Springer Proceedings in Advanced Robotics 32

Series Editors: Bruno Siciliano · Oussama Khatib

Cristian Secchi
Lorenzo Marconi *Editors*

European Robotics Forum 2024

15th ERF, Volume 1

spar

Springer

SoftGrip: Towards a Soft Robotic Platform for Automatized Mushroom Harvesting

Niccoló Pagliarani[1,2(✉)], Costas Tzafestas[3], Evangelos Papadopoulos[3], Petros Maragos[3], Athanasios Mastrogeorgiou[4], Antonis Porichis[5], Helen Grogan[6], Robin Ehrhardt[7], and Matteo Cianchetti[1,2]

[1] The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Pisa, Italy
{n.pagliarani,m.cianchetti}@santannapisa.it

[2] Department of Excellence in Robotics and AI, Scuola Superiore Sant'Anna, Pisa, Italy

[3] School of Electrical, and Computer Engineering, National Technical University of Athens, Athens, Greece

[4] TWI-Hellas Center, Halandri, Greece

[5] AI Innovation Centre, University of Essex, Essex, Colchester, UK

[6] Horticulture Development Department, Teagasc Food Research Centre, Ashtown, Ireland

[7] Mitsui Chemicals, Düsseldorf, Germany

Abstract. The fresh food industry significantly depends on manual labor, which can make up to 40% of total production costs. Until now, implementing safe robotic automation for gently harvesting fresh produce has been difficult due to the complex and delicate nature of these tasks. The EU-funded SoftGrip Project aims to revolutionize the fresh food sector with technological advancements. By integrating artificial intelligence (AI) and robotic automation, it is possible to achieve gentle harvesting, enhance productivity, and lower labor costs for small and medium-sized European mushroom farms. The innovative smart soft gripper, designed to learn skills from expert harvesters through imitation learning, seeks to provide an economically feasible, scalable, and environmentally friendly solution, transforming the mushroom cultivation industry and the wider fruit market.

Keywords: agricultural robotics · soft robotics · AI-enabled robotics

1 Motivation and Background

Robotic systems delicately handling items can be applied across various production sectors, offering substantial economic advantages. For example, deploying robots to manage pressure-sensitive products in the agri-food industry can lower labor expenses, enhance productivity, and improve working conditions [1]. In particular, the mushroom industry is particularly experiencing increasing pressure due to high labor costs, which can make up 40% of the total production

C. Secchi and L. Marconi (Eds.): ERF 2024, SPAR 32, pp. 48–52, 2024.
https://doi.org/10.1007/978-3-031-76424-0_9

expenses [2]. The white button mushroom (*Agaricus bisporus*) is the fifth most widely cultivated mushroom globally, comprising 11–15% of worldwide production, amounting to 4.4–4.7 million tonnes between 2013 and 2018–19 [3]. In Europe, *A. bisporus* production in 2020 was 1.24 million tonnes of which approx 65% was harvested by hand for the fresh market and 35% for the processed market [4]. While mushrooms can be mechanically harvested and processed for canning and freezing, more advanced automation is needed for picking and processing mushrooms for the fresh market due to stringent quality standards. Harvesting fresh mushrooms is a demanding task that requires the dexterity, precision, and sensitivity of human hands to avoid damaging the mushrooms. The conditions for harvesting can be challenging, often involving work in confined spaces with high humidity, and these conditions can vary significantly from one country to another. Despite some recent innovations, finding and retaining labor for this demanding work has remained a significant challenge in Europe and globally in recent years. As a result, the horticulture sector is increasingly turning to automation and robotics to address labor shortages. The EU-funded SoftGrip project, with its innovative approach to mushroom harvesting, offers a reassuring solution to this pressing issue. Robotic harvesting systems for fresh mushrooms have been developed in the past; however, none have yet met the precise quality requirements of the market. Mushrooms have delicate structures that are easily damaged or bruised by external forces. Conventional gripper designs often struggle with this delicacy and face challenges due to the high variability in orientation and attachment strength. Bruising and discoloration of mushrooms can happen at multiple stages throughout the crop and supply chain. Conventional rigid end-effectors are not well-suited for handling delicate organic objects in dense environments, as they often damage both the target mushroom and those nearby. Moreover, rigid end-effectors need high-resolution position and force sensors and precise transmission systems to prevent harm to the fragile mushrooms [5]. Previous efforts to replace rigid end-effectors with robotic vacuum end-effectors [6] have shown only partial success. The primary issue is that the gripping forces applied by suction cups can still be too strong because of their limited contact area. Given the high variability in size, orientation, and cluster density, improving traditional suction cup designs is unlikely to prevent damage to mushrooms completely.

2 Objectives

To address the challenges associated with gently grasping delicate items, the EU-funded SoftGrip project suggests using soft robotic structures made from food-safe and recyclable elastomeric materials. The mechanical compliance of these structures is a crucial benefit, as they can passively adapt and mold around the object, thereby distributing contact forces more evenly and minimizing damage [5]. Finger-based soft grippers, which mimic the high dexterity of the human hand by allowing significant joint deformations and a broad range of motion, have proven effective for harvesting vegetables and fruits [5]. The

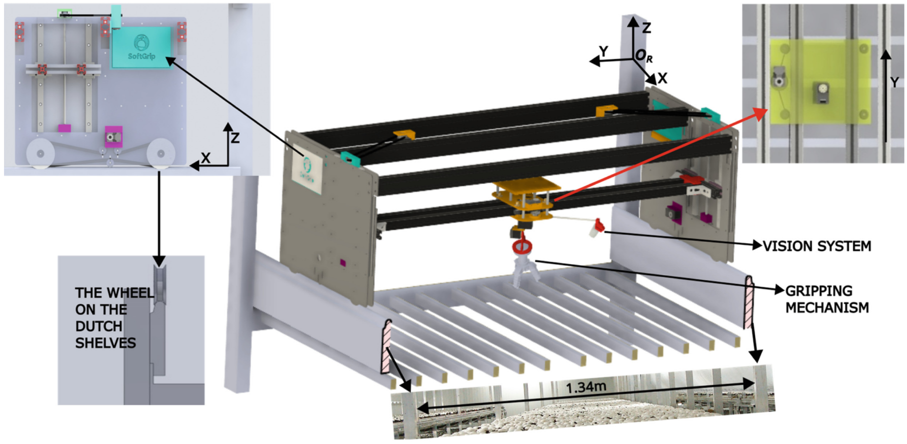

Fig. 1. Soft robotic platform installed at the level of cultivation shelves

SoftGrip project enhances these grippers with advanced modeling algorithms to improve real-time control and learning capabilities. Additionally, SoftGrip is developing a learning-by-demonstration framework that enables robots to learn mushroom-picking techniques from human workers, potentially applying these skills to similar tasks. This approach ensures safe and precise handling of delicate and high-value agri-food products.

3 Soft Robotic Platform Overview

3.1 Architecture

The overall architecture of the SoftGrip system is depicted in Fig. 1. The robot comprises two devices: (1) a Cartesian robot mounted over the shelve that moves in the x-y-z axis and (2) the soft gripper which is attached to the end-effector of the Cartesian robot and faces the mushroom cultivation. The Cartesian with the gripper will be installed over the cultivation and will be able to reach any position in the workspace. A central computer hosts the SoftGrip supervision module, which generates the sequence of grasping tasks and supervises their execution. The input to the supervision system is the estimation of mushroom size, position, and orientation. This estimation is generated by the vision module, which processes the information captured by low-cost environment cameras installed on the shelves. The supervisor generates a sequence of grasping tasks, which is fed to the grasp planner module, which in turn computes the trajectories of the robot and the grasping primitives of the soft-gripper. Then, the low-level closed-loop controllers generate the actuation commands, which are fed to the drivers of the robotic devices to execute the grasping primitives. The commands are adjusted based on feedback signals generated by the sensors, both proprioceptive and exteroceptive, embedded into the soft gripper and the encoders of the Cartesian robot actuators.

3.2 Grasping Control Strategy for Outrooting

The grasping strategy is outlined through the following sequence of steps:

1. Mushroom detection, identification, part segmentation (stem, cap), localization, and pose estimation of the cap. The information on position, orientation, and characteristic lengths of the cap of the mushroom is sent to the grasp planner.
2. The Cartesian robot positions itself above the mushroom target. The soft gripper assumes the angle of attack of the mushroom, i.e., its orientation is aligned with the orientation of the axis of the cap.
3. The fingers of the gripper are preshaped to fit the cap. The Cartesian robot moves in x-y-z until the mushroom cap is within the grasping space of the gripper. Closure of the preshaped fingers is actuated to grasp the mushroom cap.
4. The soft gripper is driven along a small curve in space to provide a combination of bending and twisting. The set of predefined movements may depend on the specific mushroom, indeed some adjustment may be required to adapt the current strategy to induce a final result that a portion of the roots is broken while the cap and the stem remain connected.
5. The soft gripper applies a small torsion on the cap and stem. This torsion results in the transfer of the tensile forces (generated in the previous step) to the rest of the roots and breaks them. Hence, the mushroom is outrooted.
6. The Cartesian robot executes a fast transfer of the mushroom in the allocated bin. The gripper releases the mushroom in the bin and returns to the workspace. The steps are repeated for the next mushrooms to be picked.

3.3 Skill Transfer Through Imitation Learning Framework

The complexity of mushroom picking, as demonstrated by the fact that it takes about 12 weeks for an adult human to master makes it impossible to pre-program grasping and force control strategies that can carry out the task reliably. This challenge is common in various other tasks involving the handling of delicate deformable objects. Thus, within SoftGrip, we aim to develop a learning-by-demonstration framework that will allow the robot to capture the mushroom-picking skill in a way that is extensible to other similar tasks. The control layer will be able to cope with the variations presented in the environment or even in the object's configuration, reinforcing the adaptability and improving the learning speed of our implementation. It will be based on the concept of probabilistic movement primitives, which constitutes a probabilistic framework that allows the exploitation of the properties of trajectory distributions for representing and learning movement primitives.

4 Conclusion and Perspectives

The Robotics 2020 Strategic Research Agenda by the European Commission underscores the strategic importance of Europe's robotics market. SoftGrip's introduction of a soft robotic system to automate mushroom harvesting is a crucial step in enhancing Europe's AI and Robotics capabilities. This innovation represents a shift in the industrial use of soft robotics, positioning Europe as a leader in this promising field with wide-ranging industry applications. Focusing on agriculture, SoftGrip addresses critical challenges in this sector through a soft robotic platform that performs sensitive tasks with a learn-by-demonstration method. This approach will accelerate robotic adoption in mushroom picking and similar sectors, marking a new era in robotic automation in the agriculture and food industries.

Acknowledgement. The authors thank all the members of the SoftGrip consortium for their valuable contribution. This work was supported by the European Union's Horizon 2020 through the SoftGrip project (contract 101017054).

References

1. Sanchez, J., Corrales, J.-A., Bouzgarrou, B.-C., Mezouar, Y.: Robotic manipulation and sensing of deformable objects in domestic and industrial applications: a survey. Int. J. Robot. Res. **37**(7), 688–716 (2018)
2. Teagasc. Horticulture input costs 2021 - impact assessment, 2021. https://www.teagasc.ie/publications/2021/Horticulture-Input-Costs-2021---Impact-Assessment.php
3. Singh, M., Kamal, S., Sharma, V.P.: Status and trends in world mushroom production-iii-world production of different mushroom species in 21st century (2021)
4. EMGG. European mushroom growers group - production figures, 2020. http://www.infochampi.eu/wp-content/uploads/2023/02/Sans-titre.png
5. Elfferich, J.F., Dodou, D., Della Santina, C.: Soft robotic grippers for crop handling or harvesting: a review. IEEE Access **10**, 75428–75443 (2022)
6. Rowley, J.H.: Developing flexible automation for mushroom harvesting (agaricus bisporus). University of Warwick, 2009