a
miniature soft gripper consisting of three AFPA's 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
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 ≤1.5 kg;
- inertia at the robot axis of ≤0.045 kgm²;
- maximum volume h × l × p ≤ 150 × 200 × 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 im-
portant 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 (PQ). 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

![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.](image)
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