CROSS-OVER BETWEEN HIGH-TECH AND AGRI- & HORTICULTURE

Food producers face the challenge of feeding nearly nine billion mouths in 2030. Here, the Dutch agrifood sector can play a crucial role, in collaboration with the high-tech industry for developing innovative machines and processes, helping the agrifood sector to achieve significant cost reductions, reduce the time-to-market and promote sustainability. Wageningen University & Research is a key player in this field, making, for example, the cross-over to high-tech for developing robots in agricultural and horticultural applications.

EDITORIAL NOTE

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The agenda has been set by the Technology Roadmap High Tech to Feed the World (HT2FtW) [1] (Figure 1). By applying high-tech systems and materials along with new ICT applications, the agricultural and food sectors will be better able to handle the major societal challenges which they face. In addition, this will improve the competitiveness of these sectors in the Netherlands and create opportunities to export the new systems and applications. Conversely, the high-tech sectors are challenged to find solutions to problems that so far have obstructed the application of these systems, such as the non-uniformity of products, the sometimes harsh operating conditions and the limited innovation budget (ultimately as a consequence of low food prices in the supermarket).

HT2FtW has been developed to stimulate cooperation between all sectors concerned through cross-overs. The application fields breeding, horticulture, agriculture, animal production, ingredients, food products and machinery for food processing are intertwined with technological developments in the field of materials, data acquisition, data analysis and usage, automation and control, and system architecture and integration. This calls for fundamental and applied research in interdisciplinary programmes.

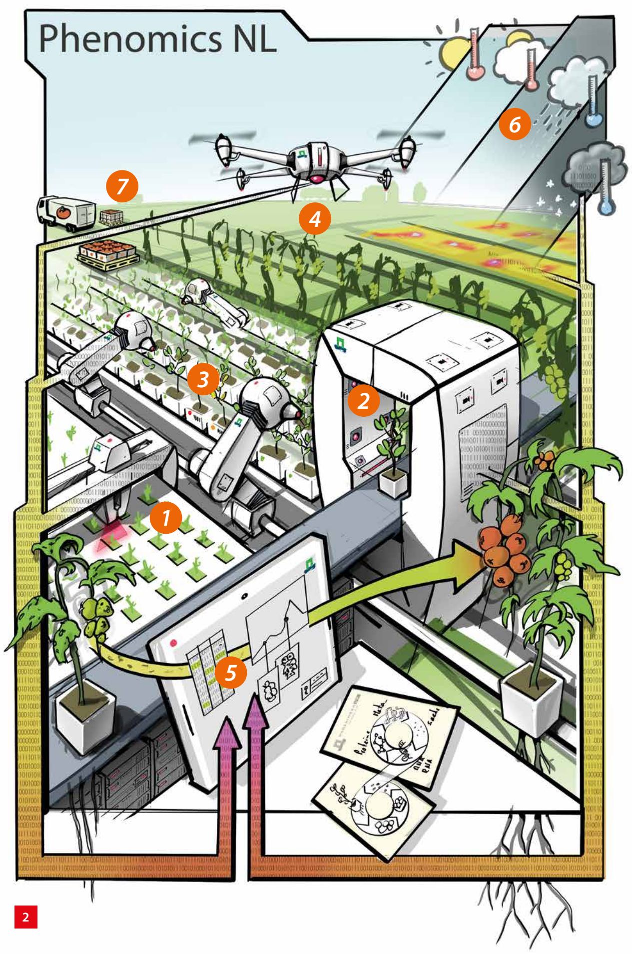
1 The HT2FtW roadmap was published in 2015 and has been integrated in the innovation calendars of four Dutch top sectors: High Tech Systems & Materials, Agri & Food, Horticulture & Starting materials, and ICT.

The HT2FtW roadmap (2015) was compiled by a consortium of high-tech companies, knowledge institutions and government to strengthen the cross-over collaboration and innovation. One of the key players is the 4TU federation, which comprises the three traditional Dutch universities of technology (Delft, Eindhoven and Twente) and Wageningen University & Research (WUR).

Wageningen

WUR's mission is to explore the potential of nature to improve the quality of life. Given the global challenges of population growth, agricultural area decrease and climate change (floods, droughts, new plant diseases), it is important to grow crops that can be cultivated efficiently and have high yields. WUR research groups, combined in the Phenomics NL platform [2] (Figure 2), are currently studying the behaviour of plants at different levels: from model and individual plants to the growth of crops in greenhouses and on the field.

One of the tools used are robots, for which WUR runs the Agro Food Robotics initiative [3], with four research institutes participating: Food & Biobased Research, Plant Research, Environmental Research, and Livestock Research. This covers the application of robots in the complete agrifood chain, from quality inspection of seeds, plants, crops and food products in the lab, greenhouse, field or factory, using computer vision, analytical techniques and handling systems; precision farming; processing and packaging; logistics and big data analysis.



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The Phenomics NL platform covers seven steps in the plant production chain:
- ① *Insights into plants' stress responses*
- ② *Measurements on individual plants*
- ③ *Quality inspection in the greenhouse*
- ④ *Measurements in the field (field phenotyping)*
- ⑤ *Data analysis of plants*
- ⑥ *Research into climate influence*
- ⑦ *Post-harvest quality preservation*

Harvesting sweet pepper

An interesting project is Sweeper [4], concerned with the development of a sweet pepper harvesting robot in an ICT Robotic Use Cases project within the European Union's Horizon 2020 programme. Sweeper's main objective is to put the first generation greenhouse harvesting robots onto the market. In modern greenhouses there is considerable demand to automate labour. The availability of a skilled workforce that accepts repetitive tasks in the harsh climate conditions of a greenhouse is decreasing rapidly. In the EU Seventh Framework Programme project Crops [5] extensive research has been performed into agricultural robotics. One of the applications was a sweet pepper harvesting robot (Figure 3).

The Sweeper project involves five partners from four countries, including WUR and sweet pepper grower De Tuindershoek from the Netherlands (system integrator Irmato Industrial Solutions abandoned the project when after bankruptcy it moved over to FMI – for this reason, more technical details cannot be published yet). The consortium integrates a wide-range of disciplines: horticulture, horticultural engineering, machine vision, sensing, robotics, control, intelligent systems, software architecture, system integration and greenhouse crop management. The project will finish in the second half of 2018. First results of constructing and testing the system have been reported [6].

The robot is an assembly of several subsystems, such as a mobile autonomous platform, a robotic arm holding an end-effector for fruit harvesting, and post-harvest logistics. Software modules are based on the Robot Operating System (ROS). The end-effector (gripper) contains sensing tools for detecting sweet pepper and obstacles, and grasping the fruit without the need of an accurate measurement of its position and orientation. A time-of-flight sensor is used to record colour and 3D information simultaneously. To improve the level of robotic cognitive abilities, crop models are applied to approximate the location of sweet peppers. This 'model-based vision' will increase and speed up fruit detection, localisation and maturity rating; a special challenge is occlusion (e.g., peppers 'hidden' behind leaves). It was concluded that robot arm control does not require the initially designed nine degrees of freedom (DoFs). In the current project an off-the-shelf 6-DoF industrial robot arm (Fanuc LR-mate 201iD) is employed; this greatly reduces costs.

Trimming bushes, hedges and roses

Another 'green' Horizon 2020 project [7], TrimBot2020, does not concern a food application but is very interesting from a mechatronical perspective. The aim of this project is to investigate the underlying robotics and vision technologies and prototype the next generation of intelligent gardening consumer robots. The project is focused on the development of intelligent outdoor hedge, rose and bush trimming capabilities, allowing a robot to navigate over varying garden terrain, including typical garden obstacles, approaching hedges to restore them to their ideal tidy state, topiary-styled bushes to restore them to their ideal shape, and rose bushes to cut their flowers.

The project partners are the universities of Edinburgh (UK, coordinator), Wageningen, Amsterdam and Groningen

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The Horizon 2020 project Sweeper uses the technology developed in the EU FP7 project Crops to introduce, test and validate a robotic harvesting solution for sweet pepper in real-world conditions.

4 *The TrimBot Garden test field in Wageningen. On the right, a Bosch Indego robot lawn mower, on which after modification a robot arm will be mounted.*

from the Netherlands), Freiburg (Germany) and Zurich (ETH, Switzerland), and German company Bosch. In Wageningen gripper design, software development (ROS control) and system integration was taken up and a test field was laid out (Figure 4). The project aims for a technology readiness level of 5-6 for the total trimming robot concept. Bosch already markets the autonomous lawn mower that will be used for the vehicle base, and is expecting to undertake further development and engineering following the project towards a new generation of gardening robots.

Objective

The system has to be capable of navigating by means of a rough user-defined garden map to approach hedges and bushes, and then, with a novel electric hedge cutter in conjunction with the 3D scene data, trimming flat surface hedges and shaped box-wood bushes. 3D computer vision research is aimed at sensing semi-regular surfaces with physical texture (overgrown formerly 'smooth' plant surfaces); coping with outdoor lighting variations; self-localising and navigating (using motion planning) over slightly rough and uneven terrain (grass, wood chips, gravel, tiles, etc.) and around obstacles; visual servoing to align a vehicle near to slightly moving target plants; and visual servoing to align leaf and branch cutters with a compliant surface.

Platform

A robot arm from Kinova will be mounted on a modified Bosch Indego robot lawn mower; Kinova is a Canadian manufacturer of wheelchair-mounted robot arms for disabled persons. The arm is partly made of carbon fibre for compact and lightweight construction. Another perk is that the controller is incorporated in the robot arm mount.

For the estimates of orientation and position of the robot a Visual SLAM (simultaneous localisation and mapping) algorithm is used. This algorithm basically uses the images from five stereo cameras; however, it additionally integrates measurements from an inertial measurement unit (IMU) and from an odometer (measuring the covered distance) to improve the solution with regard to accuracy and robustness.

The five stereo camera pairs are mounted on the platform to obtain a 360° view of the garden enabling correction for encoder inaccuracy and slip. As a starting point a rough sketch of the scenery is downloaded to provide the control system with a map of the garden. Using input of the stereo cameras and other sensors this map is continuously being refined to improve the accuracy of navigation and trimming. This is essential because, not only during the processing of a complete hedge but also when trimming a single bush, the robot platform has to move its position several times, as the range of the robot arm is too small to cover the whole surface in one pass.

Trimming control

As input for the trimming operation a model is made up comprising a polygonal mesh consisting of little triangles, derived from a scan of the actual bush or hedge. This model is used to define the surface to be trimmed. As the trimming tool works omnidirectionally (see below), it is only a matter of aligning the axis of the tool with the perpendicular of the local surface triangle and determining the depth of trimming (how many centimeters of material have to be removed). Therefore, effectively only five DoFs (three for the position in space of the tool centre point, and two to define the direction in space of the tool axis) have to be controlled, whereas the system nominally provides eight DoFs (six from the robot arm, two from horizontal platform motion). In general, this 8-DoF motion control is mathematically rather tricky, so effective 5-DoF control significantly reduces the computing power required on board the platform.


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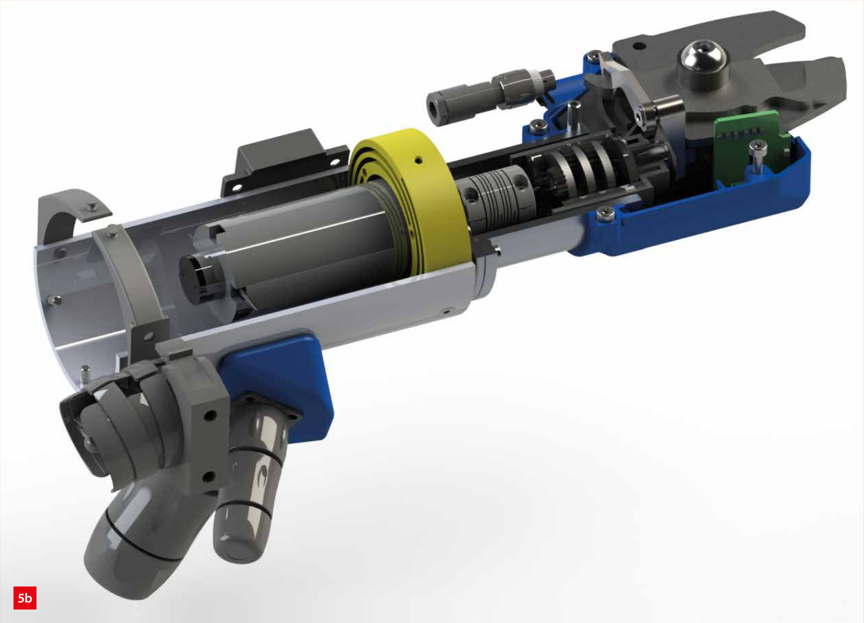
5b

The path planning has been modelled as a traveling salesman problem to minimise the aggregated path length. During operation other stereo cameras mounted near the trimming tools are used for exact localisation and depth estimation of the surface to be trimmed and to provide feedback for improving the trimming result.


6a

End-effectors

The end-effectors for trimming as well as rose cutting could not be obtained off-the-shelf but had to be custom-made (Figure 5). The design of the trimmer was inspired by commercially available counter-rotating saw blades; the toothed gear was derived from such a hand tool from the US. The star-like cutter was specially designed, with the arrow point shapes added for retaining thicker branches when trimming (this concept is used in commercial bush trimmers). The cutter blades were made by Tebra Machine Blades and Industrial Knives, specialised in manufacturing, grinding and hardening. A new housing was designed and maxon drives were integrated because of previous experience and their easy ROS control

For the rose-cutting end-effector a commercial rose-cutter was modified: the cutter and planetary gear were used and

5 End-effectors; see text for further explanation.
(a) For trimming; on the left, part of the robot arm.
(b) For rose cutting; the yellow feature is the 3D-printed flexible coupling between drive (on the left) and cutter.

6 The trimming test system in action in the Trimbot Garden at Wageningen Research.
(a) Overview showing a provisional test platform (not yet the Bosch Indego lawn mower).
(b) Close-up showing the counter-rotating cutter blades.


6b

again a maxon drive was integrated. A 3D-printed flexible plastic coupling was inserted between drive and cutter to allow for some freedom of movement of the cutter head against the sturdy rose bush; this prevents excessive forces on the manipulator when it collides with rose branches.

Accuracy
The error margin for trimming of simple geometrical shapes was set to 2 cm over the complete bush or hedge surface. Before and after trimming a 3D reconstruction of the surface can be made and the two resulting point clouds can be compared to determine the actual error. A next step in the project will be to analyse error sources, such as the tool, the trimming algorithm and the robot platform.

As the current robot arm is not very stiff, it will be quite a challenge to meet the 2 cm accuracy requirement. The demanding and varying conditions (sunlight, temperature, humidity, fouling) add to this. For example, because of sunlight intensity, LED flash light is used for imaging with extremely short shutter times and a small diaphragm.

Given the TRL 5-6 objective, safety was not part of the project scope. In a subsequent project, aimed at designing a market-ready system, detection and avoidance of obstacles such as humans and animals will have to be considered and safety measures for the trimming operation need to be integrated, providing a neatly and securely trimmed exterior of the trimming robot.

Figure 6 shows the trimming test system in action. ■

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