CROPS GA 246252

www.crops-robots.eu

CROPS “Clever Robots for Crops”

CROPS: Intelligent sensing and manipulation for sustainable production and harvesting of high valued crops, clever robots for crops.

The main objective of CROPS is to develop a highly configurable, modular and clever carrier platform (Fig. 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 agro management 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 and grasp it and softly detach it). Another objective of CROPS is to develop techniques for reliable detection and classification of obstacles and other objects to enable successful autonomous navigation and operation of the platform in plantations and forests. The rationale for this aspect of the project is that agricultural and forestry applications share many common research areas, primarily regarding sensing and learning capabilities.

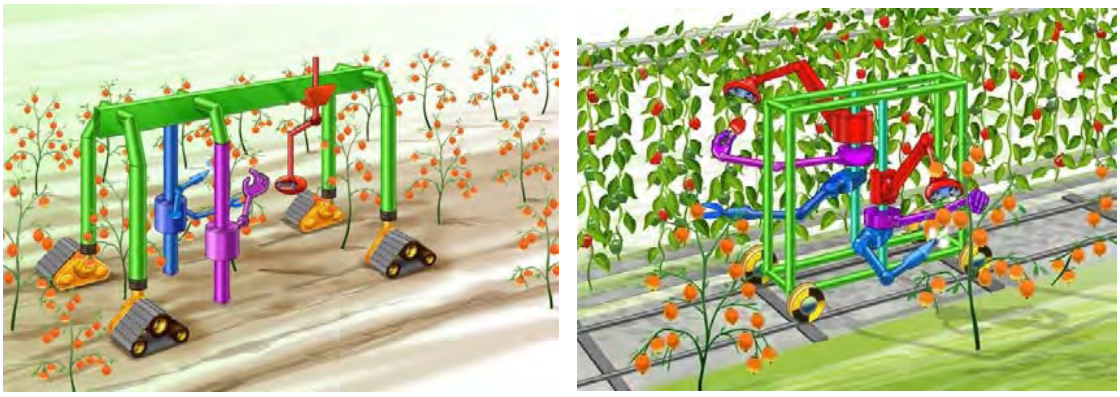


Figure 1. The CROPS modular platform, including intelligent sensing, manipulation and end-effectors.

For the robotic middleware ROS was chosen as software framework. The supervisory control system as well as the high-level software architecture have been developed and tested. The scheme of the computer hardware platform is shown in Fig. 2.

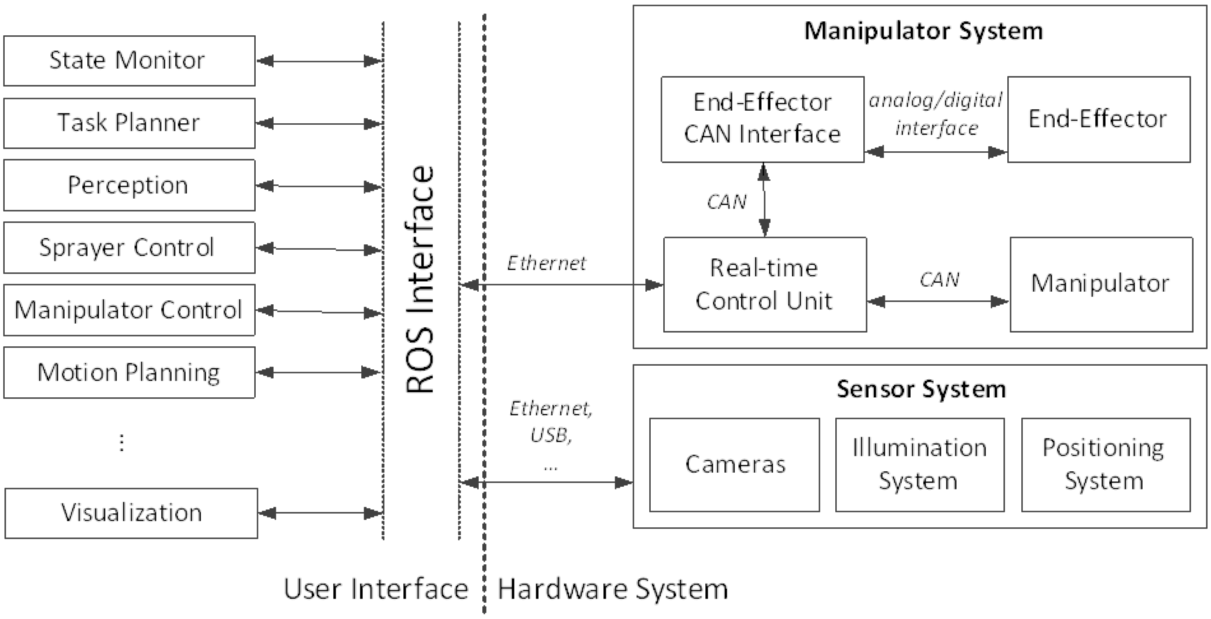


Figure 2. Hard- and Software Architecture of the developed harvesting/spraying robot system

Besides the canopy optimized sprayer and the forestry application, a modular robot system for harvesting pepper, apples, grapes as well as precision spraying has been developed. The modular robot system concept with its hardware components is shown in Fig. 3.

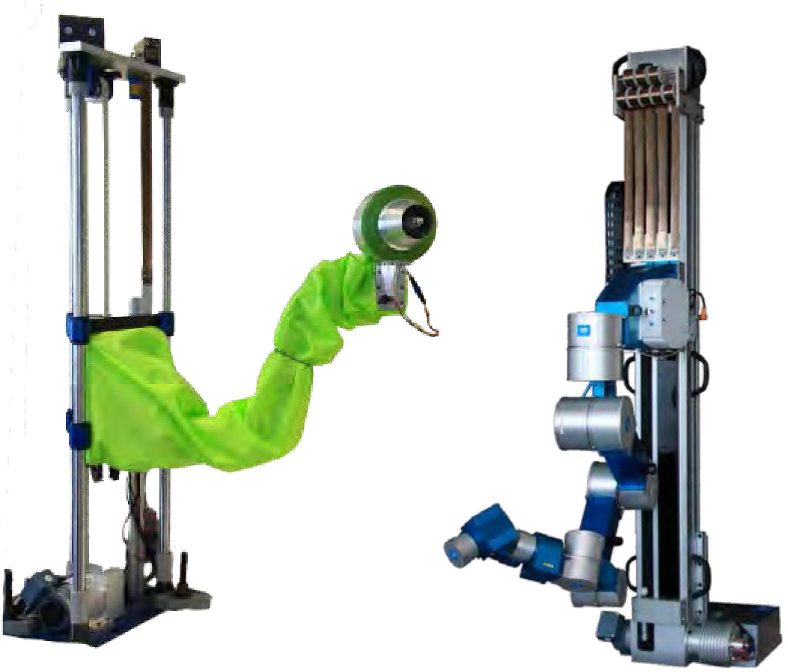
Figure 3. Overview of the developed robot system within the CROPS project

Requirements for the sensing systems for CROPS were derived. The design and implementation of the sensory systems for CROPS have been completed, including the sensory system for detection and localisation of fruits in orchards and greenhouses, the sensory system for detection and classification of objects, the sensory system for fruit ripeness evaluation and the sensory system for diseases detection in crops. In Fig. 4 and Fig. 5 examples of the detection of apples and grapes are given.

Figure 4. Multispectral classification results for an apples crop scene.

Figure 5. Multispectral classification results for a vineyards scene.

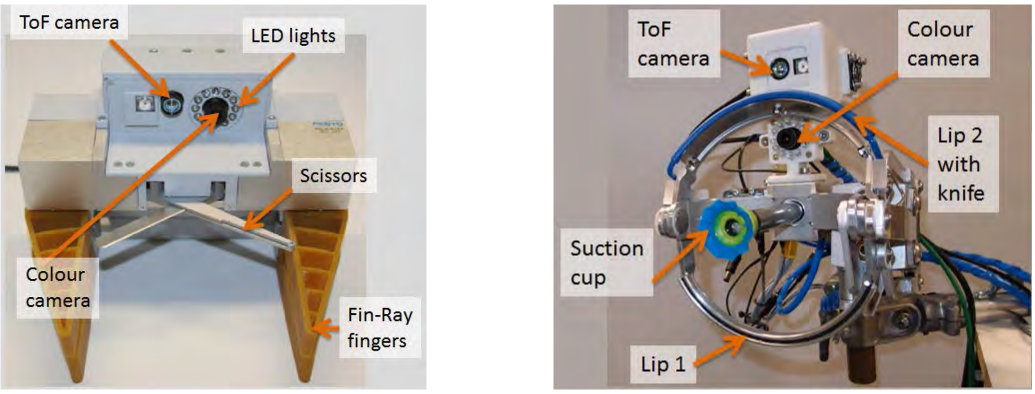
A nine degree of freedom manipulator was manufactured. End-effector prototypes were designed and tested. A prototype of a canopy sprayer was manufactured. The first manipulator prototype, the grippers, and the precision spray end-effector (see Fig. 6a) were tested in laboratory and field experiments. Based on these tests a final manipulator was designed (Fig. 6b).



(a) (b)

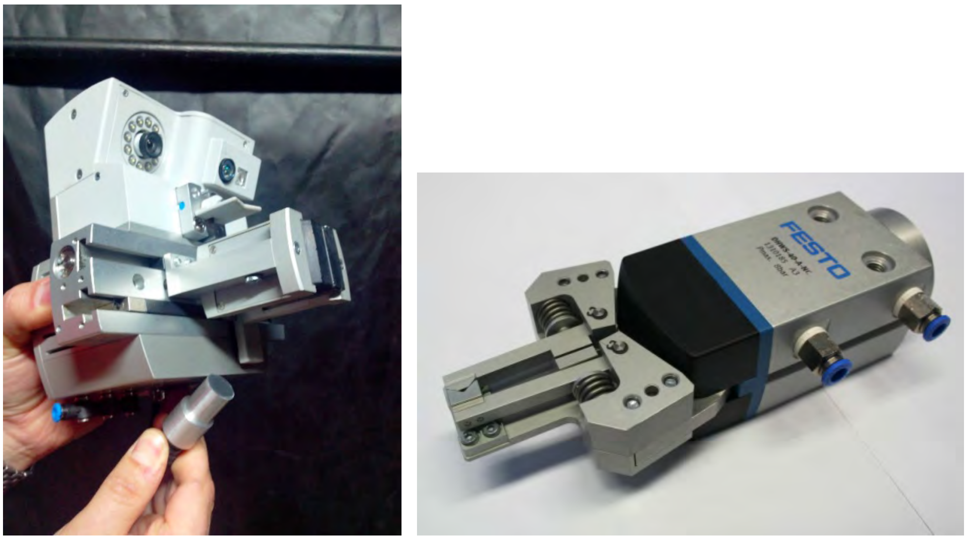
Figure 6. First manipulator prototype with precision sprayer and protection cover (a) and the final design of the CROPS manipulator (b)

Several grippers were designed, some examples are shown in Fig. 7 and Fig. 8.



(a) (b)

Figure 7. Fin-Ray type end-effector (a) and Lip-type end-effector (b) for sweet pepper harvesting.



(a) (b)

Figure 8. Apple gripper (a) and grape gripper (b).

For sensor fusion the system architectures for sensing, grasping and fusion and algorithms for sensor fusion, learning in sensing and grasping were developed. The adaptive sensor fusion algorithm was implemented and tested for apples and sweet pepper. A learning framework was demonstrated to learn features for classification of forestry objects. A method for construction of a discrete fuzzy grasp affordance manifold based on learning from human demonstration was developed. In Fig. 9 an example of the outcome of the adaptive sensor fusion is given, together with some challenges.

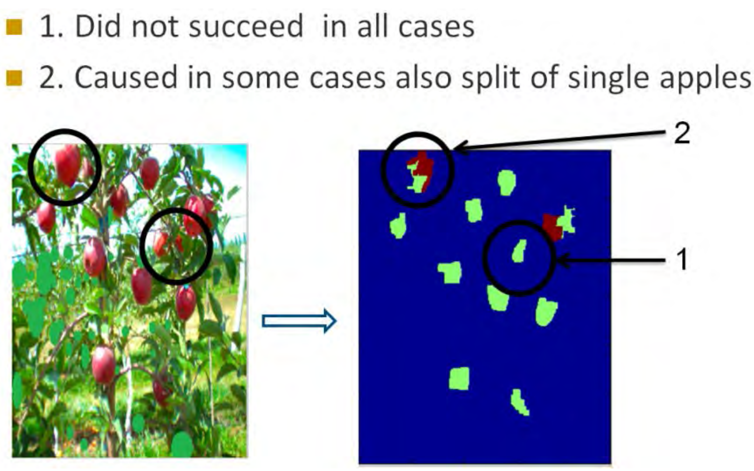


Figure 9. Example of apple detection with adaptive sensor fusion.

For sweet pepper harvesting the requirements for a harvesting robot were obtained. A number of modules for hardware (sensors, grippers) and software (e.g. algorithms for sweet-pepper fruit localization) were built and tested. The manipulator, a platform to transport the manipulator through the greenhouse, a gripper and a sensing system were integrated into a complete system. This system was successfully tested and demonstrated to growers in a laboratory setting (Fig. 10).

Figure 10. Lab demonstration of the system to the growers advisory board on July 15th, 2013.

After lab testing the robot was transferred to a greenhouse. Between April and July 2014 experiments with the final integrated pepper harvester were carried out. Fig. 11 shows the integrated harvesting robot.

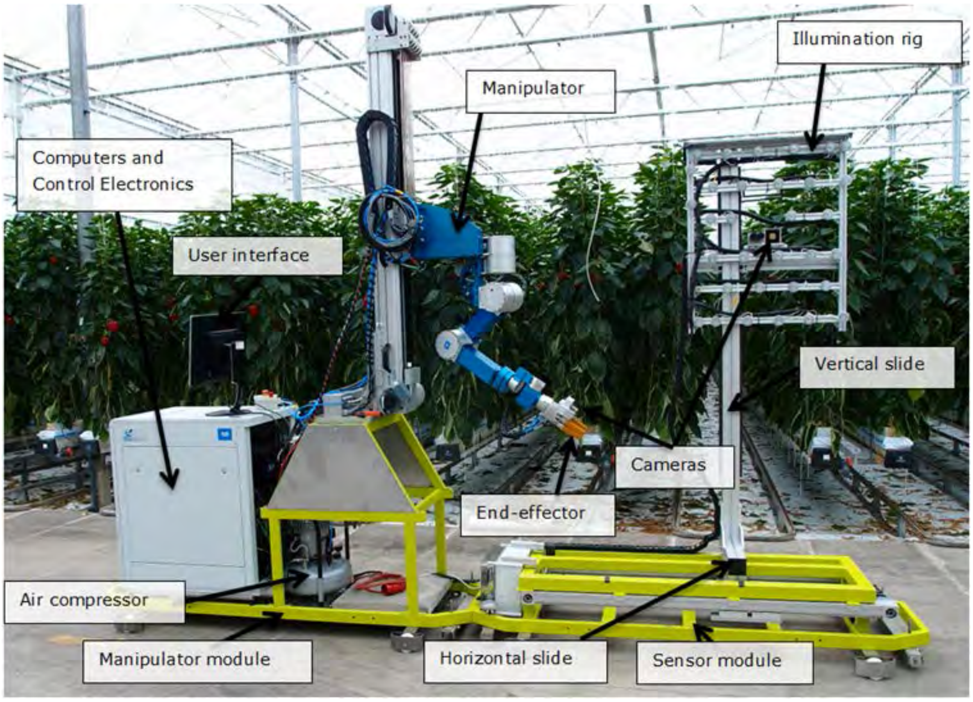


Figure 11. Final integrated robot for harvesting sweet-pepper fruit as used for the greenhouse experiments.

In Fig. 12 the CROPS manipulator is shown in a sweet pepper greenhouse.

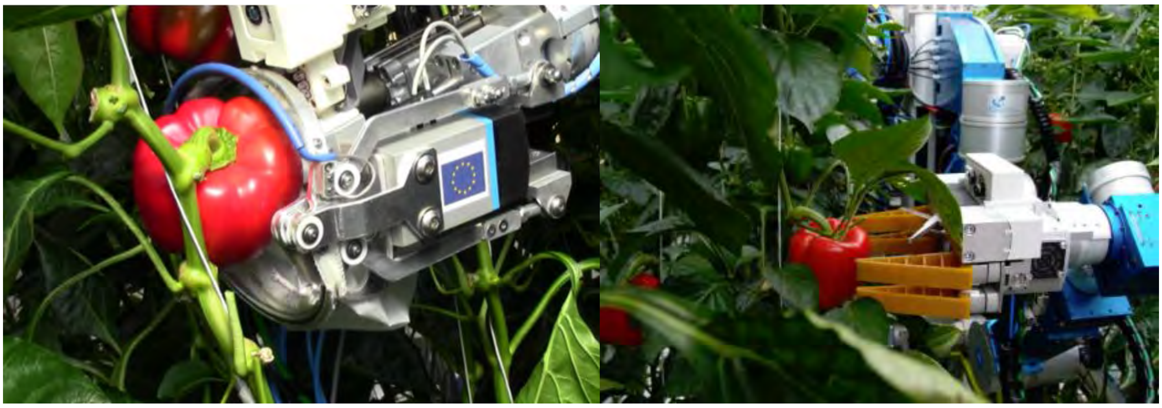


Figure 12. CROPS robot manipulator with the different end effectors in a sweet-pepper crop

For harvesting of grapes and apples the requirements have been defined based on discussions with the growers. To maximize the visibility and reachability of the fruits, the so-called ‘walls of fruit trees’ growing system has been chosen, see Fig. 13

(a) (b)

Figure 13. Illustration of the improved visibility in flat planar canopies of apples (a) and grapes (b)

The Crops manipulator, grippers, sensors and software architecture have been tested both in laboratory as well as in apple orchards and grape vineyards. All the modules have been integrated into one system, which was successfully tested in the laboratory in in the orchard, see Fig. 14.

(a) (b)

Figure 14. The robot platform for apple harvesting (a) and the CROPS manipulator inside the platform.

The integrated system for grape harvesting is shown in Fig. 15.

(a) (b)

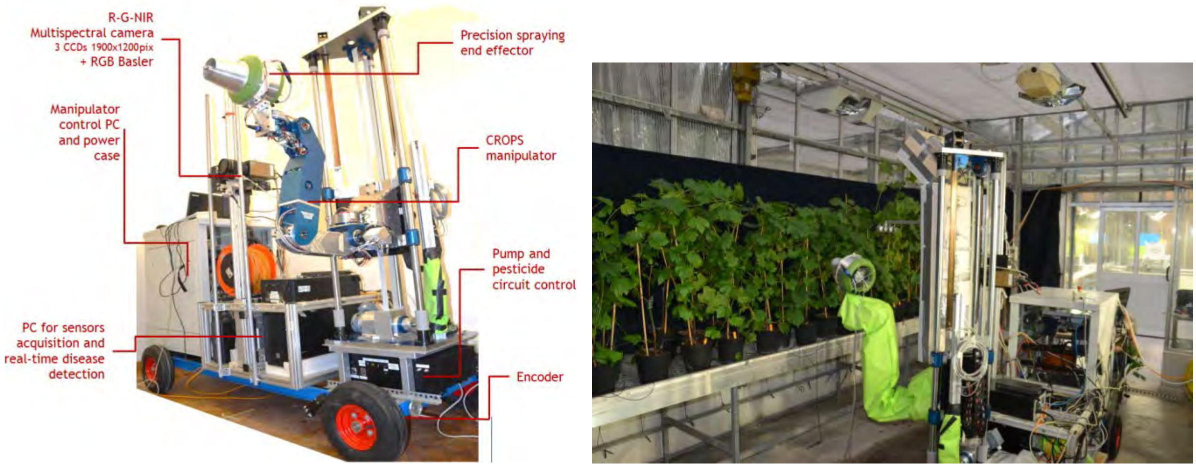
Figure 15. The robot platform for grape harvesting (a) and the CROPS end effector inside the platform.

For canopy optimised spraying and close range precision spraying requirements were selected in discussion with spraying specialists and growers. A canopy optimised sprayer was designed as a trailed sprayer with centrifugal blower. An eight DOF hydraulic driven manipulator with three arms was used. Orchard experiments were performed with the canopy optimised sprayer during 2013, see Fig. 16. A good spraying quality was achieved with significant reduction of pesticide use.

(a) (b)

Figure 16. Field experiments using the CROPS canopy optimized sprayer (a) and demonstration to farmers (b).

The close range precision spraying was focused on testing disease detection with various sensing principles. The Crops manipulator with waterproof protecting case, sensors precision spraying end-effector were integrated in a precision spraying robot for viniculture. The robot was successfully tested in a greenhouse environment and the attained pesticide reduction was 84%, see Fig. 17.



(a) (b)

Figure 17. Integrated system and field test of close range precision spraying in a greenhouse.

For the forestry application the requirements for the detection of bushes, rocks, and trees and for the estimation of ground bearing capacity (for propulsion of forest machines) have been specified. A sensory system for detection and classification of trees has been evaluated in a field test, see Fig. 18.

Figure 18. A sensory system for detecting and classifying trees was mounted the cabin of a Valmet 931 harvester from Sveaskog. Photo: Ola Lindroos.

For certain automation in forestry, a system that can detect humans is valuable to prohibit harm to humans. A system for detecting humans by analysing temperature differences in images from a thermal camera was evaluated as seen in Fig. 19.

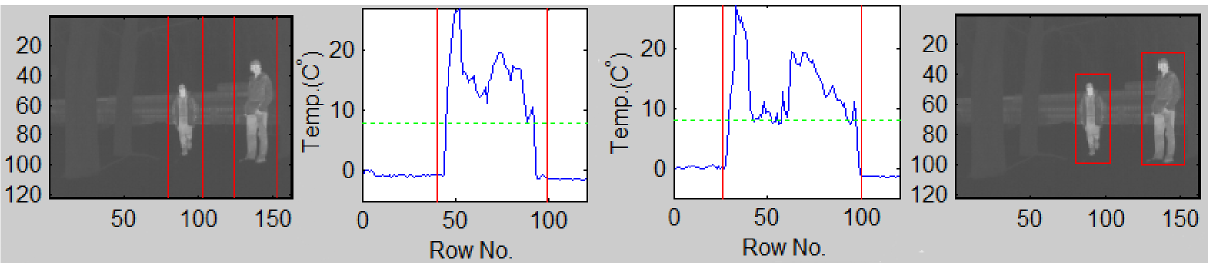


Figure 19. Infrared image with two segments identified by vertical borders (left), the horizontal borders for each segment (green dashed lines are thresholds) (mid), bounding boxes defined by combing horizontal and vertical borders (right).

The developed system worked very well, and the best of the developed algorithms had a precision of 98.6% and 89.4% recall rate in 57 images with in total 94 objects including humans, trees, cars, and buildings. The corresponding false discovery rate was 1.4%. A video has been recorded showing the system tracking two people in a forest environment. It was able to detect them even though they were behind trees or branches, see www.crops-robots.eu.

The CROPS final workshop was hold in Zurich on July 9th, 2014 as a special session within the AgEng2014 conference (6-10 July 2014 www.ageng2014.ch), see Fig. 20.

Figure 20. Moments from the CROPS Final Workshop hold at ETH of Zurich on 9th July, 2014.