Project Title: The Next Fruit 4.0

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Project size
Amount: 3,156k€ for 4 years
Agency Name: Dutch ministry of Ministry of Agriculture, Nature and Food Quality
Notes: Total project size is 3,156k€ for 4 years, 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**
Salaries	$54,000	$54,000	$54,000
Benefits			
Wages			
Benefits			
Equipment	$5,000	$5,000	$5,000
Supplies			
Travel			
Miscellaneous			
Plot Fees			
Total	$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. This requires us to be able to monitor, manage, and make decisions 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 needs further development and the other is ready for field trials. A later add on are camera's that can detect pests and diseases. Precision spraying for fruit thinning showed that aiming on the trees with a high amount of flowers gave the best results on effects on return bloom. The second example is the development of sensor platforms that detects blossom 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. The third example is the use of a non-destructive sensor to measure fruit quality like firmness and brix. The sensor Fresco showed reliable outcomes on a set of more than 20 samples. 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 make decisions 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.

The results presented are from the last 12 months. Results are presented per case study.

Case study: Precision sprayer

Objectives
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
- 1 prototype has been tested, finding is that the system was functioning well but a constant driving speed was needed. In the field the results therefor were not satisfying. The other prototype can handle difference in speed and is now far enough in development for testing in November and December 2023.

Methods
The third year of the project concentrated on:

- Building an improved sensor platform for a sprayer with LIDAR and GPS and (later in the fourth year of the project with RGB sensors).
- Processing data into usable data for spray decisions at nozzle level
- Build 2 sprayers with laser scanner that can spray at nozzle level and that can adapt dose on tree volume

Results and Discussion
In practice, the most important benefit is that in the future fewer spray products 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 of the tree volume an algorithm determines the amount of spraying liquid for each nozzle.

Within this work package, two types of sprayers have being build. The first is from Munckhof, the second from KWH. In the past period, the focus has been on getting both systems working. In collaboration with Munckhof, a first so-called timing measurement has been made, not yet in the field, but on asphalt with art objects and water-sensitive paper. This showed that the system already functions well, but that it is still very sensitive to driving speed. The results of the first measurements taken in the orchard showed that the deposition was lower than the standard sprayer that was used. In order to do further testing, the system needs to be improved.

With the KWH sprayer, work was mainly done to get communication between the different parts of the system going. The Lidar sensors are read by a separate computer. This computer also decides whether and how much to spray. These instructions are then communicated to the sprayer system (from the company BBLEAP). The entire system is now basically working and the first measurements will be taken in the coming weeks.

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

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

- Blossom detection method did not work sufficient enough, a higher resolution camera is needed in combination with flash lights.
- Detection method to detect fruit tree canker and apple blossom weevil
- Trunk detection to get the GPS locations for individual trees.
- Field trial on blossom and fruit thinning showed for third year in row that precision spraying on trees with a high amount of flowers is the most effective strategy to make the orchard more uniform.
- Experiments were done to develop a thinning decision support system for Conference pear.
- Proof of principle was demonstrated for automated detection of apples and also pear in top layer of storage bins.

Methods
The third year of the project concentrate on:

- Testing systems for automated detection of pear in top layer of storage bins.
- Building data and decision support models and dash boards for growers for presentation and management at tree level
- Setting up trails on thinning based on sensor input

Results and Discussion

At harvest, growers and sales organisations like to know what the fruit quality is in the storage bins. For apple the size can easily be determined by making a picture from the top of a bin. For pear it is in development now. For that reason an algorithm was developed for the Conference pear.

Image processing photos storage bin

Within the project, WUR is 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.

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.

Drive through automatic photo portal for picking trains
Because there is little time during the harvest to photograph each storage bin by hand, it was thought 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 the past 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.

Develop crop growth model
Within this work package, Delphy is working on developing a crop growth model. 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 in 2023. 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. The results of all tests have now been worked out.
It is clear what causes this difference. As is known, there are many factors that influence moulting, such as planting system, planting year, number of flower clusters, soil, crop health, etc.

This year, time was also spent on developing the dashboard for fruit growers together with the project partner Agromanager. An important point of attention here is the easy exchange of data.

Precision thinning
Last season, WUR and Delphy carried out an extensive thinning test on a task map at the Experimental orchard in Randwijk on Elstar apple. A total of 7 treatments in 4 flowering classes, i.e. 28 combinations, were carried out.
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. The results will be analysed in the near future
It is clear that it was a difficult thinning year. As with many growers, it was difficult to spray under ideal conditions. As a result, the thinning result was often disappointing in the trial.

Unfortunately, the Apple Blossom Beetle also caused noise in the data because counted flower clusters did not yield any fruits due to damage. The June drop may also have been less strong than we expected. It is clear that a strong thinning treatment on trees with many flower clusters does not quickly lead to over-thinning.

In Conference pear, ongoing fruit thinning research based on The Next Fruit 4.0 has been expanded with additional treatments to clarify the opportunities for precision thinning and precision fruit setting. Trees with many flower clusters have been thinned more often with Brevis to reduce the manual thinning. Trees with few flower clusters were stimulated to fruit set to increase yield. The number and weight per tree were determined during the harvest in September. These results are also currently being analysed.

Case study: Cool data

Objectives

The focus for this year was to select and evaluate tools for non-destructive quality assessment of fruit both preharvest and postharvest. Observed differences between batches of fruit should be related to relevant quality characteristics of the fruit. Not only aiming at quality assessment of freshly harvested fruits but also related to storage behavior of the respective batches.

Results and Discussion

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.

<u>Common quality assessment</u>

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

<u>Non-destructive assessment</u>

- 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. Therefor the focus was on Fresco sensor from Vertigo.

During the past harvest period, photographic recordings were made of 20 storage boxes per sample at 19 locations, of a total of 23 samples of Conference pear.

Vertigo was also present at a number of locations to validate the Fresco in practical situations in order to look at the effects of variation in light, temperature and moisture.

The preliminary results are shown in the figure below. 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 hardness 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.

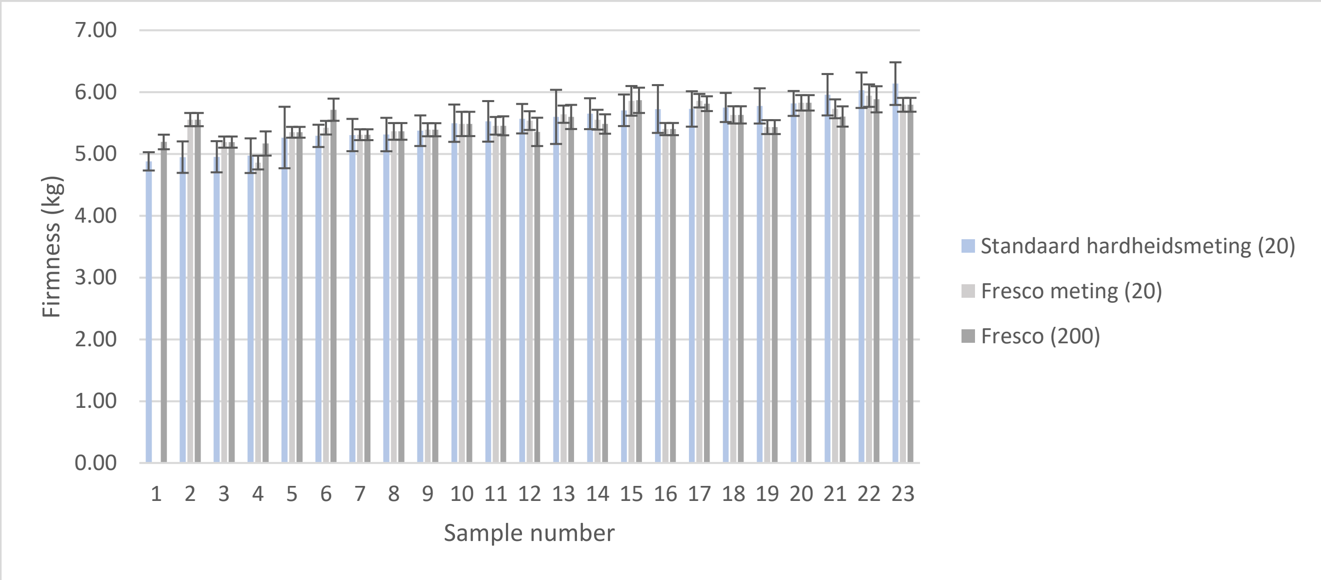

Figure: results of measurement of 23 different samples of pear fruit by hand (standard in blue), with the Fresco sensor (light grey sample of 20 fruits and dark grey with 200 samples)

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
The third year of the project concentrated on:

- Designing first prototypes for pruning and picking end effectors.
- Designing an algorithm to detect pears and pose estimation.
- Testing different camera's for making 3D models of dormant red currant plants.

Results and Discussion
Gripper testing pear picking
Within the project the prototype to pick pears was tested in the field. The most important innovation lies in the moving gripper system (photos 2 and 3) with suction cup. Unlike conventional methods that use the robot's arm movement to loosen the fruit from the tree, the new

concept allows the gripper mechanism itself to perform the crucial picking motion. The gripper also has an integrated colour and 3D (RGB-D) camera.
WUR researchers wrote software to integrate the deep-learning peer detection algorithm developed earlier in the project into an operating system for the robot using ROS2 (Robot Operating System 2).
After the first tests on the indoor test setup, a two-day test was carried out with the harvest of Conference pears at Experimental orchard of Randwijk during the harvest period in September 2023. The results are convincing: the robot can detect and harvest pears without damaging the pear. But we're not there yet. The tests in the orchard have provided valuable insights into what works well and what can be improved. The data collected during these picking experiments will be analysed to further refine the robot's capabilities and make necessary improvements.

Pruning red currant bushes
The past summer months have been used to explore better options for the sensor system. The research team is looking for high-quality sensors that can map plant architecture in 3D.
Two way are being followed for this.
On the one hand, (combinations of) various 3D sensors (cameras, LIDARs) and associated classification algorithms are investigated in collaboration with the sensor experts from the company IMEC. On the other hand, the collaboration between WUR (Jochen Hemming) and Oregon State University (Alex You, Joe Davidson and Cindy Grimm) contributed to a study investigating how a branch can be mapped in 3D with a simple 2D camera. The results of this research will be presented at a leading scientific robotics conference in Japan (ICRA 2024) in May next year

Photo 1 Robot setup in orchard

Photo 2 Gripper with suction cap

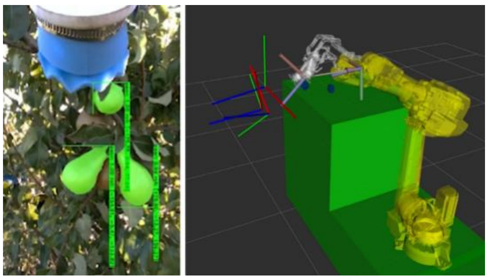

Photo 3

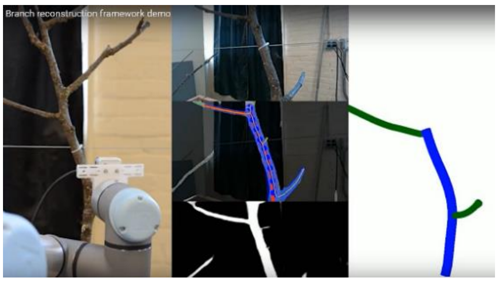

Photo 4 Making 3D model of red currant