Adaptive Gripper Jaws for High-Value Crops Harvesting

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1. Abstract

Grippers for agricultural application must be able to adapt to different sizes and different geometries of the fruit. The following paper describes two possibilities to realize adaptive gripper jaws. One of the grippers is used for apple harvesting, the other for sweet pepper handling. Further on the paper explains options to detect if such an adaptive gripper has gripped a fruit or not. Especially the integration of a force sensor into a FinRay finger produced with rapid prototyping technologies is presented.

KEYWORDS: gripper, adaptive jaws, crops

2. Introduction

In the EU-funded research project **C**lever **RO**bots for cro**PS** (CROPS) fourteen partners work together to build a roboter system for agricultural applications. The main objective of CROPS is to develop a highly configurable, modular and clever carrier platform (Figure 1) comprising a carrier plus modular parallel manipulators and “intelligent tools” (sensors, algorithms, sprayers, grippers) that can easily be installed onto the carrier and that are capable of adapting to new tasks and conditions. Both the scientific know-how and a number of technological demonstrators will be developed for the agromanagement of high-value crops like greenhouse vegetables, orchard fruits, and grapes for premium wines. The CROPS robotic platform will be capable of site-specific spraying (targeted spraying only on foliage and selected targets) and selective harvesting of fruit (i.e., it will detect the fruit, determine its ripeness, move towards the fruit, grasp it and softly detach it). The following paper is focussing on the development of the grippers for apples and sweet peppers and the sensor-integration to detect the gripper-state.

Figure 1: Artists impression of the CROPS-robot

There are two possibilities to grip high-value crops like apples and sweet peppers. You can grip the stem or directly the fruit. The first solution has the advantage of a very gentle handling of the crops, thus damages are avoided. But it is hard to localize the gripping point and often difficult to get access to the stem. Although it is part of the CROPS project to change the plants so that situations like apple bunches and pepper stacks shown in figure 2 don´t appear, it seems to be more promising to grip the fruit directly.

Figure 2: Apple bunches and sweet pepper stack

What is the difference between gripping a fruit and a normal (metal) workpiece handled in factory automation? At first the dimension of the fruit varies, this can be compensated with a longer gripper stroke. That´s why the parallel gripper HGPL of Festo with a stroke of 40 mm each jaw is used in the CROPS project. The second difference is the changing geometry of the fruit. Thus gripper jaws or fingers are needed, who adapt oneself to the surface. This also helps to reduce the pressure on the surface of the fruit, which is much more sensitive in such agricultural applications. > Another difference is the special environmental condition, comprising dust, mist and rain in the orchard or high air humidity in the greenhouse. Thus very robust grippers are needed. That´s why pneumatic grippers are predestined for this application. Another advantage is the high power density of pneumatic drives compared to electric drives leading to a low mass and a small size of the gripper. This is very important because space is very limited if you have to work in and between plants.

In the following chapters the developed grippers for apple and sweet pepper are explained. In a further chapter the possibility to identify different gripper states are explained.

3. Gripper for apple harvesting

A modern apple orchard gives the impression of a green wall full of apples and has only little similarity with a classic apple tree (compare figure 3).

Figure 3: Apple orchard

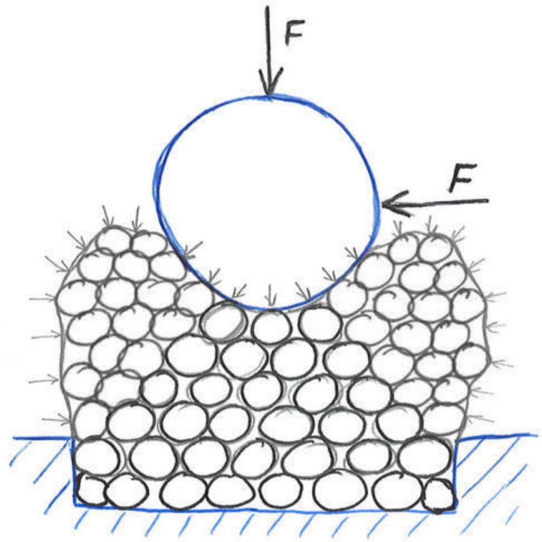

Figure 4: Working principle of the membrane jaws

Apples are harvested by a rotating movement which breaks off the stem from the plant. Because of shell life it is important that the stem sticks to the apple. In consequence an adaptive solution for gripper jaw is needed which is able to transfer the necessary torque for the rotating movement. A good solution to fulfil the described requirements is a so called membrane jaw (Figure 4). They consist of an elastomeric membrane which is filled with a granulate. If a workpiece is pressed against such a jaw, the membrane as well as the granulate is able to adopt to the geometry of the workpiece. After that it is possible to evacuate the membrane. Then the pressure difference stabilizes and stiffens the jaw which leads to a combination of positive and non-positive grip.

To find an optimized solution for a defined application it is possible to vary the parameters

- membrane material (especially shore hardness),
- membrane geometry,
- membrane thickness,
- granulate material,
- granulate geometry,
- granulate dimension and
- vacuum level.

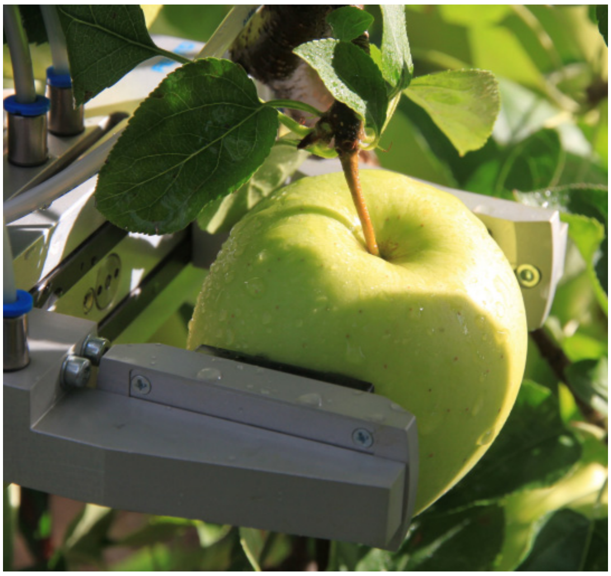

Figure 5: Gripper HGPL-14-40-A with membrane jaws for apple harvesting

The developed gripper with membrane jaws can be seen in Figure 5. With this solution very successful harvesting tests were executed in the orchard. After harvesting the apples have been stored for 17 days in a cooling cell (+1° C) followed by 5 days storage in normal room temperature. This has been done to simulate the normal storage of apples in cooling cells followed by exposure to room temperature in the store and with the consumer. The results clearly show the low stress which is loaded on the apple by using the adaptive membrane jaws during the harvesting process.

4. Gripper for sweet pepper harvesting

While apples only can be harvested in a view weeks in autumn, sweet pepper mature from March to November in European Greenhouses. The peppers ready to harvest are always on the bottom of the plant. The younger and immature fruits can be found above (compare figure 6).

Figure 6: Sweet pepper greenhouse

To harvest the pepper they need to be (partly) cut through the abscission zone. The abscission zone is the natural predetermined breaking point of the peduncle, where the pepper would break from the plant if it is not harvested. It is important to cut there because this avoids fungal attack to plants and fruits. Beside the basic gripping tasks the gripper has to support the cutting process. This can comprise two steps depending on the actual harvesting situation. The plants are growing along supporting wires fixed on the top of the greenhouse. It can be necessary to rotate the plant around this wire and/or to pull out the pepper to simplify the access to the abscission zone for the cutting device. Further on it can be helpful to generate traction forces in the peduncle. Then the pepper is separated much easier when it is cut.

Another requirement for the adaptive gripping jaws of the sweet pepper gripper is to be able to move between two peppers hanging directly beside each other. Thus small and long fingers without edges, which could injure the peppers, are needed.

The working principle of the fingers used on the developed gripper for sweet pepper bases on the Fin Ray Effect® shown in figure 7. It allows the passive adaption of the fingers to the workpiece geometry, especially for predominant round objects.

Main parameters to optimize the finger design for a given application are

- finger material,
- finger length and width,
- number of links and
- wall thickness of the beams.

The gripper for sweet pepper shown in figure 8 comprises four fingers with rounded edges on the tip. Two of these fingers can rotate around their longitudinal axis for better adaption to different geometries of peppers.

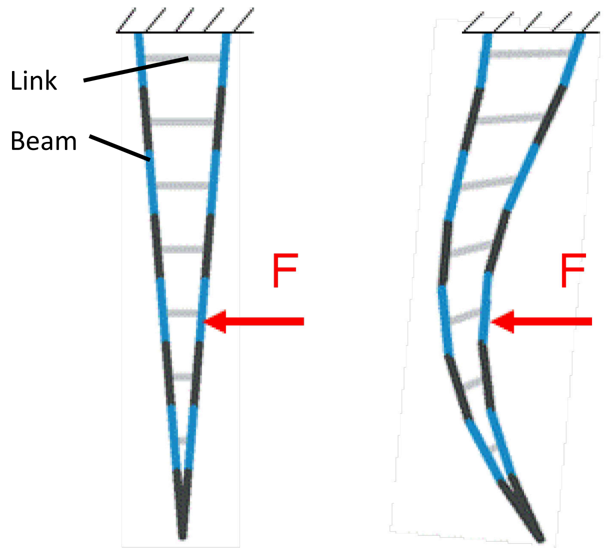

Figure 7: The Fin Ray Effect ®

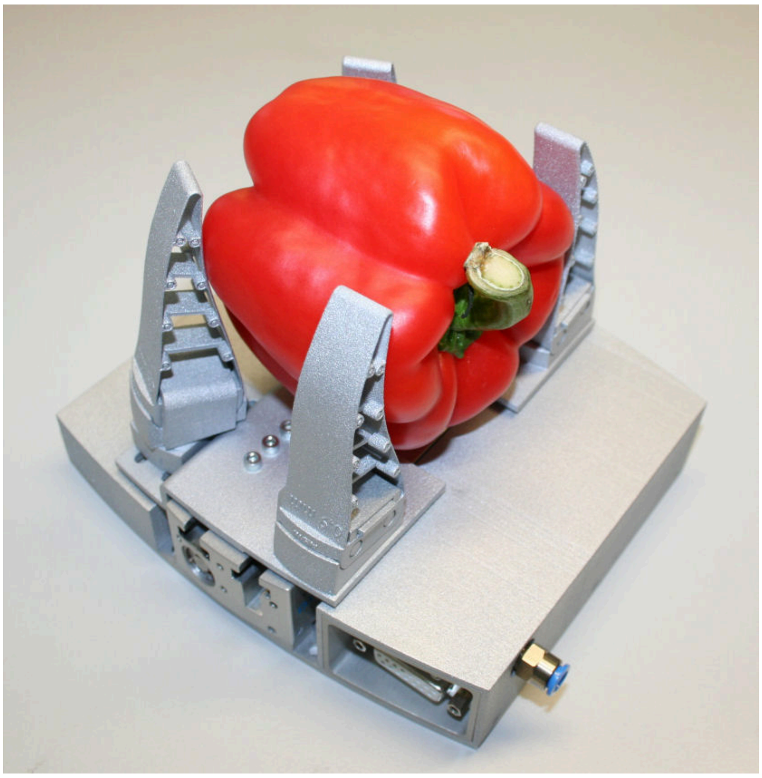

Figure 8: Gripper with Fin Ray Fingers for sweet pepper harvesting

5. Sensors for state detection

Due to the different sizes of the crops and the adaption to their geometry the piston of the pneumatic drive actuating the gripper is not on the same position every time when a crop is gripped. Thus the state “gripped”, which means something is clamped between the gripper jaws, can’t be detected by a limit switch as in standard application with defined workpieces having a fixed size. So other solutions to detect the state “gripped” needs to be developed. But what means “gripped”? There are different states of the gripper which can be combined with the state “gripped”. For example the valve current could be monitored. Assuming that a switched valve means to pressurize the chambers of the pneumatic drives, what leads to a moving piston and thus jaws hitting the workpiece. So the state “valve switched” is combined with the state “gripped”. But certainly there are a lot of possibilities, what could go wrong.

This means: Depending on the allowed risk different sensor concepts can be used to identify the state “gripped” (overview in figure 9). In the CROPS project the used level is to identify, if there is really a contact between gripper jaws and workpiece. For this purpose five sensor concepts can be used. Image sensors like cameras or optical sensors like laser sensors will not be considered because the risk to get dirty or to get occluded by leaves in the rough environmental conditions is too high. Tactile sensors need to be placed directly in the contact point between gripper jaw and workpiece. In combination with the adaptive gripper jaws developed in the crops project this is hard to realize. Thus there are two options left to identify the state “gripped”.

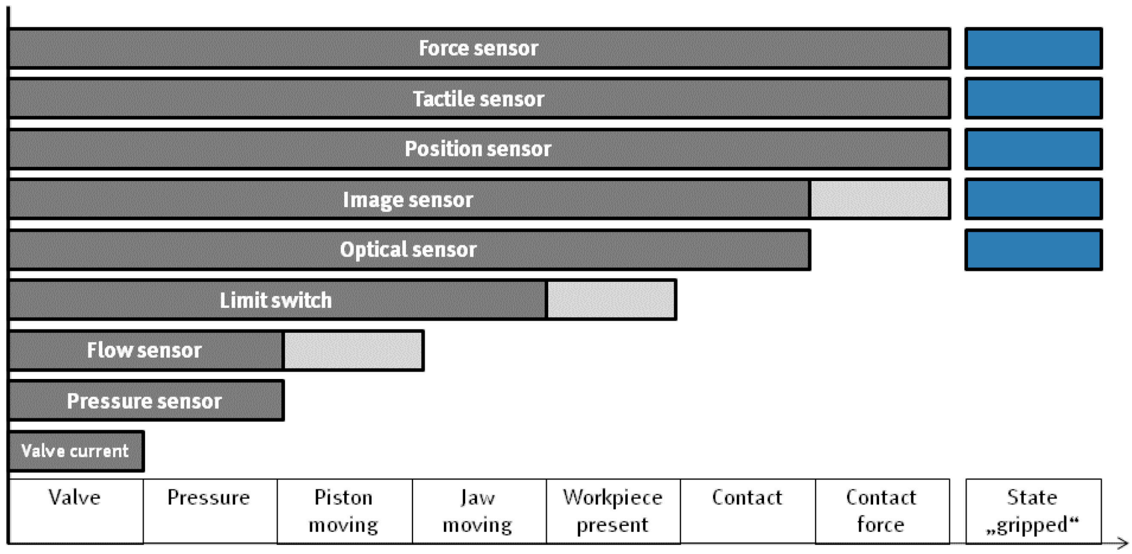

Figure 9: Detection of the state “gripped” with different sensors

With a position sensor measuring the stroke of the gripper jaws it is possible to identify the state “gripped”. The end positions of the pneumatic drive actuating the gripper are known. When the gripper is activated the open position is left and the jaw is moving in the direction of the closed position. If the closed position is reached, there was no workpiece between the gripper jaws. If a workpiece is gripped the gripper jaws will not reach the end position. Then the gripper will stop somewhere between the open and closed position. This position is marked by a constant value of the position sensor, which is not the value for open or closed position.

Main advantage of this solution is, that the sensor is not moved with the gripper jaws, thus there are no moving cables. So identifying the state “gripped” with a positions sensor is a robust solution. But if there is a small workpiece or when the adaptive gripper jaw is very flexible it can happen that the pneumatic gripper will reach the close position although there is a workpiece between the jaws. In this case the sensor concept fails. Another potential failure is that the gripper moves against an obstacle, for example a branch. Then the state “gripped” will be detected as well. In other word: With a position sensor can be identified, that the gripper jaws hit “something” but not that the desired workpiece is gripped.

If a force sensor is integrated into the gripper jaws, this is also a possible failure. A force sensor is not able to differ between contacts with a desired or not desired object. Another disadvantage is that necessarily moving cables are used because the sensor is integrated into the gripper jaw. An example for the integration of a force sensor into an adaptive finger is explained in the following chapter.

6. FinRay Finger with force measurement

The working principle of the FinRay fingers comprise that the finger is deformed under load. In the end it is a kinematic system with reproducible behaviour. The deformation depends on the force application point and the force size. Figure 10 shows the trajectories of the joints under a given load. With these trajectories a defined movement of the links connecting two joints is coupled. Thus the link movement is an indicator for the force affecting on the FinRay mechanism. InfFigure 11 a gearing mechanism is integrated in the finger so that the link movement is transmitted into the deformation of a strain gauge.

The fingers using the The Fin Ray Effect ® explained before and shown in figure 7 are produced with selective laser sintering (SLS). This rapid manufacturing technique builds a part layer by layer using a high power laser fusing powder into a mass that has a desired 3-dimensional shape. Because the Finray finger is produced with SLS, it is easy to integrate the gearing mechanism to realize the force measurement

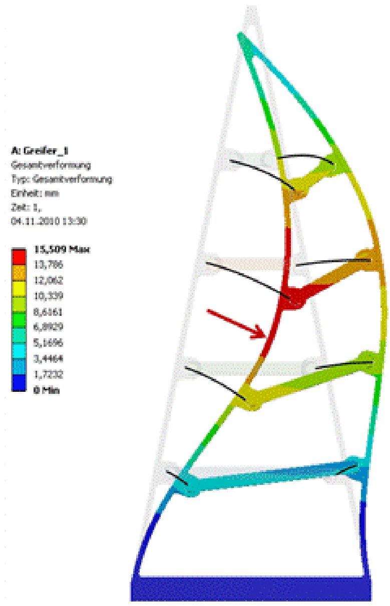

Figure 10: Joint-trajectories under load

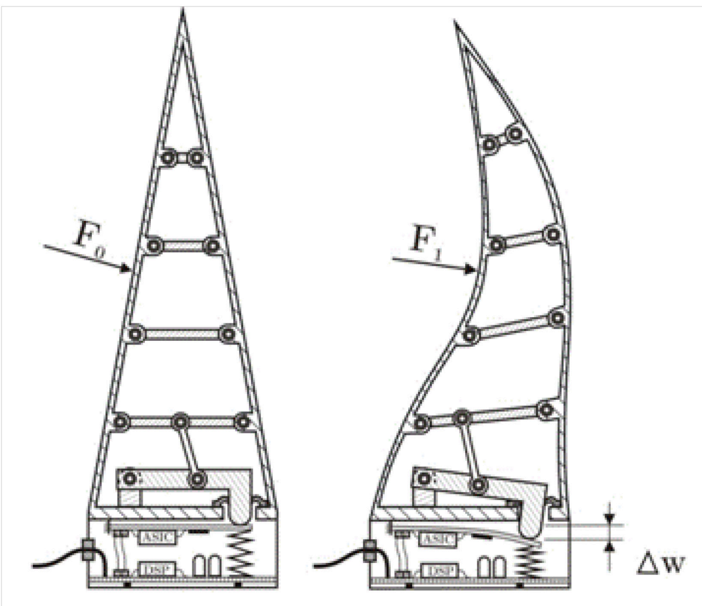

Figure 11: Transmission of link movement to sensor deformation

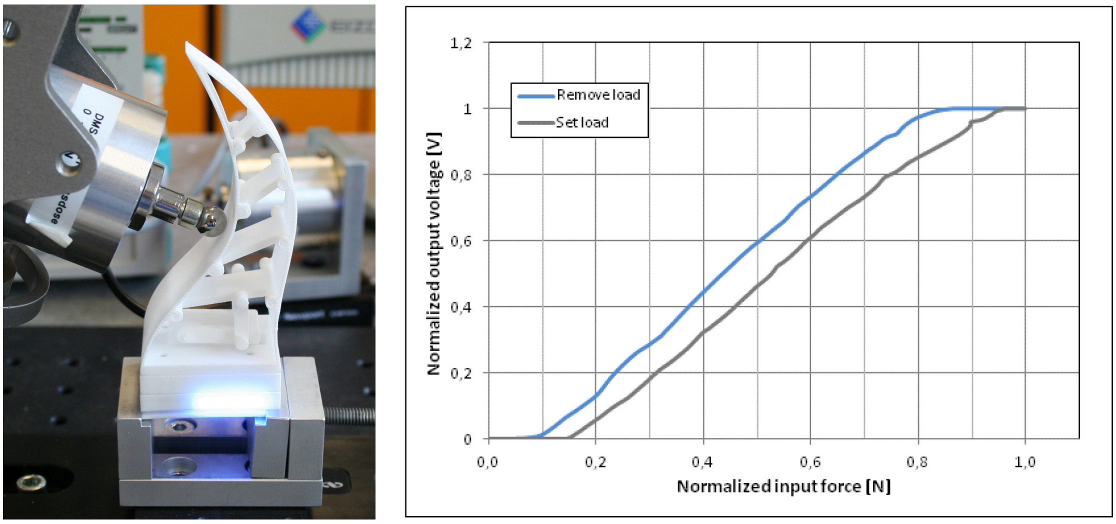

Figure 12: Test bench and measurement result of FinRay finger with integrated force sensor

A prototype of the FinRay finger with integrated force sensor was build - it is shown in figure 12 mounted into a small test bench. With the test bench a defined force can be transmitted on the finger. The diagram shows a distinct relation between input force and output voltage of the sensor. The hysteresis is first and foremost basing on the visco-elastic properties of the used material. Nevertheless the result is in every case good enough to detect a well defined state “gripped”.

7. Summary and Conclusion

In this paper the development of two grippers, one for apple harvesting and the other one for sweet pepper harvesting, is introduced. The jaws of the apple gripper consists of a elastomeric membrane filled with granulate. So it can adapt to different geometries of the apple. The adaption to different sizes is realized by a long stroke gripper.

A long stroke gripper is used for the sweet pepper gripper also. In this case FinRay fingers are used to adapt to different sizes and geometries of the pepper. Further on the integration of a force sensor into FinRay fingers produced with a selective laser sinter process was explained. This ensures to detect a well defined state, that the fruit is gripped. Another option to identify this state is to interpret the signal of a position sensor measuring the stroke of the gripper.

8. Acknowledgment

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