An approach to the automation of blueberry harvesting using soft robotics

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Abstract: Soft grippers are used to produce a significant advance in the manipulation of delicate objects. A field of application that is presented in this paper is the automation of the selective harvesting of high-value crops. This study addresses a first approach to the design of a soft gripper and its adaptation to a robotic system for blueberry harvesting. The experimental results are carried out to demonstrate the feasibility and effectiveness of the proposed prototype.

Keywords: soft robotics, soft grippers, precision agriculture, end-effectors, blueberry harvesting

1 Introduction

In the last decade, the agricultural sector has undergone a deep transformation to cope with the growing demand for food [UN15; GdPFSNE20]. Among the main tasks in agricultural processes, those that involve the manipulation of fruits and vegetables continue to be one of the most time consuming and labor intensive, resulting in low efficiency and limited competitiveness. For this reason, a great research effort is underway to automate these manual operations, as in the case of selective harvesting, combining multidisciplinary fields such as biological science, control engineering, robotics and artificial intelligence. In this regard, the gripping process in fruit harvesting is one of the most difficult tasks. Since the gripper or end effector not only needs to have the dexterity to manipulate the fruit, but also adapt to the physical properties of it to avoid bruising.

In manual harvesting, humans use their hands to move different elements of the plant, and grasp the fruits and detach them, either directly or with the help of a tool. The kinematics of human hands, the deformability of the skin and muscles, and their sense of touch give us efficient grasping abilities. Attempts to emulate human skills during harvesting have resulted in numerous mechanical end-effectors. With the emergence of soft robotics, grippers based on soft and deformable materials have recently begun to be proposed for agricultural [NFSAGdP21; NFAGdP21] and industrial applications [SFI22]. These soft grippers, which are able to continuously vary their shape without requiring complex multi-joint mechanisms, have the potential to provide greater adaptability due to the intrinsic

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properties of flexible materials while presenting lower costs and simpler structures and control algorithms than hard end-effectors [PCM17; LKK17].

One of the fields where soft robotics can offer the greatest benefits are tasks related to high-value crops. In this regard, blueberry harvesting has not yet been tackled in terms of robotic automation. Although there have been a few attempts to automate this process, all of them have been unsuccessful, since the machines had not only a lower production, but also a higher percentage of bruised and unripe fruit than manual picking [HCL83]. This work aims to present an approach in the design of a soft gripper based on a deformable structure and pneumatically actuated soft diaphragm actuators for use in automatic blueberry picking. For the design of the actuator, a detailed study for the harvesting of blueberries using finger-tracking gloves is performed, with the objective of studying the optimal movement in the harvesting of the fruit, as well as identifying the pattern of the fingers involved.

2 Materials and methods

The use of finger-tracking gloves is a novel approach to the study of fruit picking. Traditionally, the visual method has been the most common approach in the scientific literature to identify harvesting movements [DSMA15]. This method, although simple, is inaccurate to measure in detail the motion pattern made by humans in fruit harvesting. With the use of finger-tracking gloves, it is possible to monitor numerically the movement patterns performed during agricultural tasks, such as harvesting. This allows analyzing the different picking patterns in a detailed manipulation study. Harvesting experiments were conducted under real conditions at the Leibniz Institute of Agricultural Engineering and Bio-economy e.V. (ATB). The blueberries (Vaccinium corymbosum) selected for the experimental test were harvested from ATB Marquardt fields in Potsdam, Germany. The finger-tracking gloves used, shown in Figure 1, were the Manus Prime 2 gloves [MM22], which can track the angles between the different joints as well as the angle of stretch between the fingers.

Fig. 1: Blueberry harvesting with Manus Prime II finger-tracking gloves

3 Soft gripper for blueberry harvesting

To identify the soft gripper requirements to be fully operational, both fruit characteristics and manipulation patterns data have been collected. Analysis of the latter, as well as meeting other requirements such as simplicity and avoidance of bruising of the fruit, determined the limitations of the design. Finally, the soft gripper has been designed to be used as an end effector on a WLkata Mirobot robotic arm, being able to perform almost all the harvesting movements required, also known in the literature as picking patterns [NFSAGdP21]. The robotic manipulator selected is characterized by its light weight and low power consumption. It is composed of six interlinked segments providing 6 Degrees of Freedom (DoF) with a maximum payload of 0.4 kg in mid-range continuous operation, which is a suitable load capacity for blueberry harvesting.

3.1 Preliminary analysis

For the measurement of blueberry characteristics, 20 blueberry samples were randomly selected. The average diameter was 13 mm, with a maximum of 15 mm and a minimum of 10 mm. The average weight was 1 g, with a maximum and minimum weight of 1.4 g and 0.6 g, respectively. During the harvesting of 20 blueberry samples, the angles of the finger joints were tracked. As shown in Figure 2, the thumb and index finger were used in most of the manipulations. For a fast analysis to identify the fingers involved, the maximum values of the joints were used. The spread angles of the thumb, index, middle, ring and pinky were 39º, 0º, 0º, 0º, 0º, 0º, 0º, respectively. It is important to mention that those spread angles did not vary, particularly the angle of the thumb and index finger remaining completely static, which explains a greater stiffness in the grasping motion. With all of the above, it can be determined that a two-point grip is adequate for blueberry picking.

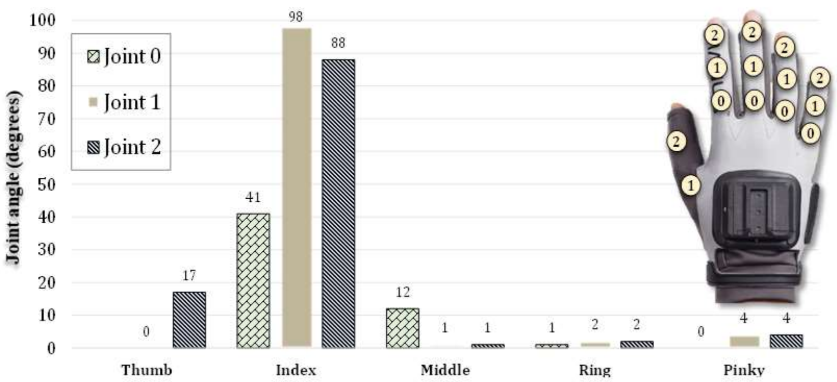

Fig. 2: Maximum angle reached by the finger joints during blueberry harvesting

3.2 Soft gripper design and control system

For the design of the soft gripper, two types of soft technologies were used, flexible structure and pneumatic actuation. The embedding of the pneumatic actuation in the flexible structure is novel, as the literature shows that although these technologies have been used together, they have always been physically independent [TGPSA19]. The integration of them gives the possibility of having a more compact and reliable gripper, as well as making them easy to manufacture by rapid prototyping printers. On this last point, it is important to highlight that the soft gripper has been designed to be manufactured on a 3D printer, as both the structure and the soft actuator have been printed in polylactic acid plastic (PLA) and AR-G1L, respectively. To drive the soft gripper, sensor and control elements are required to ensure the accuracy of the air pressure measurement and constant airflow. In Figure 3, the electronic and pneumatic systems are schematically described. Figure 3a shows that the core of the electronic system is an Arduino, particularly a Mega 2560, which controls the different elements. Furthermore, Figure 3b displays the pneumatic system, which consists of (i) an ONPIRA air pump with an airflow of 0.25 L/s; (ii) a pneumatic solenoid valve; and (iii) a Freescale Semiconductor MP2200DP air pressure sensor (measurement range: 0-200 kPa, linearity: ±0.25%).

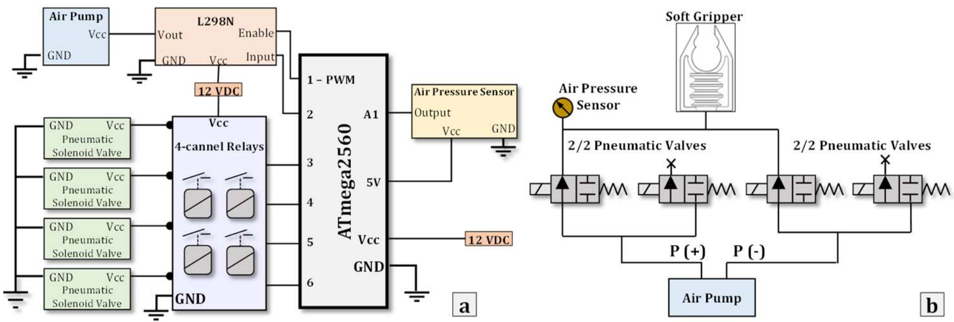

Fig. 3: Schematic presentation of the (a) electrical and (b) pneumatic circuits for controlling the soft gripper

4 Evaluation

In order to validate the feasibility of the proposed approach and evaluate its performance, several experimental tests were carried out as shown in Figure 4. To measure the gripping force a grasping force test was conducted. This study, also known in literature as a slip payload [GKK19], was performed by using a system designed to both generate a downward force and measure the slip payload. The characteristics obtained in the tests were as follows: (i) mass of the soft gripper: 38 g, (ii) max. Displacement of the soft actuator tip (50 kPa): 55 mm, (iii) operating pressure range: -60 – 50 kPa, (iv) slip payload test (-60 kPa): 350 g and (v) mean response time of around 1s. Specifically, Figure 4a shows the gripper is in its extended mode with the position that is used to adapt to the various sizes of blueberries. Figure 4b shows the gripper in its closed mode, where it can be used to move leaves or branches. In Figure 4c, another more precise type of grasping can be seen, where in addition to serving for picking, it also serves for positioning the blueberry in pick-and-place tasks as well as for putting aside branches or leaves for easier picking in a possible bimanipulation situation. Finally, Figure 4d shows the position of the gripper where it has more pulling force to pick the fruit, since the object is completely blocked.

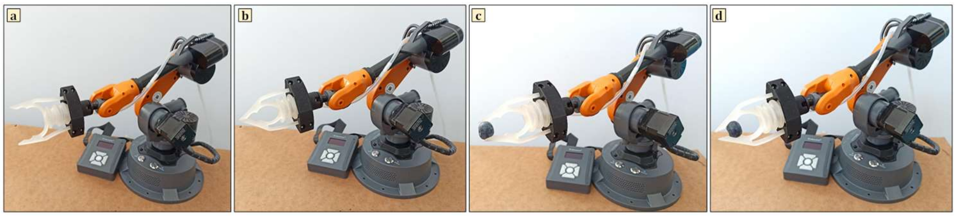

Fig. 4: WLkata Mirobot robotic arm with the custom-designed soft gripper showing (a) extended position, (b) closed position, (c) blueberry grip with the tip, and (d) blueberry grip in locked position for harvesting

5 Conclusion

The soft robotics field has been rapidly increasing, especially in sectors such as manipulation and rehabilitation. However, less attention has been given to the agricultural sector, where soft technology can have a significant impact, enabling the development of robotic harvesters with responsive, safe and adaptable grasping capabilities. This article proposes a soft gripper whose main features are its versatility, ease of manufacture and assembly, affordability and adaptability for small fruits and the capability to handle agricultural products with all the advantages offered by soft robotics technology. For this purpose, an approach to the novel concept of a flexible structure with an embedded soft diaphragm-type actuator is studied by adapting it for blueberry harvesting. As a future line, it is intended to add the gripper to ROS for its integration in the manipulator as well as in the control system.

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