SoftGrip: Towards a Soft Robotic Platform for Automatized Mushroom Harvesting

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Abstract. The fresh food industry relies heavily on manual labor, which often accounts for up to 40% of total production expenses. Until now, achieving safe robotic automation for the gentle harvesting of fresh produce has been challenging due to these tasks' intricate, contact-rich interactions. The EU-funded SoftGrip Project was established to drive a technological transformation in the fresh food sector. The incorporation of artificial intelligence and robotic automation can facilitate delicate harvesting, boost productivity, and reduce labor expenses for small and medium-sized European mushroom farms. The smart soft gripper may be capable of skill transfer through imitation learning from expert harvesters and aspires to become an economically viable, easily expandable, and environmentally sustainable solution that will reshape the realm of mushroom culture and the broader soft fruit market.

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

1 Motivation and background

Robotic systems that efficiently handle delicate objects can be used in a diverse range of production applications, with significant economic benefits [1] [2]. For instance, using robots to manipulate pressure-sensitive products in the agri-food sector could reduce labor costs, boost productivity, and improve working conditions [3]. In particular, the mushroom industry is under growing pressure due to high labor costs which can account for 40% of production costs [4]. The white button mushroom *Agaricus bisporus* is the fifth most widely cultivated mushroom in the world accounting for 11-15% of global production (4.4 - 4.7 million tonnes) between 2013 and 2018-19 [5]. 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 [6]. Mushrooms can be mechanically harvested and processed for canning and freezing, but there's no automation available for picking and processing mushrooms for the fresh market due to the stringent quality standards. The actual picking of fresh mushrooms needs the dexterity, precision, and sensitivity of the human hand that can pick the mushroom and not damage it [7]. Harvesting conditions can be challenging – working in narrow spaces at high humidity and can vary from country to country. Although few innovations have been introduced, sourcing and retaining labor for this demanding work in Europe and globally has remained a challenge in recent years[8] [9]. The horticulture sector, in general, is looking increasingly towards automation and robotics to help manage labor shortages [10]. Robotic harvesting systems for fresh mushrooms have been developed in the past but to date, none meet the exact quality demands of the marketplace [11] [12]. Mushrooms have a soft body that can easily be damaged and bruised by external forces. Indeed, mushrooms can be easily damaged by conventional gripper designs and present high variability across multiple factors such as orientation and root strength. Bruising and discoloration of mushrooms can occur at various times during the crop and supply chain. Conventional rigid end-effectors are ill-suited for the manipulation of delicate organic objects in such a dense environment, as they are likely to damage both the collected target and mushrooms growing adjacent to it. In addition, a conventional rigid end-effector requires high-resolution position and force sensors and precise transmission systems to avoid damaging the delicate object [13]. Prior attempts have been made to eliminate the rigid end-effector by employing robotic vacuum end-effectors [14]. This solution has proven only partially successful, as gripping forces applied to the cap surface can still be excessive due to the limited contact area of the suction cup. Optimizing the conventional suction cup designs is not likely to fully eliminate damage inflicted on mushrooms due to the high variability in mushroom size, orientation, and cluster density.

2 Objectives

To overcome the challenges of delicate grasp actuation, the EU-funded SoftGrip project proposes a solution based on soft robotic structures comprised of food-safe and recyclable elastomeric materials [15]. This inherent mechanical compliance is a major advantage for gripping delicate produce, as the structure can passively morph and conform around the object to distribute its contact load [13]. In particular, finger-based soft grippers offer large joint deformations extending the range of motion and seek to replicate the high dexterity of manipulation of the human hand and have been successfully applied to harvesting vegetables and fruit [13] [16]. The SoftGrip solution relies on a set of fast-computed modeling algorithms to enhance real-time model-based control schemes and advanced learning capabilities of the soft gripper. Moreover, SoftGrip aims to develop a

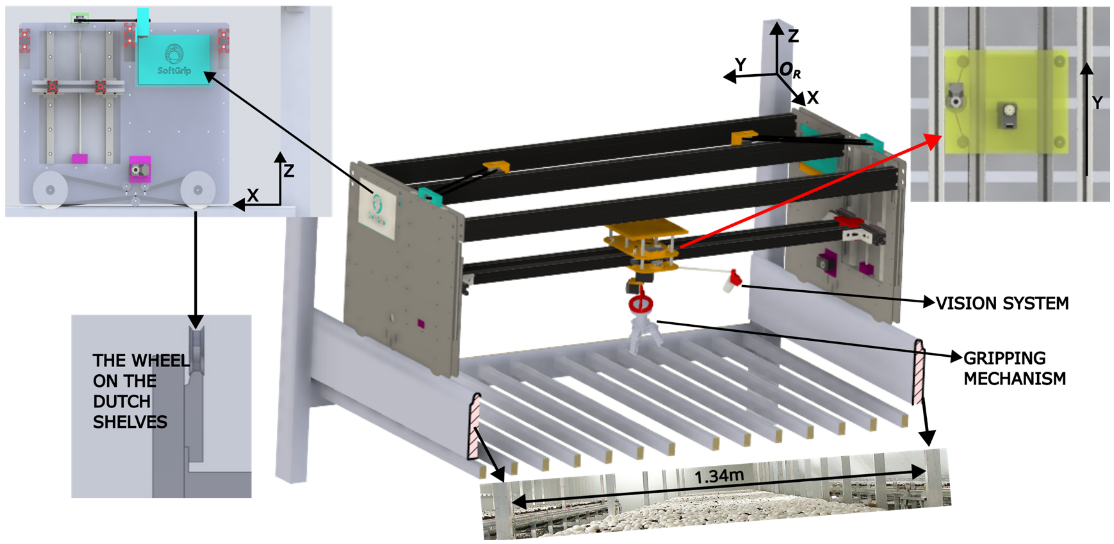

Fig. 1. Soft robotic platform installed at the level of cultivation shelves

learning-by-demonstration framework that will allow the robot to capture the mushroom-picking skill as demonstrated by the human worker in a way that is extensible to other similar tasks. This results in the ability for safe and skilled grasping that is transferable over a range 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 Figure 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.
3. 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.
4. The fingers of the gripper are preshaped to fit the cap. Step 5: The Cartesian robot moves in x-y-z until the mushroom cap is within the grasping space of the gripper.
5. Closure of the preshaped fingers is actuated to grasp the mushroom cap.
6. 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.
7. 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.
8. The Cartesian robot executes a fast transfer of the mushroom in the allocated bin.
9. 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 [17], 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

As described in the Robotics 2020 Strategic Research Agenda, the European Commission recognizes the strategic importance of the European Robotics market and the need to maintain and where possible advance these leads against a rising global market. SoftGrip proposes a soft robotic platform for automatizing mushroom harvesting and contributes to strengthening European excellence in AI and Robotics. It will set forth a paradigm shift concerning industrial adoption of soft robotics, establishing a firm foothold for Europe to take the leadership position in this hugely promising robotics sector with potential applications across a vast range of industries. SoftGrip targets the agricultural sector, which is one of the most promising application areas of robotics based on its crucial strategic importance and the severe resource efficiency challenges it faces. Implementing a soft robotic platform capable of carrying out delicate, contact-rich tasks utilizing a learning-by-demonstration approach means addressing the challenges that have so far been limited to a new wave of robotic automation in the agri-food industry. As a result, our project will stimulate rapid robotic adoption not only in fresh mushroom picking but also in tangential sectors such as pressure-sensitive food harvesting.

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