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Design and test of a gripper prototype for horticulture products

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ABSTRACT

This paper describes the design of a gripper for horticulture product grasping. The design solution has been achieved by means of a systematic approach by evaluating all the possible architecture. The proposed structure is optimized and numerically simulated. Then, a prototype has been built and tested in laboratory. The design process and test results are discussed to show the efficiency of the built prototype with lab tests.

1. Introduction

The end-effector can be considered the most important component of a robot when it deals with horticulture products, since it acts as interface between the robotic system and product. Since fruits and vegetables usually have irregular changeful shapes and low mechanical properties, the end-effector must be designed properly to grasp them. Robotics applied to horticulture products handling has been studied for more than twenty years. However, research results have been focused on single-product applications and end-effectors have been designed only for specific targets [1], such as tomatoes [2–4], strawberries [5] and cucumbers [6]. In particular, [2] describes the design process and the prototyping of a gripper for tomato harvesting. In [3], the mechanical properties of tomatoes while grasped by robotic fingers are analyzed by measuring maximum deformation for different grasp conditions at collision status. In [4] a packaging system for tomatoes with underactuated fingers is presented, while a gripper for strawberry harvesting is introduced in [5] and [6] describes the development of an autonomous robot for cucumbers harvesting. Those experiences show that current grippers are specifically designed for a single application and they are not flexible enough to adapt to a wide variety of shapes and sizes.

An important challenge to improve grippers can be recognized in the use of compliant components. They are non-rigid materials that are able to adapt passively to the irregular shape of horticulture products. Furthermore, compliance increases contact surfaces and reduces the stress on grasped objects. Even if an end-effector with compliant elements is not a universal gripper for all horticulture products, it can deal with a wide variety of objects in a wide range of shapes and dimensions. The MultiChoiceGripper, shown in [7], is an example of compliant gripper.

This paper presents the development of an end-effector that is able to grasp medium-sized spherical fruits. This gripper shows suitable functioning for careful grasp and release of horticulture products. In Section 2, horticulture products are analyzed to identify the requirements for a suitable gripper. In Section 3 the chosen structure is described, and then its mechanical design is optimized and elaborated for rapid prototyping. Section 4 presents the experimental tests made with the built prototype. Finally, Section 5 contains conclusive remarks on this work and possible future developments.

2. Requirements for horticulture products handling

Nowadays, the harvesting of horticulture products is usually performed manually by workers. Post-harvesting operations are usually executed by automatic selection and packaging lines, as

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a) b)

Fig. 1. Examples of packaging lines: a) Automatic packaging line for apples; b) Packaging operations performed by human workers.

shown in Fig. 1a. However, packaging for high-quality products are still performed mostly by human operators, as shown in Fig. 1b. The main obstacle to an automatization of the task is the efficiency of grippers, since a gripper should be able to carefully grasp and hold horticulture products. This can lead to lower production costs and to decrease the lead time between the harvest and market sale.

In order to design a gripper for a robotic unit, object analysis is required [8]. This paper deals with medium-sized horticulture products, such as apples, tomatoes, citrus fruits and peaches. Since 1961, the Organization for Economic Co-operation and Development (OECD) sets international standards for fruits and vegetables, with information about the standard dimensions for commercial products [9]. Relevant information is summarized in Table 1. The OECD sets standards, even for the quality of fruits and vegetables, but a scientific approach is not used for quality checks, since only a visual observation is required for quality parameters [9]. The average diameter of most of the considered horticulture products is in the range of 40 to 100 mm. Weight varies even within species, but it is always in the range of 50 to 500 g [9]. The shape of those products is approximately spherical with some notable exceptions in lemons and oblong tomatoes. The mechanical properties of apples, pears and tomatoes were measured in several research projects [10–12]. Data are summarized in Table 2. Since a tomato has the worst mechanical properties, it can be used as a reference fruit for the design of grippers for horticulture products.

Possible end-effector solutions can be identified through general considerations among the following architectures, as summarized in Table 3:

- Grippers, which are composed by two or more rigid fingers and a mechanism to move them against an object. A gripper usually has a 1 to 3 degrees-of-freedom structure. Force control is essential for functioning and even a single sensor is enough to avoid damaging the object. The low flexibility of a gripper is its main disadvantage, since rigid fingers cannot wrap around an object or adapt to it.
- Artificial hands, whose design makes them similar to a human hand. They are composed of multiple anthropomorphic fingers and they are capable to close them onto an object by wrapping around it. They can be flexible and adapt to most shapes, but they need several actuators and sensors. This makes the control complex and leads to excessive costs.
- Pneumatic devices, which use partial vacuum to lift objects with non-porous surface. The grasp is difficult to control and it can leave traces on the surface of horticulture products or even damage them. In addition, suction cups could not adhere to some curved or irregular surfaces, failing to pick the product up. For those reasons, pneumatic devices cannot be considered suitable for applications with horticulture products.
- Other end-effectors, which can be based on magneto- or electro-adhesion; they are not able to manage organic products.

Thus, a suitable end-effector design can be considered as a crossover of grippers and hands, since it should be flexible to

Table 1
Sizes of horticulture products as from standards in [9].

Product:	Min. size [mm]:	Max. size [mm]:
Apples	60	110
Apricots	30	60
Clementines	35	60
Lemons	45	90
Oranges	53	120
Peaches	56	100
Tomatoes	35	105

Table 2
Mechanical properties of common fruits and vegetables [10–12].

Product:	Young's Modulus average [MPa]	Young's Modulus deviation [MPa]	Poisson's Ratio [–]
Tomato – Ripe	2.32	N.A.	0.74
Tomato – Unripe	4.07	N.A.	0.55
Pear	5.80	0.50	0.25
Apple	12.89	2.43	0.32

Table 3
Requirements for end-effectors in the grasp of horticulture products.

Requirement	Gripper	Hand	Pneum. Devices
Geometry:			
Radius: 20–50 mm	Yes	Yes	Yes
Forces:			
Firm grasp	Yes	Yes	No
No damage	Yes	Yes	No
Energy:			
Electric drives	Yes	Yes	No
Materials:			
Non-toxic material	Yes	Yes	Yes
Operation:			
Easy to control	Yes	No	Yes