Automation and robotics in the protected environment, current developments and challenges for the future

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1. Wageningen University & Research Agro-Food Robotics

Wageningen University & Research (WUR) is a university plus a contract research organisation for innovation in life science and agri-food. The contract research organisation is mainly working with industry, governmental authorities and other knowledge institutes. According to the Times Higher Education World University Rankings WUR is the best university in the Netherlands and no. 1 worldwide, in agriculture and forestry for 2017 on the QS World University Rankings charts. WUR currently counts about 11.000 BSc/MSc students and almost 2000 PhD students. About 5.000 full time equivalent employees are employed at WUR. Students and employees originate from over 100 countries. The WUR Agro Food Robotics initiative is a joint program by several research groups of WUR [1]. More than 50 people are passionately working in this field within the different science groups of Wageningen. The program tries to bring new knowledge to practice by carrying out feasibility studies, functional designs, prototype development, testing and validation and by supporting new product implementations. Furthermore, the members of the program give expert advice and support management and government decisions on when and how to use or not use robotics.

2. Demand for automation and robotics in agro & food

During the last decades greenhouse crop production has become a green industrial production process. Horticultural production faces a growing demand for mechanisation, automation and robotics as labour costs are increasing and the availability of skilled labour is decreasing. The modern consumer demands guaranteed and constant quality. Moreover, there are intensified hygiene, food safety and traceability demands. Robots and drones play nowadays an important role in agriculture, horticulture. By using such technology growers can use less energy and raw materials, they can avoid unattractive working conditions and revenues are higher and the products are of better and better controlled quality.

2. Current developments and example projects

Automation in commercial greenhouses is not new. Many highly automated systems are already applied in practice. This includes logistics and autonomous transport of plants and harvested product in the greenhouse and to the sorting and packaging facilities, spraying robots for plant protection, machine vision based sorting systems for pot-plants and cut-flowers and robotic cutting, planting and grafting machines. Current research is carried out in the fields of automated phenotyping, crop scouting and disease detection and on autonomous harvesting and plant manipulation.

2.1. Phenotyping

One example of advanced phenotyping equipment is the MARVIN high-throughput 3D seedling sorter technology developed by WUR in cooperation with Flier Systems BV [2]. This device has the goal to perform seedling assessment based on human expert knowledge modelling. The machine rapidly acquires images from multiple viewpoints and makes 3D models of the plants and then accurately evaluate their size and features in milliseconds. The information can be automatically recorded in a database and used to sort out uniform batches. The same technology is used to build a 3D data generator for breeders, facilitating the measurement of plant features to the smallest detail. In near future the Netherlands Plant Eco-phenotyping Centre (NPEC) will be established at the WUR campus. NPEC will host different high-tech modules for high throughput plant phenotyping in the lab, in the greenhouse and in the open field.

2.2 Crop scouting and disease detection

WUR cooperates with the Dutch company Hortikey on the realization of the Plantalyzer. The Plantalyzer is an autonomous platform that drives on the heating pipe rail system in the greenhouse to automatically image tomato fruits in the greenhouse while they are not yet harvested. This system will be able to give objective information about the amount and ripeness of fruits. In the ongoing Smart Greenhouse Horticulture project the Gerbera-scout platform is developped (Figure 1). The goal of this device is to assess the plant load (number of flowers and flower buds) for yield prediction. Furthermore, automatic stress and diseases detection (for example powdery mildew) are under development. For this purpose imaging sensors (colour camera and/or multi- or hyperspectral cameras) are used and image analysis is performed by applying deep-learning methods. In a the Healthy Greenhouse Project a multi-spectral filter-wheel camera was successfully developed for the detection of botrytis in cyclamen in the greenhouse [3]. Several other research projects currently are focussing on the detection of insects or the detection and mapping of defects caused by insects. The European coordinated integrated pest management (C-IPM) project PeMaTo-EuroPep for example is develolpping methods for automatic counting of white fly and beneficial insects trapped on yellow sticky traps using deep learning F-RCNN image analysis methods [4]. An example of a detection result is displayed in **Figure 2**.

2.1. Robotic harvesting and plant manipulation

Research on greenhouse robotics started at WUR in 1998 with the development of a cucumber harvesting robot (Figure 3). The goal of the project was to reduce labour costs through automatic harvesting. As cucumber fruits and leaves are both green fruit detection based on colour features only was not feasible and a custom made dual-spectral camera was developped. The prototype was able to detect 94% of ripe fruit and suceeded in harvesting 74% [5].

Between the years 2010 and 2014 WUR coordinated the European Clever Robot for Crops (CROPS) project [6]. CROPS has developed scientific know-how for a highly configurable, modular and clever carrier platform that includes modular parallel manipulators and intelligent tools (sensors, algorithms, sprayers, grippers). This system can adapt to new tasks and conditions. The CROPS robotic platform was capable of site-specific spraying (targets spray only towards foliage and selective targets) and selective harvesting of sweet pepper, apples and grapes (detects the fruit, determines its ripeness, moves towards the fruit, grasps it and softly detaches it).

To further develop and to enhance the still limited performance of the sweet-pepper harvesting application [7] the European research project SWEEPER [9] started in 2015. SWEEPER used the technology developed in CROPS to introduce, test and validate a robotic harvesting solution for sweet pepper under real-world conditions. The project involved 6 partners from 4 different countries (The Netherlands, Belgium, Sweden and Israel). In the consortium a wide-range of disciplines was available, including: horticulture, horticultural engineering, machine vision, sensing, robotics, control, intelligent systems, software architecture, system integration and greenhouse crop management. The SWEEPER robot comprises the following modules: an end-effector to cut and grasp the pepper; a RGB-D camera to detect and locate the fruit and to estimate fruit ripeness; active LED illumination to better detect fruit and obstacles under alternating environmental conditions; a robot arm to search, move to fruit, and to convey fruit; a platform to move the robot through the greenhouse and logistics to convey and store picked fruits. As shown in figure 5 the computer vision system of the robot makes use of deep-learning methods for plant part segmentation, see [10] for more details. In the summer of 2018 greenhouse experiments were carried out with the developed robot (Figure 4) to evaluate its performance. For a simulated single row growing system (when only fruits on front side of a plant stem were evaluated) the robot was able to harvest 29% of ripe fruit in a unmodified, commercial crop. When leaves that completely occluded fruits and the most severe fruit clusters were removed manually before robotic harvesting, the system could harvest 55% of the ripe fruit. The average time to harvest one fruit was 24 seconds. While these numbers maybe still seem to be rather low the SWEEPER robot had significantly increased performance and was 4 times faster than the CROPS prototype. Furthermore, there are currently many research and development activities ongoing throughout the world by different research groups and start-up companies concerning robotic harvesting of strawberries and tomatoes.

The TrimBot2020 is a project that runs from 2016 through 2019 and researches the robotics and vision technologies to prototype the first outdoor garden trimming robot. The robot's mobile platform is based on an autonomous lawnmower. It will navigate itself over varying terrain, approach rose bushes, hedges and boxwood topiary, to trim them back to an ideal shape. Achieving this will require a combination of robotics and 3D computer vision research and innovation activities. Original developments will be required for 3D sensing of semi-regular surfaces with physical texture (overgrown plant surfaces), coping with outdoor lighting variations, self-localising and navigating over real terrain and around obstacles, visual servoing to align the vehicle with potentially moving target plants, visual servoing to align leaf and branch cutters to a compliant surface. Figure 6 shows the current state of development of the Trimbot2020 mobile platform with a mobile robot arm and bush trimming tool.

3. Challenges for the future

Still more research is needed to make robotic systems performing fast, simple and safe to use in practice. The success rate and cycle time is in most developed systems still too low to allow an economically sound implementation in commercial practice. Human-robot collaboration and "human in the loop" applications are important stepping-stones towards full automation. These must also include the key issues of user safety and user acceptance. From the plant side, the breeding of crops with novel phenotypes and plant architectures, such as fruits which are easy to see and reach by robots, will simplify and accelerate the application of robotics in the horticultural field. Challenges involve the complex integration of multiple disciplines and technologies (e.g. navigation, safe operation, grasping, manipulation, perception, learning and adaptation).

From the hardware side robust mechanics, hardware and sensors that can even better cope with the harsh environmental conditions (changing light levels, dust, water, extreme temperatures) are needed. From the software point of view fast and intelligent data handling and interpretation methods need to be further developed. The current developments in high-tech horticulture are supported by the worldwide rapid improvements in computer hardware and software. Big players like Google, Amazon and Facebook are pushing the development on relevant topics (autonomous navigation, big-data and artificial intelligence).

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FIGURES

Figure 1 - Gerbera scout platform (left image) and image analysis example of counting flowers and flower buds using deep-learning (right image).

Figure 2 - Example results for automatic insect detection and counting on a yellow sticky trap. *Source: [4]*.

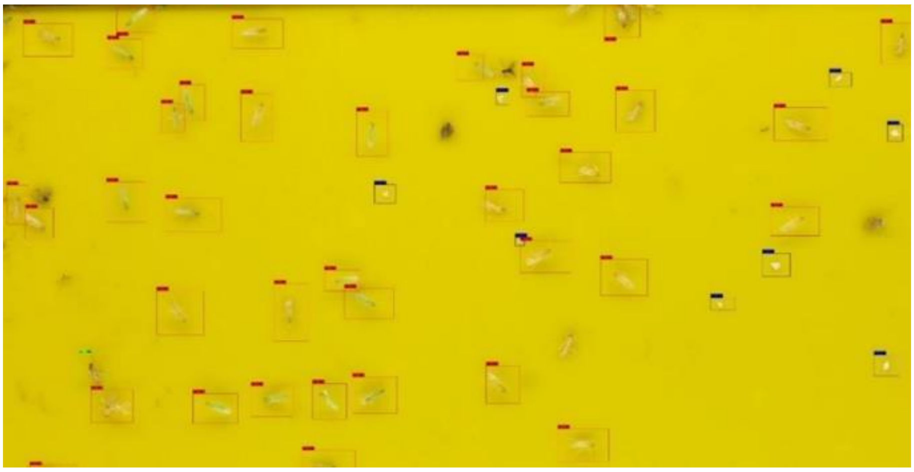
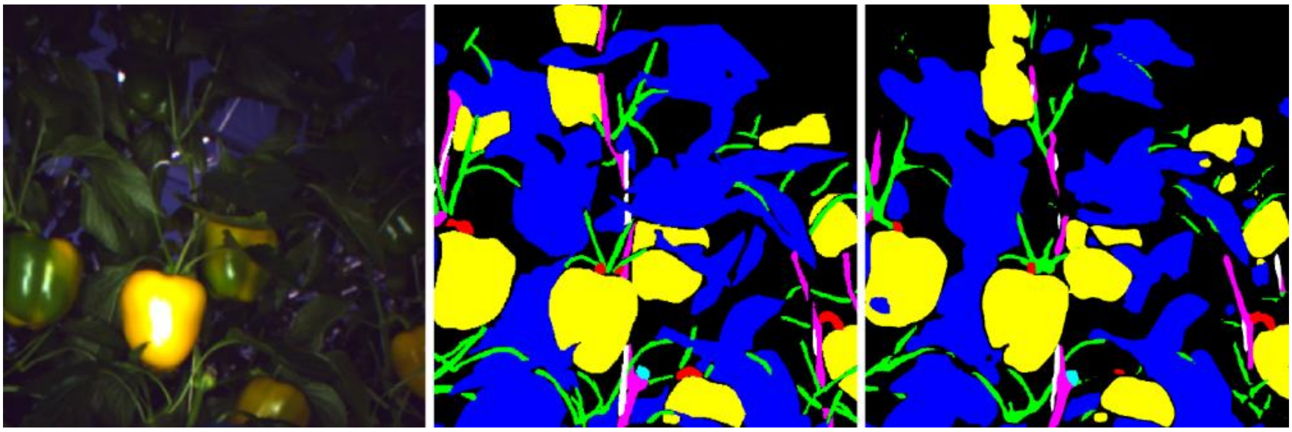


Figure 3 - Harvesting robot for cucumbers developed by WUR.

Figure 4 - The final prototype of the SWEEPER sweet pepper harvesting robot. *Source: [9]*.

Figure 5 - Example deep-learning plant part segmentation result of a sweet pepper image. *Source: [10]*.



Empirical image Ground truth labels Deep-learning result

Figure 6 - Trimbot mobile platform with Kinova robot arm and bush trimming tool.