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Development of a Robot for Harvesting Strawberries ⋆

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Abstract: The lack of available workforce threatens the sustainability and preservation of the agricultural industry in developed countries. The raise of salaries will additionally have a negative impact on the viability of this industry. European farms risk to disappear from markets if no solution is found for the shortage of affordable operating resources. Labor is the most important component in the production cost of a strawberry. In order to preserve the strawberry sites in Europe, the cultivation must become more cost-efficient. The agricultural R&D-company Octinion develops a picking robot that harvests strawberries on tabletop cultivation systems. The robot is a complete, fully autonomous system: it detects the ripe fruits, picks them with no damage, and puts them in a punnet (box in which strawberries are put). The picking system is mounted on a mobile platform that navigates autonomously through the greenhouse. The current prototype of the robot is able to pick a strawberry in 4 seconds. It is therefore a viable alternative for costly human pickers who will be less available in the near future.

Keywords: strawberry, picking, robot, tabletop

1. INTRODUCTION

1.1 Motivation of development

Due to socio-economic changes in the Western society, less and less people are available to perform agricultural work. Currently less than 5% of the available workforce are employed in the agricultural industry (Roser, 2018). In twelve European countries, among which Bulgaria, Croatia, Ireland, Italy, Portugal and the UK, they report employee shortages in the agro-food sector (Reymen et al., 2015). Almost 80% of the applicants with necessary skills are not willing to take the job due to the following reasons: low salary, and hard and unattractive work compared to other jobs in the services or manufacturing sector. At this moment employment policies target to educate and improve skills of people, so that jobs in general can be filled and unemployment can be addressed. The vacancies in the agricultural sector however are for rather simple jobs. Thus, people look for other opportunities. So the question is: who is going to pick fruits and harvest vegetables?

The lack of workforce became a real threat to European strawberry farmers. A raise of salaries will make the cultivation industry unviable because labor represents 40% of inputs to grow strawberries (Kubota-Kroggel, 2014), and European farmers fight hard with competition from Turkey (number 2 in world production) and Egypt (number 4 in world production) (Yara, 2015) who sell fruits at a lower price.

Apart from economical perspective, the job itself remains unattractive. Picking a strawberry is a very delicate operation. They have to be harvested at the right point of time. If they are harvested too late, they are overripe and not suitable for consumption anymore. The training period of a new picker is at least one year before he/she works with the same capacity and picking quality as an experienced person.

If the lack of affordable pickers is not solved soon, European strawberry farmers (20% of world production today (Yara, 2015)) will disappear from markets.

This work describes the development of an autonomous strawberry picking robot. It is intended to resolve the emerging hurdle of the Western agriculture: the lack of affordable workforce that endangers the business' sustainability and preservation. Precision farming and robotic automation are emerging solutions which can address this issue. However, they are still in their very early stages, and current market solutions are not yet mature.

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1.2 Market study on picking robots

There are some competing technologies that are near to commercialization. Most of them however were not developed for tabletop cultivation, which is becoming the dominant method for strawberry cultivation.

The earliest prototypes were created in Japan (Shibuya-Sheiki, 2018) (Ikegami, 2018). They operate in greenhouses which are specifically adapted to these robots. An introduction of these machines in European greenhouses would require very large investments costs, which makes it economically not viable.

Competitors in the United States are the Harvest CROO (Harvest-Croo, 2018) and the Agrobot (Agrobot, 2018). These systems are designed for open-field cultivation. The machines are very large, which indicates a potentially very high cost. In addition, the Agrobot still needs human operators for removing the cut stem and sorting the harvested fruits. The Agrobot requires also some modifications to the open-field cultivation systems, and these are apparently not economically viable. The Harvest CROO works only if the plant density is reduced, but the economic implications of this constraint are not clear.

The Dogtooth system (Dogtooth, 2018) from Cambridge (UK) is an autonomous robotic machine for table-top cultivation. It cuts the strawberry stem instead of removing it completely. Searching for the stem is a time-intensive part of the whole picking operation. Cutting the stem produces a small wound, which allows diseases to enter easily into the plant. The remaining part of a stem can bruise other strawberries during transportation, when the fruits shake around in their boxes. Also, in many countries strawberries are sold without any remaining of the stem. Another disadvantage of Dogtooth is that they start from an expensive industrial robot of which the kinematics are not optimized for strawberry picking.

The competing technologies are in a prototype phase, but their concepts demand drastic changes to the infrastructure and/or the harvested strawberries do not meet the specifications demanded by the market. The agricultural R&D-company Octinion started to develop a strawberry picking robot that harvests the fruits fully autonomously and also offers an answer to these disadvantages.

1.3 Octinion approach

Bringing together experts in mechanics, robotics, software, vision, and system control, Octinion developed the first robot that picks a strawberry exactly like a human. They specifically focus on tabletop systems, which is dominant in Western Europe, but is spreading more and more all around the world. The fully autonomous robot is unique because it decides to pick only if its action won't bruise other strawberries or crops. It picks at least 70% of all ripe strawberries, and always damage-free. The picking quality and speed are comparable to the ideal human picker.

Harvesting the strawberries autonomously has, apart from keeping the industry in Europe, some additional benefits:

- Higher picking quality (less bruising).
- Higher sorting quality (more categories, more optimal placement in packaging, better and more flexible categorization).
- The productivity of the robot is constant and predictable. No need for training, thus no high cost at the start.
- New management tools with the gathered data: yield prediction, more complex harvesting assignments (picking a certain size, picking a day earlier or later).
- Unrestricted timeframe for picking (weekends, nighttime).

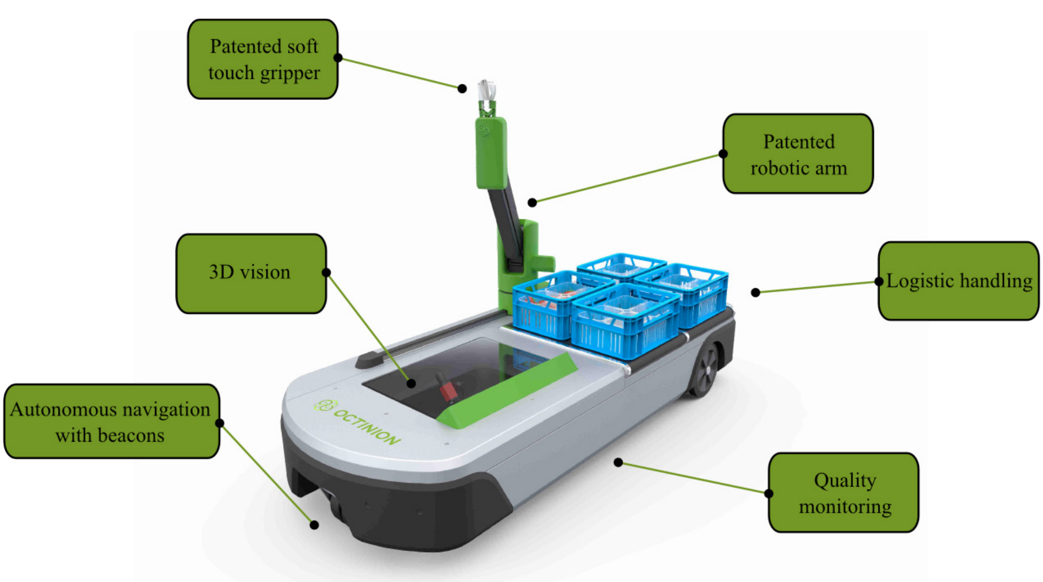

Fig. 1. Conceptual design of picking robot with its components

Fig. 2. Current prototype in a greenhouse with tabletop cultivation

The percentage of strawberries picked by the robot depends on the variety. The remaining of the strawberries are either undetected or unreachable by the robot. They will have to be harvested by hand. At this moment the developed robot does not replace the human pickers completely. Nevertheless, a substantial amount of the harvest is already performed without any human picker interaction. Further research and development will improve this ratio in favor of the robot.

This paper describes the status of the picking robot in September 2017. Octinion has planned to start selling the robot in September 2018.

The design of the picking robot is described as follows: Sec. 2 describes the design of the system. It provides an overview of the different components that are indicated on the sketch in Fig.1. Sec. 3 shows the objectives for creating a viable machine, and Sec. 4 explains the challenges to make the robot ready for sale. Finally, Sec. 5 concludes the whole paper.

2. DESIGN OF THE SYSTEM

The harvesting robot is a fully autonomous system. It does not require any human interaction or intervention during its operation, and could therefore work during day and night. The independence and effectiveness of the system relies on seven components: the electric vehicle, the localization system, the camera detection system, the custom designed robotic arm, the gripper, the logistic handling module and the quality monitoring software. Each of these components are briefly explained in the following subsections. Fig. 1 shows the different components on a sketch, the prototype of the system, created in September 2017, is shown in Fig. 2.

2.1 Electric vehicle

The vehicle is an electric platform. It is equipped with a chargeable battery that supplies all subsystems. The vehicle drives autonomously from a docking station to a user-specified crop row. The platform drives at a constant, low speed while the robotic arm is picking strawberries.

2.2 Localization and autonomous navigation

In order to determine the position of the vehicle, information of the following sensors is combined in a state estimator: wheel encoders, a gyroscope and an ultra-wideband (UWB) indoor positioning system.

In the UWB system, beacons (further called anchors) are placed at the boundaries and corners of the greenhouse (see Fig. 3). The vehicle itself is also equipped with a beacon which emits electromagnetic waves to these anchors. By measuring the time-of-flight of these waves, the position of the vehicle can be determined through trilateration. The anchors can communicate with each other in order to calibrate their locations, which are necessary for the trilateration algorithm. The state estimator generates and tracks the vehicle's pose with centimeter precision.

The estimated pose is the input of the platform position controller. This controller sends signals to the motor drives, based on the pose estimation and the planned trajectory. The driving precision is equal to the precision of the estimator.

2.3 3D vision and strawberry detection

The strawberries are detected by three RGB cameras. The detection is performed by investigating the colors of the images. The three cameras are mounted on different points. This allows to determine the position of the strawberries and to maximize the detection rate. A complex aspect to resolve is that strawberries might appear in bunches, and the individual strawberries of the bunch need to be identified. Therefore, specific image processing techniques are employed. Fig. 4 shows the results of the strawberry detection algorithm.

2.4 Custom robotic arm

A custom robotic arm is developed to reach for the detected strawberry. The movement of the patented arm (Gielis et al., 2017) and performance are comparable with a human's working activity. The time needed to move to the strawberry, pick it, and put it down in a punnet (box in which strawberries are put) is 4 seconds.

Fig. 3. UWB navigation anchor

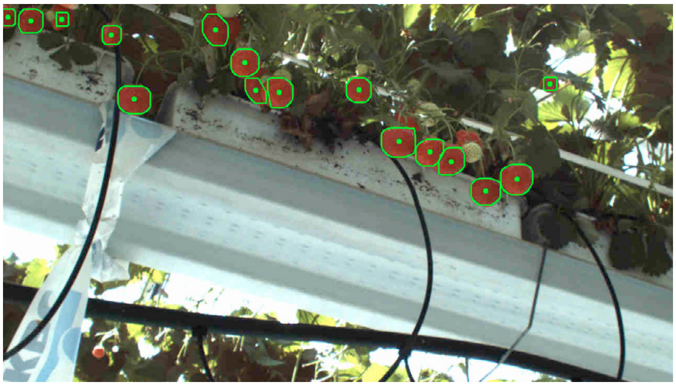

Fig. 4. Detection of individual strawberries

Strawberries grow on flower trusses. When the strawberry is formed and starts to develop, the mass increases and gravity pulls the fruit down. Ripe strawberries are the heaviest and can be found in the lowest positions. The picking process of the strawberries is therefore done from underneath the fruit (see Fig. 2).

The kinematics of the robotic arm are designed so that the gripper can be moved easily underneath the strawberry, and subsequently moved vertically, with a minimum of degrees of freedom. The arm is therefore only applicable for crops cultivated in tabletop systems.

2.5 Gripper

The gripper is attached at the end of the robotic arm and grabs the detected strawberry with its fingers.

The fingers consist of a soft, 3D printed framework structure that creates a larger contact surface and a better pressure distribution with the strawberry compared to human fingers. Therefore they bruise the fruit much less. Additionally, the design of the length, thickness and configuration of the framework structure's beams also influence the force applied to the strawberry. Hence, the damage can be reduced to a minimum if these parameters are optimally chosen.

When humans pick strawberries, they impose a rotational motion to the berry while pulling gently. The gripper performs, in combination with the robotic arm, a similar movement. The result of this picking strategy is that the patented, soft touch gripper (Gielis et al., 2017) picks the strawberry without the stem. No cutting or burning handling is involved during the picking process. Fig. 5 shows the gripper that is inducing a rotational motion while holding the strawberry.

2.6 Logistic Handling module

Once the strawberry is picked, it is held by the gripper and moved upside down to the punnet. In Belgium, Netherlands, Germany and France, and also more and more in other countries, strawberries are always positioned in the box with the calyx (green leaves) down. In this way, the red flesh of the berry is shown to the customer. The full punnets prepared by the robot are immediately ready for final packaging and transportation.

Fig. 5. Gripper in action

2.7 Advanced quality monitoring

This system sorts detected strawberries according to their ripeness, shape, size and sweetness. Information about the characteristics of each fruit is a set of data that is processed by cloud-based software to provide valuable insights about the crop to the user. As such, the user can have an accurate product quality analysis based on the harvested individual fruit, instead of on spot samples used by human pickers. Therefore, growers can harvest at the most optimal moment and deliver good and uniform quality to the market.

3. OBJECTIVES FOR VIABILITY

In order to have a system that is reliable and viable for commercialization, the following statistics have to be reached:

- A total picking time of 4 seconds.
- Minimum 70-95% of strawberries picked up in tabletop cultivation, depending on the variety.
- A robust detection of the location of ripe strawberries.
- Mechanical robustness for a desired lifetime of 5 years.
- Drive train components, including electric engine and battery, optimized to work for at least 8 hours continuously.

The robot's performance (picking speed, damage of the fruit, strawberries not picked, sorting) depends a lot on the on-field conditions, which depend on many parameters. In order to make a meaningful measure, the performance of the robot will be compared with the human work in the same conditions. This will make a quantitative analysis of the benefits and necessary improvements possible. The product development of the project will paramount and conclude with the implementation of the quality monitoring system. This will be performed by comparing the quality assessment by the robot with laboratory assessment. Due to the changing conditions over the year, which might impact the assessment of the robot, this also needs to be performed continuously.

4. FUTURE CHALLENGES

This section describes the technical challenges in order to reach the objectives described in Sec. 3. The improvements will transform the current prototype (see Fig. 2) to a reliable and marketable product.

4.1 Hardware: improvements on gripper

Optimize picking mechanism The picking mechanism of the robotic arm is being fine-tuned in order to reduce picking time. During the year the picking conditions change a lot. Even within the same cultivar plant characteristics (e.g. strawberry size, presence of bunches, long/short stems, stem condition) can be very varied. The picking mechanism will have to cope with all these conditions. In case there is a need for adjusting or installing another picking mechanism, the adjustments or replacement of components should be made very user friendly in order to limit machine downtime.

Optimize finger dimensions The dimensions and configuration of the fingers' framework structure can influence the contact force distribution over the strawberry (as described in Sec. 2.5). These parameters will be optimized further in order to make the contact area bigger and to eliminate any fruit damage. This will make the gripper suitable to pick strawberries in bunches as well.

4.2 Improve software layer

Intelligent and optimized trajectory planning The current ad-hoc trajectory generation for the robotic arm works already quite well. However, further optimization is very important to guarantee the arm will meet the expected picking speed and success rate. Octinion will gradually develop an intelligent and optimized trajectory planning algorithm.

Coordination vehicle and robotic arm The vehicle localization system will be integrated with the robot to coordinate the vehicle movement with the picking operation. A synchronized coordination of these two processes (movement and picking) is very important for the picking capacity. Ideally, the vehicle moves in-between two picks only when the robot arm is finished with picking the strawberry. However, the efficiency of picking-while-driving will also be explored.

Quality monitoring system The robot gathers a lot of data while navigating through the greenhouse. It can count the strawberries and quantify their different stages of ripeness. The robot will also be able to detect diseases. Octinion is currently also working on a harvest prediction system to further support growers with this data.

Because of its accurate ripeness measurement, it is recommended to program the robot to pick the strawberries once a day instead of every 2-3 days. This will allow to control the production by picking a strawberry a bit sooner or a bit later. A human cannot see these small differences in ripeness, but a robot can. This ensures a guaranteed quality of the harvested product.

System reporting tool Octinion will develop the monitoring/reporting tool to facilitate the user experience and to allow a proper monitoring of the robots and strawberry distribution. It will be customized based on the user needs and feedback that will be gathered from the pilot customers during the project.

4.3 System integration and inhouse assembly

The integrated mechanical, optical, electrical and software components will be synchronized to result into an optimal picking operation. The objective is to pick one strawberry every 3 seconds. The current picking speed is 4 seconds. Perfect integration and calibration of the different software components is a key element to achieve this. In addition, tight cooperation with electronic, electrical and mechanical specialists is necessary to identify hardware bottlenecks and to tailor explicitly the hardware to the requirements.

Integration of the hardware and software components is an art. Octinion will identify best practices that could be possibly used for the future design of the manufacturing process. During the hardware design and software development, the respective teams will also have a focus on how the robot can be industrialized, because this can definitely influence some of the initial engineering decisions.

The integrated mechanical, optical, electrical and software components will be tested in the real operational conditions. The whole system is the key aspect to achieve the target picking time. On-field test will identify hardware constraints and improvements in both hardware and software specifications.

5. CONCLUSION

This paper describes the development of a robot for harvesting strawberries autonomously. Based on the common cultivation method (tabletop), a complete and fully autonomous system is developed that could work without any human operator. A brief description of all the system components is provided. These are the electric vehicle, the positioning system, the vision setup, the robotic arm, the gripper, the logistic handling and the quality monitoring modules. The current prototype can pick a strawberry within 4 seconds, which is already a very promising result.

The objectives to turn this prototype into a viable and robust product have been provided. Finally some challenges regarding hardware, software and component integration are listed. The whole system will be evaluated in lifelike environments to ensure robustness and to identify its shortcomings.

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REFERENCES

Agrobot (2018). URL `http://www.agrobot.com/`.
Dogtooth (2018). URL `http://www.dogtoothtech.com`.

Gielis, D., Dondeyne, P., De Backer, S., Anthonis, J., and Coen, T. (2017). Inrichting voor het plukken van fruit met een verbeterde robotarm. BE2017/5187.

Harvest-Croo (2018). URL http://www.harvestcroorobotics.com/.

Ikegami (2018). URL https://www.ikegami.co.jp/en/archives/1010.

Kubota-Kroggel (2014). Off-season hydroponic strawberry production. URL https://www.slideshare.net/sberries/01-kubota-nssi-strawberry-new.

Reymen, D., Gerard, M., De Beer, P., Meierkord, A., Paskov, M., Di Stasio, V., Donlevy, V., Atkinson, I., Makulec, A., Famira-Muhlberger, U., and Lutz, H. (2015). Labour market shortages in the european union. URL https://www.europarl.europa.eu/RegData/etudes/STUD/2015/542202/IPOL_STU%282015%29542202_EN.pdf.

Roser, M. (2018). Employment in agriculture. URL https://ourworldindata.org/employment-in-agriculture.

Shibuya-Sheiki (2018). URL http://www.shibuya-sss.co.jp/sss_e/index.html.

Yara (2015). URL http://www.yara.us/agriculture/crops/strawberry/key-facts/world-production/.