

## Project Title: The Next Fruit 4.0

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### Project size

**Amount:** 3,156k€ for 4 years  
**Agency Name:** Dutch Ministry of Agriculture, Nature and Food Quality  
**Notes:** Total project size is 3,156k€ for 4 years, half is paid by the Dutch Ministry of Agriculture, Nature and Food Quality and the other half (1,578k€) is financed by Dutch growers and companies (in cash/in kind) and the Washington Tree Fruit Research Commission. The part that is financed by WTFRC is stated below.

Item	2021	2022	2023	2024-mid 2025
Salaries	\$54,000	\$54,000	\$54,000	\$54,000
Benefits				
Wages				
Benefits				
Equipment	\$5,000	\$5,000	\$5,000	\$5,000
Supplies				
Travel				
Miscellaneous				
Plot Fees				
<b>Total</b>	\$59,000	\$59,000	\$59,000	\$59,000

### Executive Summary The Next Fruit 4.0

The object is to make fruit cultivation more efficient, intelligent, sustainable, and future-proof. A crucial step is to be able to monitor, manage, and to act at the level of individual trees with the help of smart technology. The **first example** is the development of a precision sprayer that can spray at a nozzle level with sensors that detect the volume of the trees. Two prototypes were build and one is commercially available for growers. A later add-on are RGB camera's that can detect pests and diseases. For the detection of fruit tree canker the first algorithm was developed. Precision spraying during fruit thinning showed that aiming the trees with a high number of flowers gave the best effects on return bloom and that orchards will become more uniform. The **second example** is the development and or tests of sensor platforms that can detects blossoms and tree positions in the orchard or a platform that can examine the fruit quality of a storage bin. Specially for pear an algorithm was developed to measure the size. Colour measurements will follow in a follow-up project. The **third example** is the use of a non-destructive sensor to measure fruit quality like firmness and brix. The Fresco sensor showed reliable outcomes for both firmness as brix. And finally the **fourth example** is the build of end effectors for picking and pruning to make robots multifunctional. The first end effector to pick pears was made and tested with success in the field. This winter red currant plants will be pruned with the pruning end effector.

## Objectives overall project

Making fruit cultivation more efficient, intelligent, sustainable, and future-proof requires us to be able to monitor, manage, and act at the level of individual trees. **Smart Technology** will enable getting the most out of an orchard through the targeted, efficient use of crop protection agents, plant hormones and fertilizers, while saving on labour and minimizing food waste. This all contributes to the creation of a sustainable fruit cultivation system.

The project has therefore three key objectives in relation to technology development:

1. Improving the sustainability of cultivation and the supply chain by:
  - a) developing ways of applying crop protection agents, plant hormones or fertilisers to individual trees (or parts of trees) based on new ways of detecting stress, pests, and diseases (using sensors and new algorithms) and
  - b) by combining data to develop new decision support models using AI. This will, for example, give decision support in storage duration and conditions to prevent loss and waste of the fruit, or help to determine the optimal dose of crop protection agents, growth regulators and fertilisers.
2. Maximising yields by optimising cultivation and storage through the optimisation of individual tree growth.
3. Minimising costs by developing multifunctional robots to replace human labour and ensure the efficient use of inputs.

The need to achieve these objectives has led to the project being organised in four case studies. A brief description of the four case studies is provided below, including an explanation of how they mutually reinforce each other.

### *Case study 1: Further development of precision sprayer*

The former project Fruit 4.0 demonstrated that precision spraying at the level of individual trees is possible. In The Next Fruit 4.0 we want to further develop and broaden the application of precision spraying by controlling it down to individual nozzles and by using sensors to detect pests and diseases and apply sprays in response. Being able to control sprays at the level of individual nozzles also optimises the use of regulators for growth and fruit setting, resulting in a more uniform orchard. Hot spots of insect infestation can also be controlled without spraying the whole orchard.

### *Case study 2: Advanced crop management and yield registration*

This case study is based on the use of sensors to collect data and translate it into decision support models visualised as clear dashboards. This will involve making the sensor platform from the Fruit 4.0 project applicable to more than just apples. The wide range of data and information gathered will also be distilled into clear insights around cultivation management. With help from experts and the use of modern AI algorithms, decision models will be created that can contribute to optimising and improving the sustainability of fruit cultivation.

### *Case study 3: Cool data*

Apples and pears are often stored for a long time, even up to the following harvest. Storing the fruit for any length of time often leads to substantial losses due to a lack of clear, objective information on how long a particular batch can be stored. This case study will focus on maximising the use of data derived from the cultivation phase (climate, crop, and soil) and the focused application of new technology (sensors), leading to decision models that deliver better risk assessments and storage strategies. This will help reduce loss and waste during storage.

### *Case study 4: Multifunctional robot*

Finally, The Next Fruit 4.0 will also work on expanding the functionality of existing robots which are already in development (e.g. by adding a gripper for picking pears, or for pruning and

removing suckers) and which could perform more efficiently through technological improvements and better orchard design. All of this will help solve the problem of increasingly limited availability of seasonal labour.

Results of the projects are presented per case study.

### **Case study: Precision sprayer**

#### *Objectives on building precision sprayer*

A validated prototype precision sprayer for several fruit crops, which is directed at nozzle level on the basis of smart algorithms and decision models and combined with stress, disease and pest detection.

#### *Significant Findings*

- Laser scanner data can be translated into spray actions
- 2 prototype sprayers were build
- Both prototypes were tested in the field.
- Munckhof is already selling the sprayer developed in this project to the first customers.
- Factors that influence successful market introduction focus on compatibility (brand-independent integration), plug-and-play (simple operation), and techniques that allow growers to be independent.

#### *Methods*

The project concentrated on:

- Building 2 prototype sprayers with Pulse Width Modulated nozzles together with the manufacturers KWH and Munchhof.
- Building an improved sensor platform for the sprayers with LIDAR and GPS.
- Processing data into usable data for spray decisions at nozzle level based on tree volume.
- Tested the sprayers on leaf deposition and also on savings on spray volume.

#### *Results and Discussion*

In practice, the most important benefit is that in the future fewer spray volume will be needed to achieve the same result and that emissions to the environment will be further limited. The LIDAR scanners that make this possible are placed at the front of the sprayer. They determine the tree volume and gaps while driving. Both spray systems use PWM (Pulse Width Modulation) technology to vary the amount of spray liquid. This is done by changing the length of those pulses. Based on the tree volume an algorithm determines the amount of spraying liquid for each nozzle. Munckhof build their own algorithm and KWH used an algorithm developed in this project by Wageningen University & Research.

At the end of the project both sprayers were working and were tested in the orchard. The deposition on the leaves with the use of the sensors turned on were as good as when the sprayer did not use the sensors. If the deposition was not as good, it would have meant that the nozzles sprayed too late. The savings were around 15% in summer, during spring this can be better. Also the settings are very conservative so it will not miss anything. The optimum settings still need to be determined. Also the PWM nozzles are set to be turned on or off, in other words they spray at 100% capacity or 0%. In a future project the sprayer will be able to spray a lower amount (between 0-100%) if the density of leaves is less. In that way, more spraying product can be saved.

Below 2 pictures of the sprayers, one in the field during tests and one during installation of the components.



### *Objectives work on economic validation and innovation adoption*

Within this work package work is also done on the economic validation and innovation adoption of a precision sprayer. This research clarified the factors that influence successful market introduction. This includes, on the one hand, economic feasibility and, on the other, factors that can drive or hinder the implementation and/or user acceptance of technological innovations for fruit growing.

### *Methods*

The preconditions for faster practical adoption of new precision technologies were examined. The focus is on which factors influence the purchase of a precision sprayer or the use of precision features on the sprayer. Interviews were conducted with growers, advisors, dealers, manufacturers, and/or developers. The questions are based on the Behaviour Change Wheel method (see figure below).

This allows us to:

- Conduct a behavioural analysis: which behavioural characteristics play a role in the use or non-use of the precision sprayer?
- Diagnose what needs to change.
- Identify which interventions are likely to bring about behavioural changes.



### *Results and Discussion*

The following interventions can help accelerate the adoption of precision spraying techniques. Work with growers as ambassadors and role models. A success story told by a grower is the most convincing. As developers, **focus on compatibility** (brand-independent integration), **plug-and-play** (simple operation), and techniques that **allow growers to be independent** from other companies like in the case of hiring a drone pilot to scan the orchard versus having a sensor platform on their own so they can scan any time they want.

A recommendation at the system level is to develop a shared strategy and vision for the sector, focusing on "it is important for health and the environment that we reduce crop protection options, and precision farming is the way to make this possible and thus the future." The second recommendation is to adapt legislation to the possibilities of precision farming. Legislation currently lags behind the possibilities of precision farming (for example: adjusting the maximum

number of applications per plot per year to the maximum amount of permitted pesticides per plot per year).

### **Case study: Advanced crop management and yield registration**

#### *Objectives*

- Validated sensors and algorithms to collect physiological and phytopathological characteristics of apple and pear.
- Validated decision models developed on the basis of collected data and expert knowledge; targeted on production optimization.

#### *Significant Findings*

- Trunk detection to get the GPS locations for individual trees.
- Detection method to detect fruit tree canker and apple blossom weevil
- Proof of principle was demonstrated for automated detection of pear in top layer of storage bins.
- Experiments were done to develop a thinning decision support system for Conference pear.
- Field trial on blossom and fruit thinning showed that precision spraying on trees with a high amount of flowers is the most effective strategy to make the orchard more uniform. Stimulating trees with a low number of flowers is less effective.

### **GPS position of trees**

#### *Methods*

In this part of the research, sensor platforms of Aurea Imaging and AgroWizard were used to see if they are able to detect the GPS position of trees. This is relevant if orchards were not planted with GPS and the grower wants to use precision fruit thinning.

The sensor platform of Agrowizard is mounted on a quad and scans the trunks. Combined with the GPS and an algorithm it determines the GPS position of the trees (picture below with setup). The system of Aurea Imaging is mounted on the top of the tractor. The camera's face downwards to scan the trees but also the trunks during winter time. During the summer, this is not possible. With Agrowizard system 6 orchards were scanned with 86-162 trees per orchard and with the Aurea Imaging setup, 2 orchards with 64-96 trees. Outcomes were compared with GPS measurements done with a handheld RTK-GPS.



#### *Results and Discussion*

The Agrowizard system could determine 69% of the trees position within an error margin of less than 10 cm (~ 4 inches). With a higher error margin of 20 cm, 92% of the trees could be determined. An error margin of 20 cm (~ 8 inches) is found to be enough for most of the growers to use precision fruit thinning.

The Aurea Imaging system found 47% of trees within the 10cm error of margin and 89% within the 20cm error of margin.

For both system the challenges were orchards with slanting trees or with interfering elements like nets to protect the trees against wildlife

damage. Aurea Imaging will have an option in the future to position their sensor platform to a lower position in order to be able to detect the trunks in a better way. But with those 2 systems, it is now possible for growers to start using precision spraying in older orchards. The same camera

systems can be used for other things as well, like detection of blossoms, fruits and diseases. In the project algorithms to detect the disease fruit tree canker and the pests apple blossom weevil were developed. Further development is still needed to be able to use the algorithms on a commercial level.

## Image processing photos storage bin

### Methods



Within the project, WUR was developing image processing in which the size distribution of the pear is initially determined from photos of the storage bin. In subsequent steps, other quality aspects can also be analysed, such as fruit shape, colour and certain damages. For the size measurement specific points in the shape are now detected. This concerns the stem and nose position and the widest point of the fruit to determine the diameter. Several steps are required to validate the data. First, it must be determined how reliable the size measurement for the detected pears is and then it must be determined how well this size distribution corresponds to the entire storage bin or the entire batch.

### Results and discussion

The performance of the various AI models (developed in 2023 and optimized in 2024) and combination of models were tested on pears. The maximum deviation in size was determined, for both size and weight. The best model for size had a deviation of deviation 3.8 mm (0.15 inch), while another model was better to determine fruit weight (deviation 24.8 grams/ 0.055 pounds). The image processing model is running on a trial basis at the project partner Bodata. The goal is to bundle the collected information into a quality report. We are currently discussing with the consortium partners involved how the analyses can be incorporated into daily practice. Preparations are also being made for market introduction.



Because there is little time during the harvest to photograph each storage bin by hand, it was suggested that it would be practical to drive a picking train under a gate where the photos could be taken automatically. By then linking the photo to this storage bin via an RFID chip, it will be possible to quickly gain insight of a complete batch.

A test setup was tested at the experimental orchard Randwijk during a harvest period. As soon as a storage bin passes the camera, a photo is automatically taken and the RFID chip is scanned. To ensure consistent photo quality, it was decided to shield the portal from daylight and artificially illuminate it with construction lights. To minimize motion blur in the photo, the picking train had to pass in the lowest gear. Integration with RFID stickers turned out to work fine. There are still some points that require attention, such as fruit brilliance and colour correction. The latest insight is that growers prefer a setup on a forklift. This idea will be

examined in another project.

## Precision thinning

### Methods

Extensive thinning tests were done at the Experimental orchard in Randwijk on Elstar apple and Conference pear during the course of the project. Different thinning treatments were done with a

focus the product Brevis. Those treatments were done *on the whole* orchards or *based on a task map* and compared with *an untreated* orchard. In the task map the trees with a high amount of flower clusters got the strongest thinning treatment, the middle group of trees got the standard treatment and the trees with a low amount of flowers got nothing.

Counting was carried out at three times, namely at the end of June (end of June drop), in July (hand thinning) and in August (just before harvest). Just before harvest, a random fruit size measurement was also carried out in all treatments.

### *Results and discussion*

Precision thinning in the Elstar apple variety has several advantages: 1) avoiding chemical thinning in the lowest flowering class prevents yield loss, 2) a significant reduction in the required manual thinning when thinning according to the task map is possible, particularly in the highest flowering classes, 3) in the case of a high flower cluster numbers, overthinning is less likely to occur.

By applying precision thinning according to the task map, each flowering class can be given the optimal thinning strategy, making it easier to achieve the target number fruits/tree in more trees; the orchard becomes more uniform and alternate bearing in the following year is prevented.

In Conference pear, applying fruit thinning in the "high" flowering category results in a reduction in the number of fruit per tree, and gave a higher average fruit weight, resulting in a comparable net yield in kg. This can reduce the labour required for hand thinning and harvesting.

In the figure below the effect of precision spraying is clearly demonstrated. In the untreated block the different categories of trees from low to high numbers of flowers, show a different size distribution at harvest time. In the case of the orchard were each category got another treatment the size distribution is uniform.

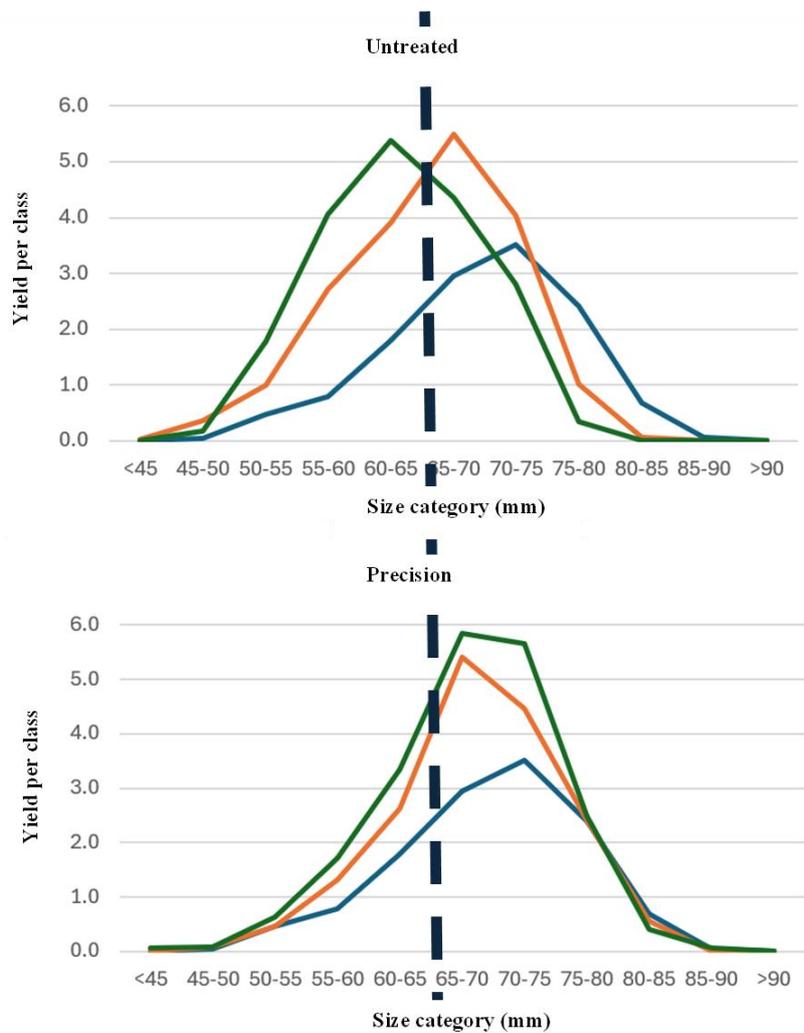


Figure: blue line: low amount of flowers, orange: normal amount, green: high amount of flowers.

## Develop crop growth model

### Methods

Within this work package, Delphy is working on developing a crop growth model for pear (Conference). The aim is to predict the June drop and the final fruit numbers for Conference pear. Many counts and measurements were again carried out in various tests from 2021-2024. In addition to validating the model, work has been done to collect information about the course of the June drop and the factors that influence it on 3 different pear orchards.

### Results and Discussion

It was found that it is possible to determine the leaf development based on degree days as is shown in the figure below. It was also found that the chance of a fruit drop is determined by the relative growth of the growth of the pear. This can be described by formulas. The measurements are plotted in the figure below. Camera systems with the right resolution could in the future follow the growth of pears and predict the fruit drop in a better way.

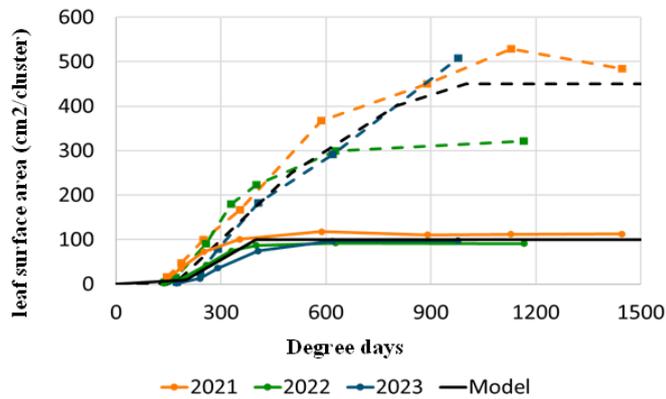
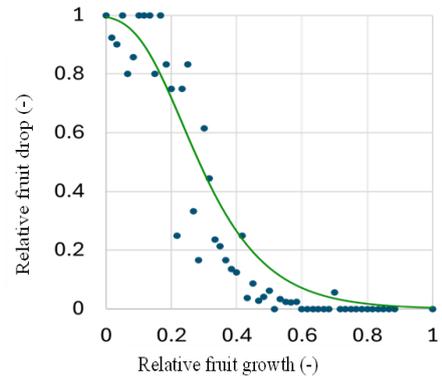


Figure: Development of cluster leaves (solid lines) and shoots (dotted lines) in 2021-2023.



The probability of a pear falling or remaining stuck depends on its relative growth. Example: May 2022.

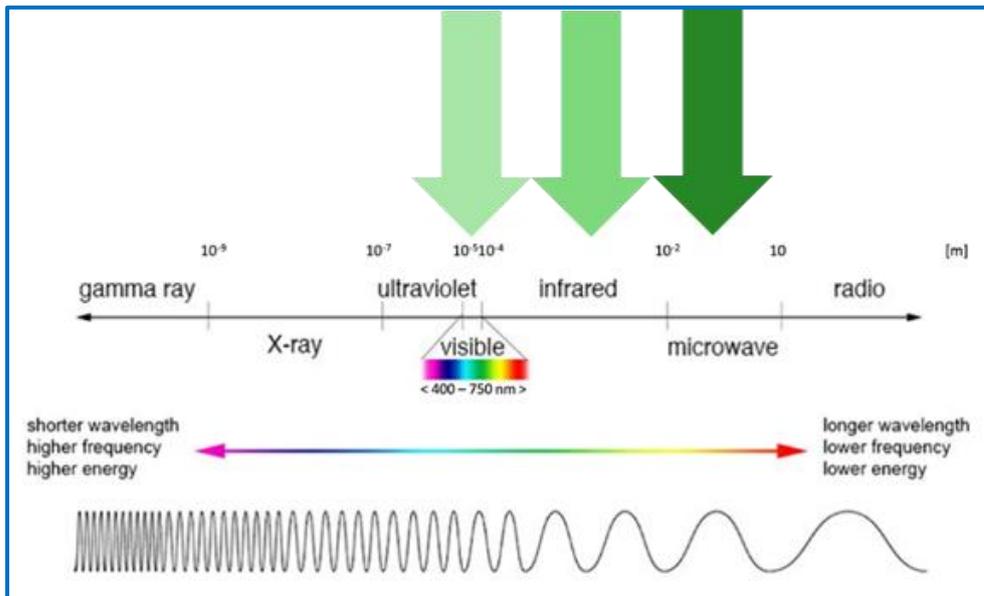
### Case study: Cool data

#### Objectives

This project investigated two techniques for non-destructively measuring the internal fruit quality of Conference pears. Both utilize electromagnetic waves from the invisible part of the spectrum. Kubota investigated the application of Near Infrared (NIR) technology, while Vertigo investigated the application of Microwave technology.

#### Significant Findings

- It was possible to measure the Brix with both systems but measuring the firmness was only possible with the Fresco scanner from Vertigo.



#### Methods

First the tools to evaluate the fruit have been selected. Non-destructive measurements using new tools are being related to common (destructive) quality assessment methods.

### Common quality assessment

- Firmness, Brix, Weight
- Photographic analysis (colour, shape, percentage russeting)

### Non-destructive assessment

- Near Infrared – both a hand held sensor from the project partner Kubota and hyperspectral imaging from our in-house facility
- Microwave based – a hand held sensor from the project partner Vertigo



The project partner Kubota decided to pause the further development of the NIR hand held sensor. Therefore the focus was on Fresco sensor from Vertigo.

Companies were visited in the most important Conference growing regions (Limburg, Zeeland, the Betuwe, Utrecht, Flevoland, North Holland and the Belgian fruit region). In some cases, the storage boxes were labelled so that they can be reanalysed as soon as they leave storage. Fruits from each batch were collected and stored in parallel at WUR Randwijk. Photo material and data about firmness and sugar content are added to the Agromanager database as much as possible. Agromanager is data platform for fruit growers where all data can be collected and analysed by the grower.

### *Results and Discussion*

Both Kubota and Vertigo meters are suitable for non-destructively measuring Conference Brix. The Vertigo meter (Fresco) is suitable for non-destructively measuring Conference firmness. Although the Brix is easier than the firmness. The nice thing about the hand held sensor is that multiple measurements can be taken to get a better average firmness value. In consultation with Vertigo, a plan is being developed to launch the Fresco.

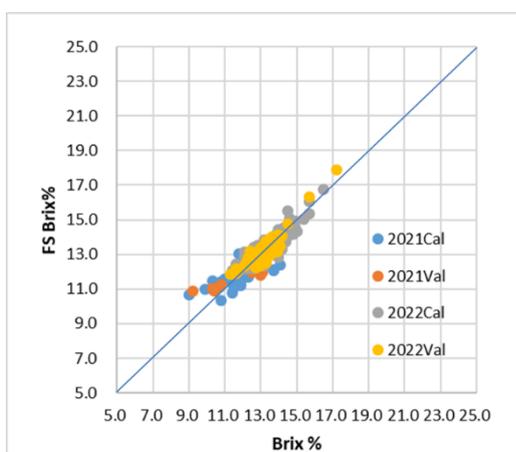


Figure: on y-axis predicted Brix value and on the x-axis the measured ground truth data of Brix.

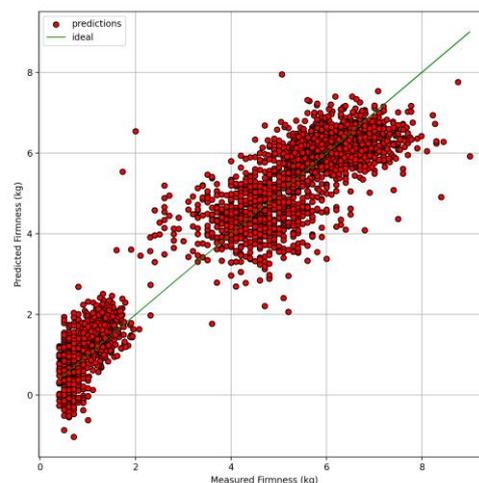


Figure: on y-axis predicted firmness value and on the x-axis the measured ground truth data of firmness.

## Case Multifunctional robot

### *Objectives*

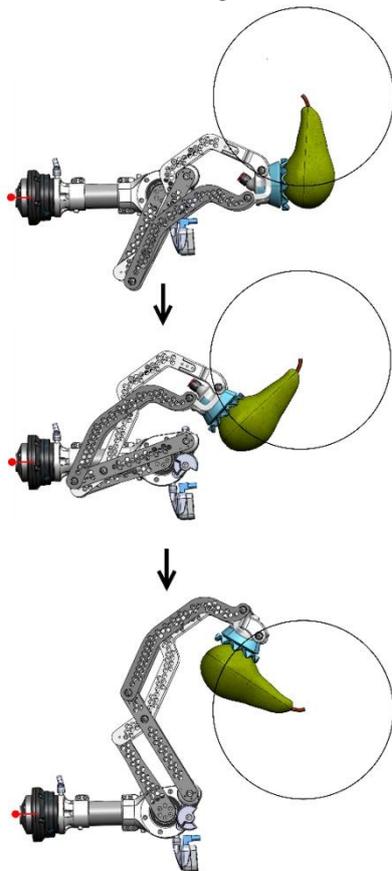
The main objective of the multifunctional robot case is to expand the functionality of existing orchard robots and of orchard robots currently under development in parallel research projects. The focus of the work is on two topics, namely the development of a sensing system and a gripper for picking pears and on a sensing system, robot control and end-effector(s) for robotic pruning of fruit trees and red currant bushes. On the longer term additional tasks such as automatic thinning, removing weeds and precision spraying will be targeted.

### *Significant Findings*

- Detection system developed for robotic harvesting pear to detect the position but also the orientation and some other key points of the fruit.
- Prototype gripper that can do the required motion to detach a pear from a tree which is significantly different from that to detach an apple.
- Extensive knowledge and expertise on automatic pruning and fruit harvesting is exchanged with Washington State University and Oregon State University. Close cooperation and knowledge exchange between Dutch and US researchers is of mutual benefit.
- A prototype gripper for pruning is developed and tested on red currant.

### *Methods*

When harvesting by hand, the pear is often lifted perpendicular to the stem, causing the pear to detach from the tree during the natural separation of the stem. The new pear gripper concept uses the same



motion. A soft silicone suction cup uses a vacuum pump to grip the pear. The key innovation of the pear gripper lies in the lifting motion that is integrated into the gripper mechanism. This means the robot arm no longer has to perform this motion itself. This increases the picking speed and reduces the risk of collision between the robot arm and the tree.

A small stereo vision camera attached to the gripper detects and locates ripe pears. This information is passed to the control software, which calculates the correct path for the robot arm to grasp and pick the pear.

To detect the pear and estimate its grasp point, Deep-Learning Keypoint R-CNN is used. This algorithm is a region-based convolutional neural network (R-CNN) that can simultaneously detect the object (the pear) and the grasp point (a point on the pear) in an image. Not only the position of the pear but also the grasp point can be learned end-to-end using hand-labeled training images.

The robotic arm systematically moves the gripper with the camera along a preset search frame approximately 20-30 cm from the tree. Upon detection, the pear is harvested immediately. If multiple pears are detected in a single frame, the pear closest to the robotic arm is picked first, as this is generally the easiest to reach.

### *Results and Discussion*

During the harvest period in September 2023, WUR conducted experiments with this setup at the experimental fruit research station Randwijk to harvest Conference pears. The results are convincing: the robot can detect and harvest pears without damaging them. The

tests in the orchard provided valuable insights into what works well and what can be improved on the gripper. For example, some fruits are difficult to reach, and the lifting mechanism only works optimally for a predetermined fruit size. Furthermore, the robot does not yet detect obstacles, such as branches or crop wires. This can be risky for both the tree and the robot. The gripper is therefore not yet ready for practical introduction, but it is an important piece of the puzzle for the development of future robots for fruit growing.



Photo 1 Robot setup in orchard



Photo 2 Gripper with suction cap

## Pruning red currant bushes

### *Methods*

The main challenge in the end-effector for pruning lies in the sensors responsible for determining the correct pruning positions. Electric battery-powered pruning shears for manual pruning have developed into robust systems over the years. For this reason, it was decided to use an existing pruning tool (Makita DUP361ZN) and modify it so that it could be controlled by the robot. This pruning shear is capable of cutting branches with a diameter of up to 33 mm. To operate this tool safely, a digital output signal from the robot was converted into a mechanical input to actuate the lever in the tool. This was achieved using a coil with an electromagnet. To accommodate this additional component and enable mounting on the robot flange, a new 3D-printed housing was designed. The power for cutting is supplied by two 18V 5.0Ah batteries. These can cut over 70,000 times on a single charge.

The camera system's task is to determine which branch the robot should prune, and where. In addition to colour information, this requires 3D information. A stereo camera (Intel RealSense D405) is mounted on the end-effector for this purpose. This small and lightweight camera (4.2 cm × 4.2 cm × 2.3 cm; 60 g) provides colour and 3D images between 7 cm and 50 cm. This makes the camera suitable for detecting detailed features or improving target position estimation based on additional sensors on the robot. The completed prototype of the pruning end-effector is shown below. Linux and the Robot Operating System (ROS2) are used to control the end-effector, the camera, and the robot.



### *Conclusion and discussion*

Experiments in the lab and outdoors with redcurrant have confirmed that it is possible to prune branches using a robot arm and this end-effector. The prototype end-effector for pruning meets the wishes and requirements defined in the project. In addition to pruning redcurrants, this prototype can also be used to prune large fruit. The prototype does not yet meet all the requirements of a commercial product, such as watertightness. The biggest challenge for robotic pruning is not the pruning shears themselves, but sensors and algorithms for detecting the correct pruning positions.

