SHIVAA - an Autonomous Strawberry Picking Robot for Open Fields

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***Abstract*— Strawberries, known for their fragile nature, require careful handling to prevent bruising and spoilage. Traditionally, harvesting is performed by skilled workers, however, persistent labor shortages and rising production costs have created a demand for automation. This extended abstract presents an autonomous agricultural robot designed for the selective harvesting of strawberries in open field ridging cultivation. The system features a scalable main body, along with a passive suspension that maintains stability and traction on uneven terrain. It autonomously navigates the field and employs a multi-spectral computer vision approach to identify ripe strawberries. The harvesting apparatus includes a low-inertia, belt-driven manipulator for fast picking, and a soft robotic gripper with a suction cup to isolate individual fruits.**

Fig. 1. The Strawberry picking robot SHIVAA during field test.

I. Introduction

Strawberries are delicate fruits that bruise easily during picking and transportation. To prevent overripeness and spoilage, individual fruits must be picked as soon as they are ripe. Harvesting is still performed manually, but is physically demanding and low-wage. As a result, skilled workers become increasingly scarce and interest in automation is growing. This emphasizes the need for selective robotic harvesting technology.

Hayashi et al. [1] conducted initial research on strawberry picking robots. Their rail-guided robot, designed for elevated substrate cultivation in greenhouses, features a scissor-type end effector for cutting and handling the strawberry's peduncle. If desired, a suction device is employed to fix the fruit during picking. Strawberry detection is performed by a stereo vision system identifying red and green regions in an image that meet specified Hue-Saturation-Intensity (HSI) conditions. Feng et al. [2] present a system that navigates the greenhouse autonomously utilizing sonar and cameras. It is equipped with a suction device and a heated knife for peduncle cutting. It relies on stereo vision as well as HSI conditions for strawberry detection.

A robot equipped with a soft robotic gripper is introduced by De Preter et al. [3]. Navigation relies on an ultra-wideband indoor positioning system, which requires the initial placement of beacons. It is capable of clawing and separating strawberries without their peduncle, however, difficulties were reported when handling clusters of strawberries. To more effectively handle densely clustered strawberries, Xiong et al. [4], [5] developed a bowl-shaped end effector. To separate the target strawberry a specialized approach trajectory is calculated. Afterward, the peduncle is cut, and the fruit drops into the gripper, where it lands among previously harvested fruits. Parsa et al. [6] present a scissor-type gripper with additional separator fingers to push peduncles of adjacent strawberries aside.

These systems are tailored for elevated substrate cultivation, however, open field ground cultivation is also widespread, particularly during the normal production season [7]. One system suited for ground cultivation is the Harvest Croo [8]. It is equipped with a comb-like mechanism that lifts the plant's leaves exposing all strawberries to a scanning head that rotates around the shrub to create a 3D-model. The strawberries identified in the model are then gripped and removed without their peduncle by revolving the gripper assembly. Another system is the Agrobot E-Series [9]. Featuring multiple scissor-like end effectors and a modular design, it is adaptable to different field layouts.

The existing systems reveal potential for improvement. Regarding gripper design, cutting and handling the peduncle is safe but requires its subsequent removal. Only De Preter et al. [3] and the Harvest Croo [8] show advantageous picking without the peduncle. For strawberry detection, only visible light is used - an extension of the processed spectrum might bear potential for better results. Handling clusters of strawberries is still a hurdle. Despite extensive research a notable gap persists in the availability of a small robotic system for open field ground cultivation. To address these issues, we propose SHIVAA (Strawberry Harvester: an Innovative Vehicle for Application in Agriculture), depicted in Fig. 1. The system is designed for autonomous selective harvesting of strawberries in open field ridging cultivation.

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II. System Overview

SHIVAA features a scalable, flat body housing the electronic sub-assemblies within modular drawers. Crates for strawberry storage are positioned on top of the robot and can move lengthwise via conveyor belts. Two lightweight manipulators are mounted on linear rails along the sides of the body, allowing them to move lengthwise as well. The system weighs $160\,\mathrm{kg}$ and measures $2.5\,\mathrm{m} \times 1.1\,\mathrm{m} \times 1.2\,\mathrm{m}$ (length$\times$width$\times$height), excluding the reach of the manipulators. The body is elevated on four wheeled legs, enabling it to traverse above a ridge as depicted in Fig. 2. All four wheels are actively driven, with the rear wheels being steerable. This allows for Ackermann steering as well as a point-turn mode.

A passive suspension mechanism ensures all-wheel-contact on the uneven open-field terrain. To achieve this, the legs pivot at their connection points to the central body and are internally linked, forming a mechanism with one degree of freedom. This mechanism evenly distributes the robot's weight across its four wheels while averaging the inclination of the central body, as described in [10]. The result is a smoother traverse, enhancing both image recognition and integrity of the transported strawberries.

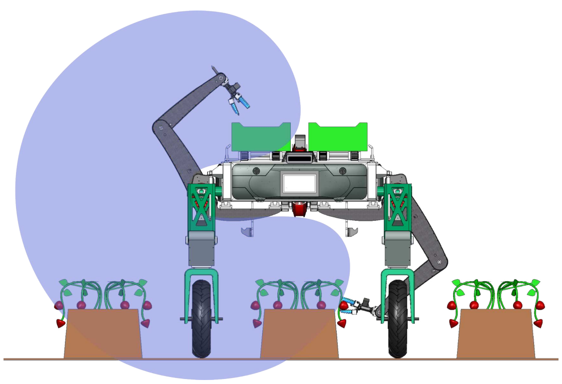

Fig. 2. Work view of SHIVAA with one manipulator's action space shown.

In the field SHIVAA is designed to autonomously follow a ridge of strawberry plants that is recorded by a front-mounted camera. In the camera image this ridge is segmented from the neighboring grass paths through the real-time object detection and image segmentation model *YOLO_V8* [11]. The segmentation mask is then converted to a binary image, after which *Canny Edge Detection* identifies the traversing path.

The ridges are traversed in $1\,\mathrm{m}$ segments. At each segment, the robot stops and the manipulators move along their linear rails. Cameras, mounted at the base of the manipulators, scan the entire segment for strawberries. These behaviors will be coordinated by a behavior tree.

The computer vision approach, detailed in [12], uses multi-spectral image data as input for a classification method. Individual pixels are classified based on their ripeness status and subsequently grouped to identify and classify entire strawberries. To determine the 3D-position of strawberries deemed ready for picking, an additional sensor will be selected and employed.

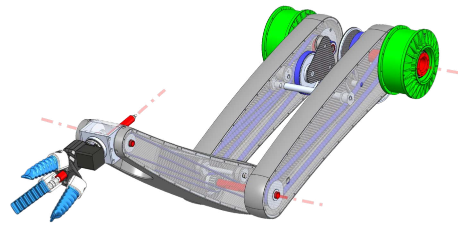

Fig. 3. Manipulator, with its two double motors highlighted in green, the belts in blue, and the four joint axes in red. Figure from [13] without labels.

The manipulator must bridge long distances between the strawberry picking and placing location, which requires it to be agile. This resulted in a parallel-actuated serial manipulator that is shown in Fig. 3 and detailed in [13]. It is a four degree of freedom manipulator with a fifth provided by the linear rail it is attached to. Due to a belt coupling, passing through the hollow link structure, the joint space is separated from the actuation space, which consists of four motors located at the manipulator's base. This reduces the accelerated mass to only $2.6\,\mathrm{kg}$ and leads to an advantageous torque transmission. Laboratory tests demonstrated trajectories from picking to placing within $0.8\,\mathrm{s}$ using four identical direct drives supplying a peak torque of $6\,\mathrm{Nm}$ each. These trajectories are achieved by a Model Predictive Controller tracking a precomputed trajectory of an iterative Linear-Quadratic Regulator, inspired by [14].

The gripper, mounted at the tip of the manipulator, as shown in Fig. 3, consists of three pneumatically actuated soft robotic fingers encased in a soft silicone shell. The fingers open when a vacuum is applied. A suction cup, positioned between the fingers, extends to pull the target strawberry out of the shrub and into the gripper. Subsequently, positive pressure causes the fingers to close around the fruit, which is then detached using a twisting and pulling motion, mimicking the technique of a human worker.

III. Outlook

During field tests, challenges with the current gripper were identified, including difficulties in suctioning strawberries due to their hair-like trichomes as well as detaching firmly attached fruits. Although, no damage to strawberries was observed, a redesign of the gripper is necessary. For manipulator-control constrained optimization is required to avoid collisions with the ground, ridges, and the robot itself. A direct-collocation method that can account for these task space constraints is implemented in Drake [15], but not yet tested. Adaptations to the cost function of the iterative Linear-Quadratic Regulator are also examined. Additionally, an adaptive Model Predictive Controller that integrates machine learning techniques to identify contact environments, as described in [16], is considered for the harvesting interaction with the plant. For successful implementation a prior system identification might be required. Furthermore, the high level control, which orchestrates the different behaviors, must be implemented along with a navigation system for moving between ridges.

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