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Bologna – EIMA International 2014

Overview of two recent EU-projects in robotic agriculture

Roberto Oberti – roberto.oberti@unimi.it

Disclaimer

This is not an in depth analysis about impact of innovation on sustainability of EU agriculture

This is just a technical communication about two major EU projects on agriculture robotics:

RHEA: Robot Fleets for Highly Effective Agriculture and Forestry Management (*credits to Pablo Gonzales, CSIC-Spain*)

CROPS : Clever RObots for croPS Intelligent sensing and manipulation for sustainable o production and harvesting of high value crops

RHEA : figures & partnership

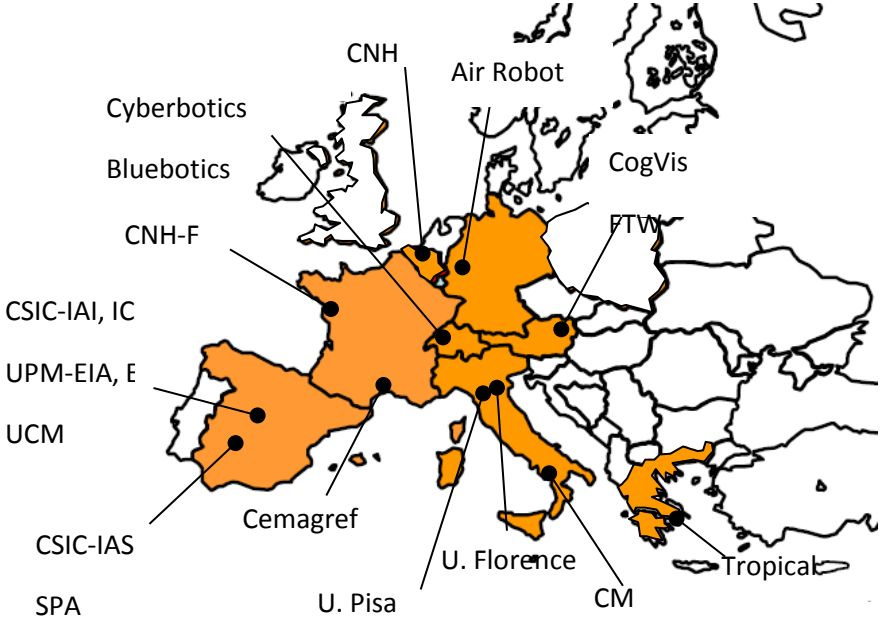
4 years project 2010–2014 (6,6 Meuro)

15 partners from 8 Countries

- 3 Research Centers
- 4 Universities
- 7 SME
- 1 Multinational Industry

Highly interdisciplinary partnership

- Agronomists
- Robotics specialists
- Manufacturers of Ag Machinery
- Perception/Sensing
- ICT
- Electronics
- Renewable energy system



RHEA : overall objective

Main idea in RHEA was to configure and operate a fleet of reconfigurable, heterogeneous and complementary robots to cooperate in weeding and pest management in order:

to minimize

- chemical products
- energy
- operation time

to maximize

- the quality of products
- safety

to guarantee

- application of the procedures to the entire operation field

RHEA : application cases

Project scenarios:

- Narrow-row crops:
  - Wheat
  - Barley
- Row crops:
  - Maize
  - Sunflower
  - Sugar beet
  - Tomatoes
- Tree crops:
  - Olive trees
  - Walnut trees
  - Almond trees

RHEA : subsystems

Autonomous ground units

derived from CNH T3050 (37 kW / 1.2 tonne)

On board unit controller for autonomous functions:

- communication /cooperation with remote mission controller
- steering,
- throttle,
- clutching,
- braking

Aerial mobile units

Based on AirRobot Drone AR-200

- Diameter: 2.2 m
- Maximum payload : 3 kg
- Flight duration: 20-40 minutes

RHEA : sensing and perception

Aerial mobile units

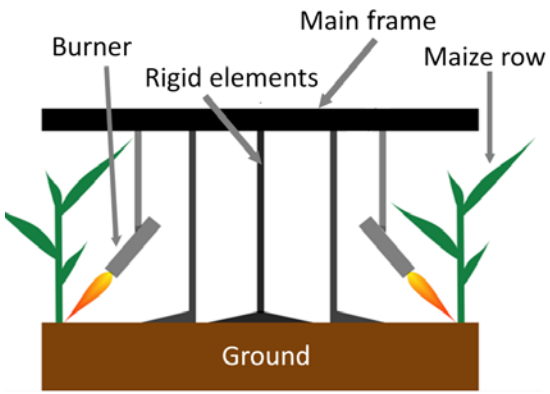
MultiSpectral HiRes Camera *reflex cam for remote sensing*

Ground autonomous units

- Double GPS and inertial unit (IMU) to complement vehicle positioning;
- RT crop row detection on machine vision;
- Weed patches detection that relies on machine vision;
- Obstacles detection by LIDAR
- Remote communication to operator base station,

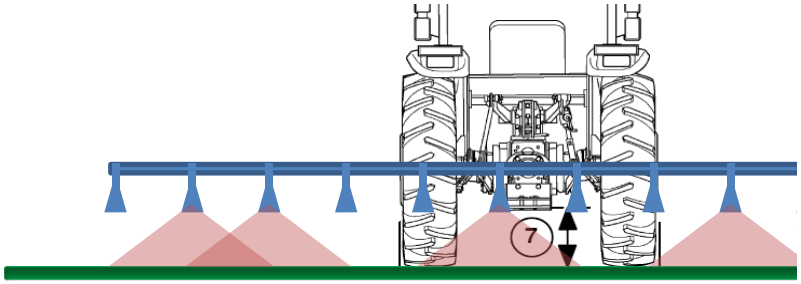
RHEA : actuators

Physical weeding for row crops

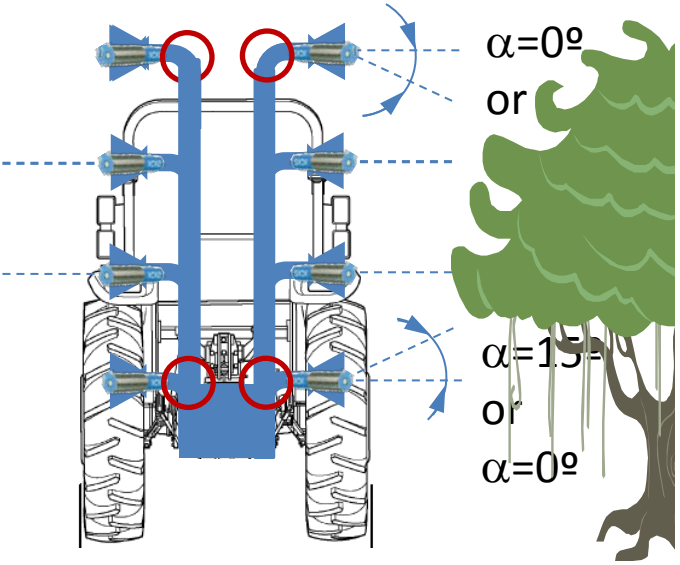


http://www.rhea-project.eu/Videos.php

Patch spraying for field crops



Canopy volume optimised spraying



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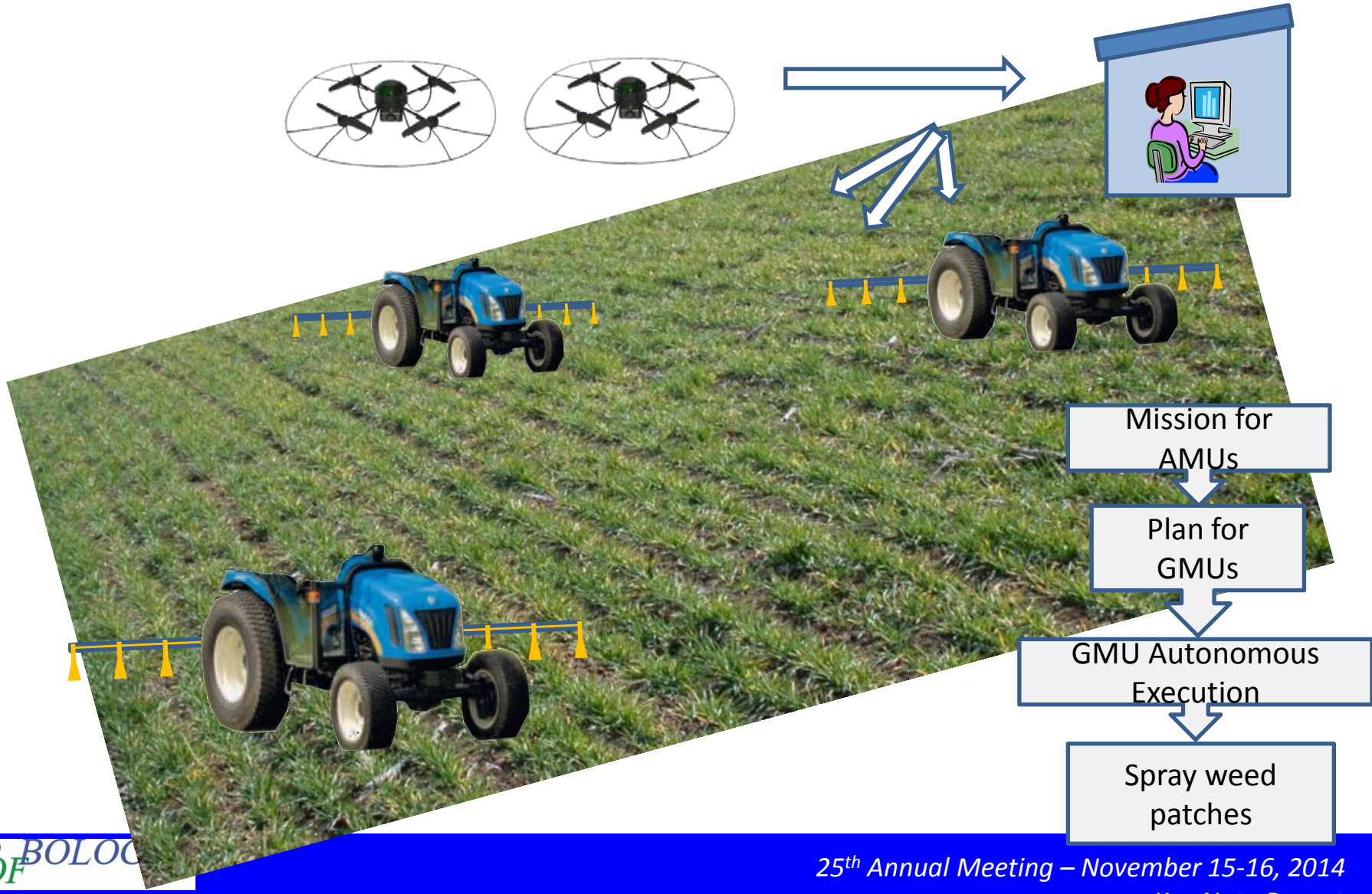
RHEA : cooperative application cases

Mission 1: Weed patch spraying in wheat



RHEA : cooperative application cases

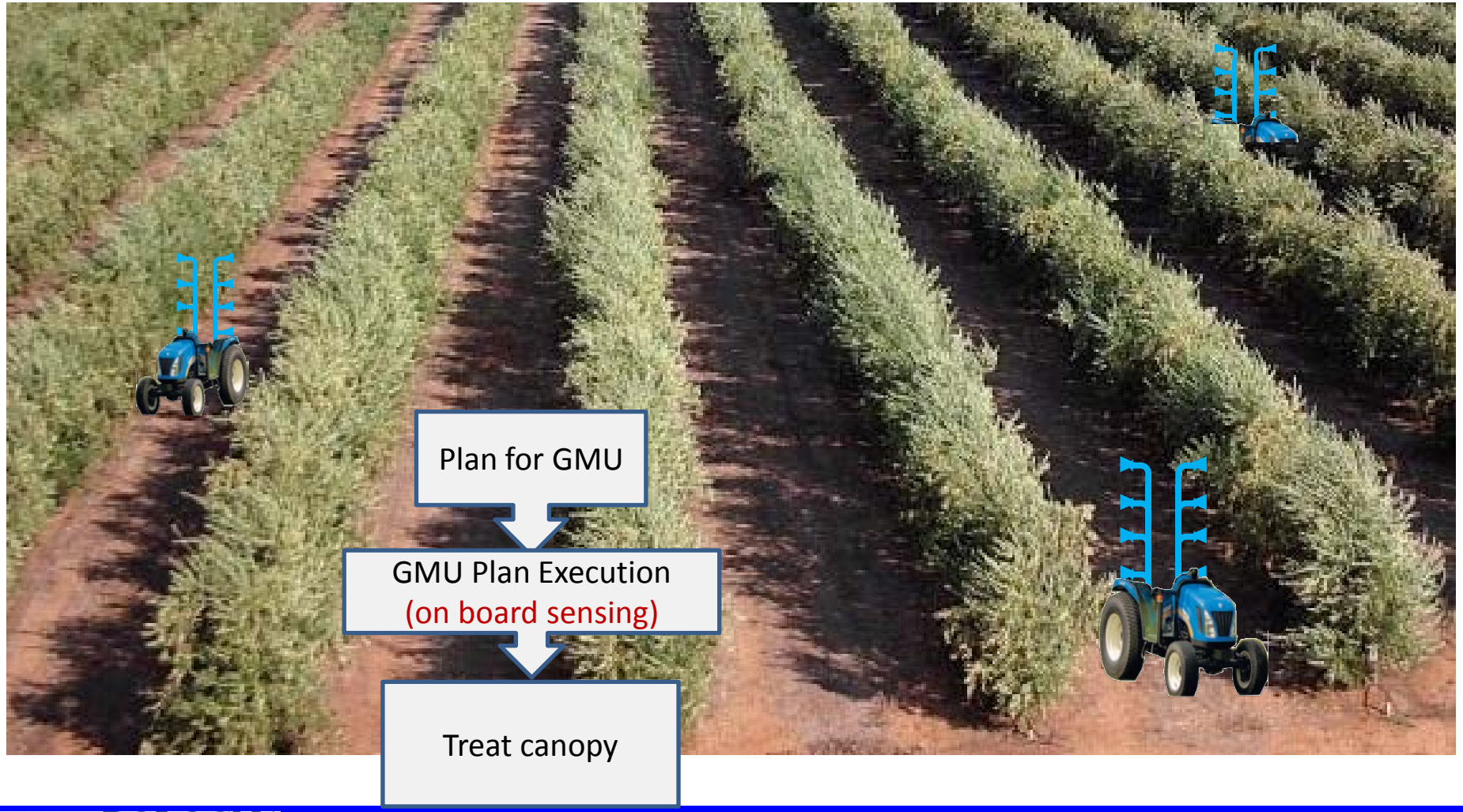
Mission 2: Physical weeding in corn

Plan for GMUs

GMU Autonomous Execution (on board sensors)

Selective Thermal treatment

Mission 3: Canopy spraying of olive trees



RHEA : field demo

May 2014 , field missions demonstration in Madrid (SP)

Presentations, videos and dissemination at www.rhea-project.eu

CROPS : figures and partnership

4 years project 2010–2014 (7,6 Meuro)

14 partners from 10 Countries

- 7 Universities
- 3 Reaserch Centers
- 2 Large industries
- 2 SME

Highly interdisciplinary partnership

- Agricultural engineers
- Mechanical engineers
- Robotics specialists
- Computer scientists
- Software engineers
- Sensing
- Manufacturers of Ag Machinery

ONDERZOEK/WAGENINGEN UR (Netherlands)
KATHOLIEKE UNIVERSITEIT LEUVEN (Belgium)
BEN-GURION UNIVERSITY OF THE NEGEV (Israel)
UNIVERZA V LJUBLJANI (Slovenia)
UMEA UNIVERSITET (Sweden)
UNIVERSITA' DEGLI STUDI DI MILANO (Italy)
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS (Spain)
TECHNISCHE UNIVERSITAET MUENCHEN (Germany)
CNH INDUSTRIAL BELGIUM NV (Belgium)
INSTITUTO DE INVESTIGACIONES AGROPECUARIAS (Chile)
FORCE-A SA (France)
FESTO AG & CO KG (Germany)
SVERIGES LANTBRUKSUNIVERSITET (Sweden)

CROPS: a general robotic platform for specialty crops

Main target were **specialty crops**, i.e. fruits, vegetables, ornamentals , herbs etc. :

- High value crops
- Frequent management operations
- High intensity of crops needs (fertilization, water, protection etc.)
- High labour input (management+harvest)
- Suitable for selective harvest
- Market for diversity
- Typically grown in enclosed fields or protected environment

CROPS: overall objective

Overall idea in CROPS was to develop and operate a **modular**, highly reconfigurable, **multifunction** robot suitable for:

- different **operations**
  - Maturity/quality monitoring
  - Selective harvesting
  - Intelligent, selective spraying of diseases
- different specialty **crops**
  - Grapevine, apples , sweet-pepper

Modular architecture: a common manipulator…

Evolution of the developed manipulator for multifunction applications

Robust, dexterous and modular

Prototype 1

2012

Prototype 2

2012

Prototype 3

2014

Modular architecture: a common manipulator…

Evolution of the developed manipulator for multifunction applications

Robust, dexterous and modular

Prototype 1

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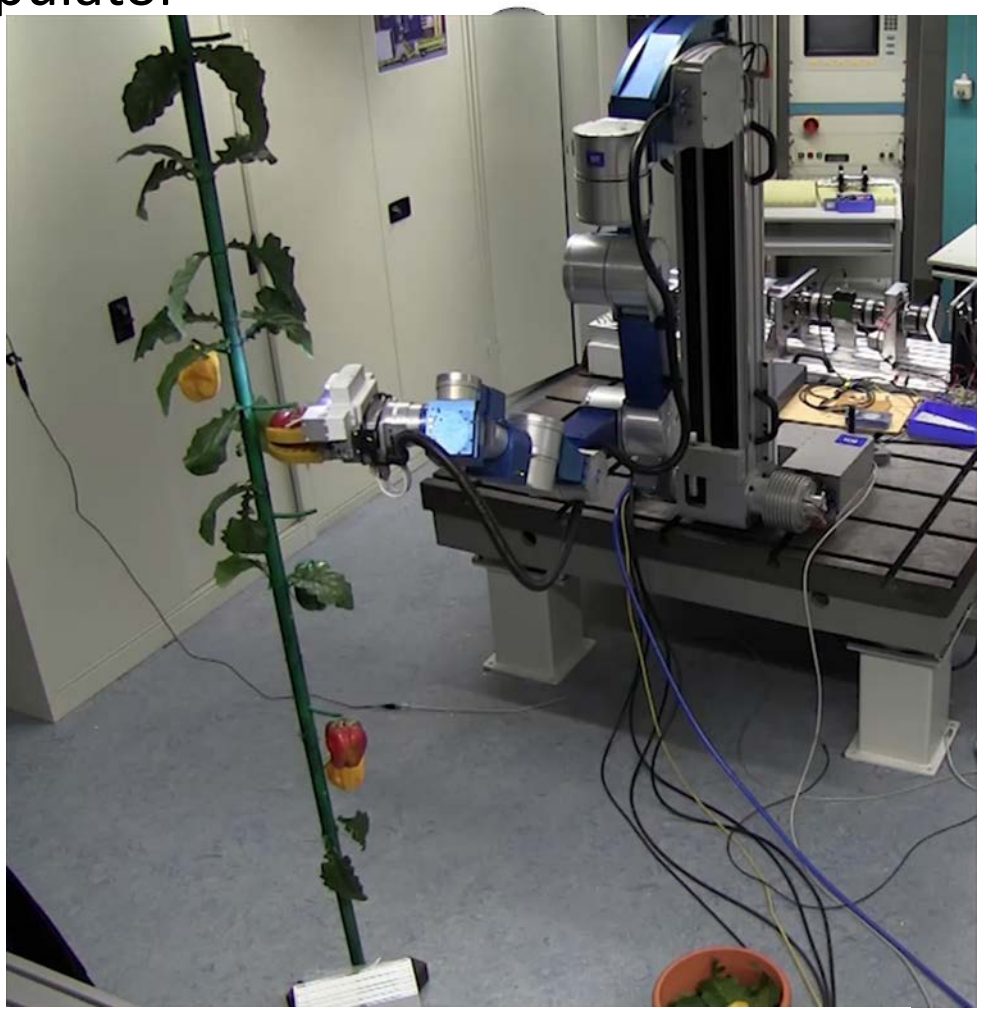


http://www.crops-robots.eu/media

Modular architecture: … specialised end-effectors

Development of specialised end-effectors and «plug & play» interfaces to the manipulator

Apple gripper

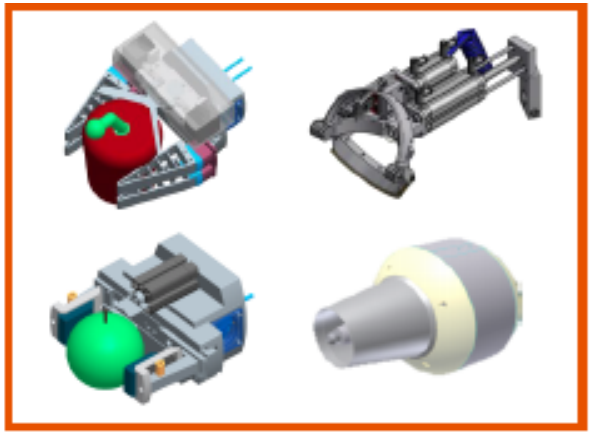
Sweet-pepper gripper

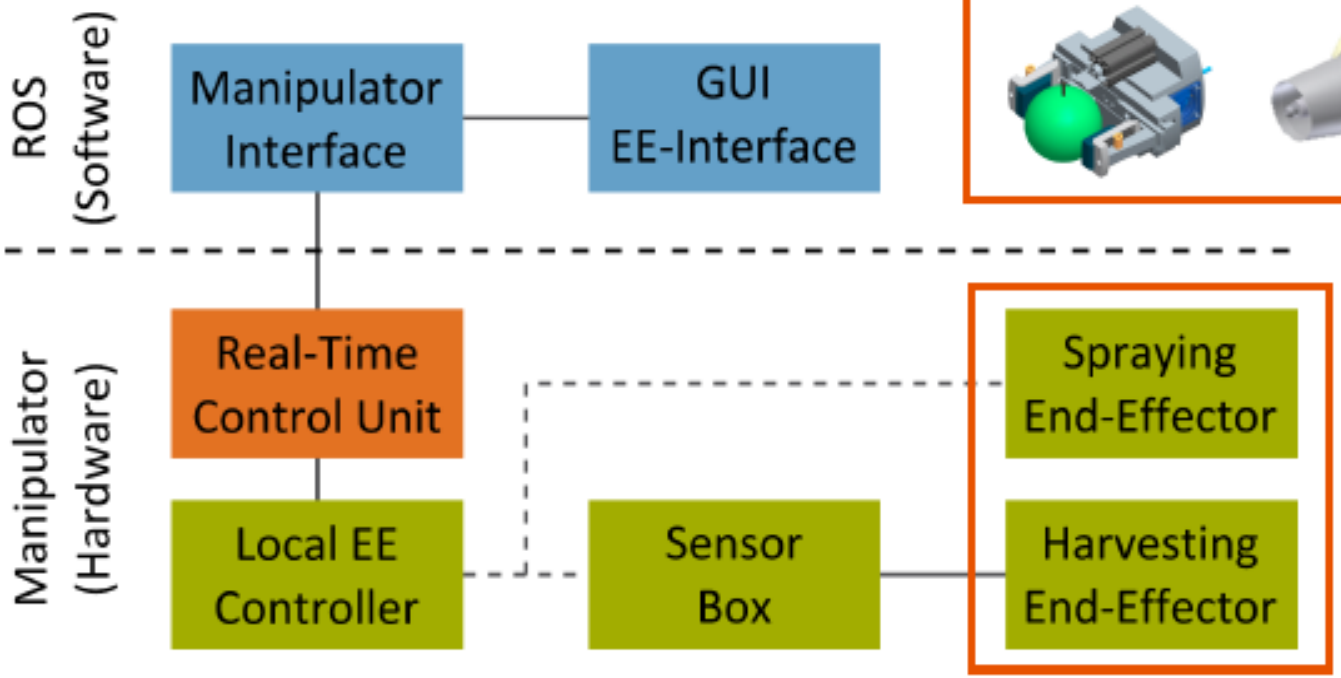
Grapes gripper

Spot spraying end-effector

Modular architecture: … software

«plug & play» interfaces also needs for modular software (ROS)

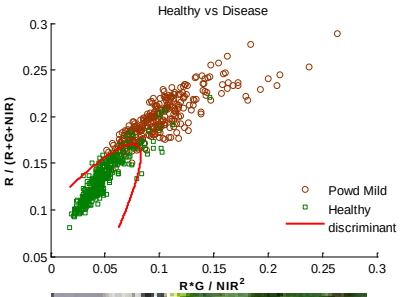


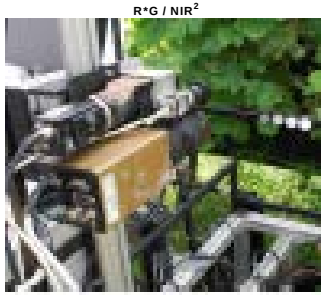


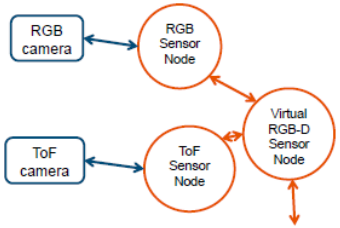
CROPS sensing

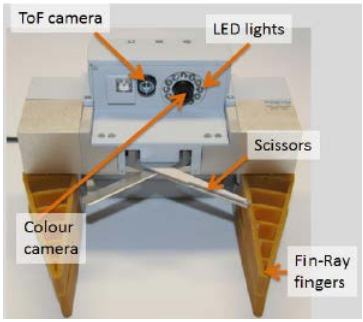
Development of sensors modules and associated processing algorithms:

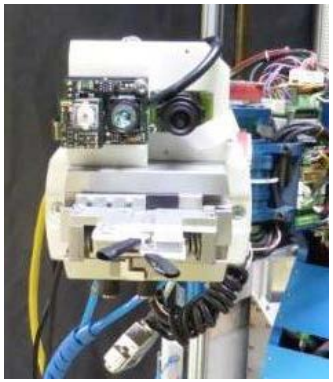
- Detect, identify position of fruits and detouching point (imaging + TOF)
- Maturity of apples and grapevine (NIR spectrofotometry and fluorescence sensing)
- Detection of disease sysmptoms (multispectral imaging)



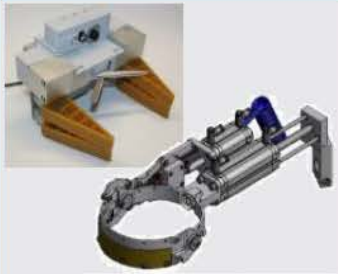
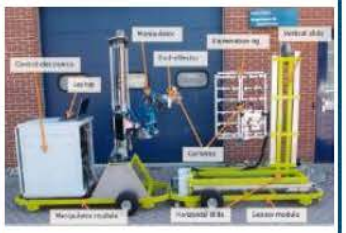








CROPS: multifunction robotic platform for specialty crops

Modular, highly onfigu-rable Robot System		Pepper	Apples	Grapes	Spraying
Manipulator 	End-Effector				
	Platform				
	Sensors			 +Ripeness	

Integration of demonstration protoypes (1)

CROPS platform ready for robotic harvest of sweet-pepper in a commercial greenhouse Wageningen (Netherlands), July 2014

- Fully autonomous detection of ripe peppers
- Limits in harvest: less than 40% successfully detached and realised
- Cycle time slow

http://www.crops-robots.eu/media

Integration of demonstration protoypes (2/3)

CROPS platform integrated for robotic harvest of apples in an experimental orchard Leuven (Belgium), Oct 2013

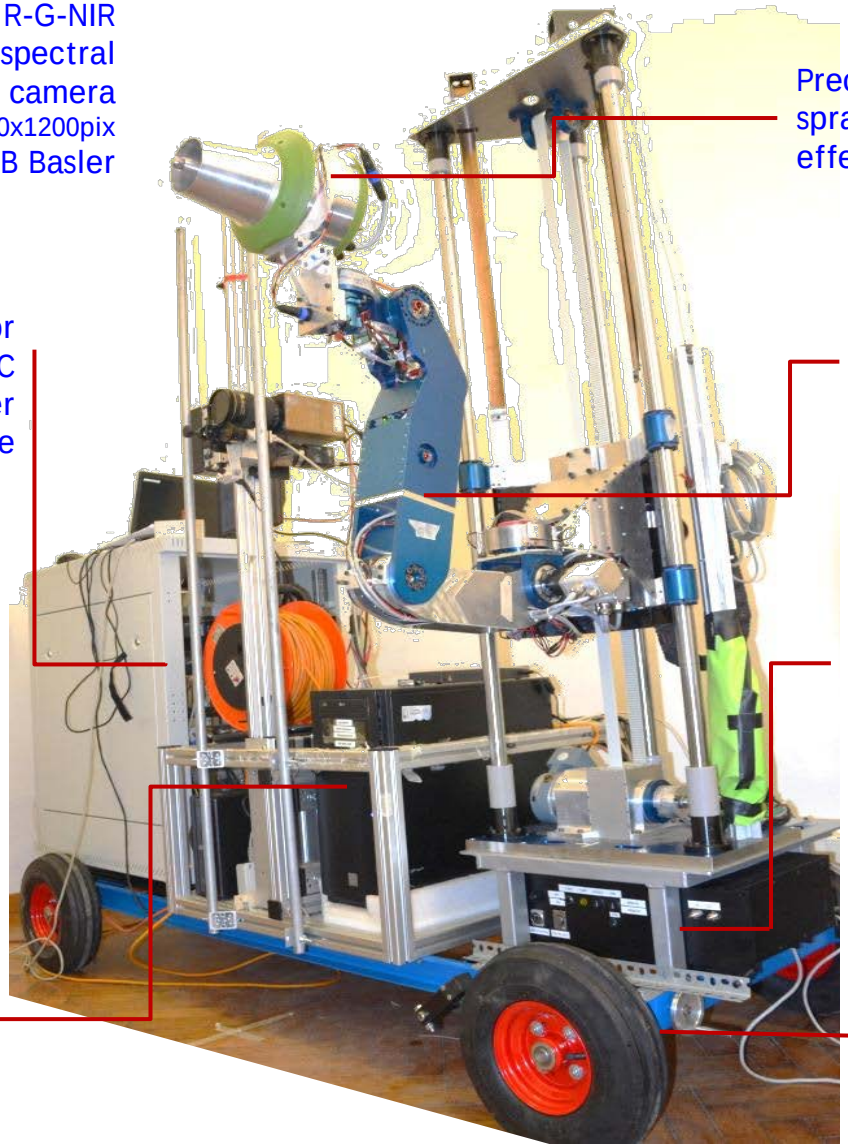
and for robotic harvest of grapes in vineyard, Sept 2014

- Autonomous detection of 100% of ripe apples
- 90% success grasps, 72% released (mostly touching fruits)
- Satisfactory time cycle (<15s)

Integration of demonstration protoypes (4)

CROPS platform integrated for selective spraying of disease foci

University of Milano (Italy), Feb 2013



Disease detection: optical techniques/algorithms development

Different approches applied in lab/greenhouse and in field conditions

- Point-wise spectrophotometry at leaf and sub-leaf scale
  - Characterizing optical features for disease detection
  - Preliminary tests and algorithms reinforcing
- Fluorescence radiometry at multi-leaf/bunch scale, fluorescence imaging
  - Pre-visual sensing
- Transportable multi-camera imaging system at canopy scale
  - Multispectral, hyperspectral, RGB, monochromatic imaging
  - Multispectral imaging = sensing approach transferred to final application

Accuracy of CROPS precision spraying

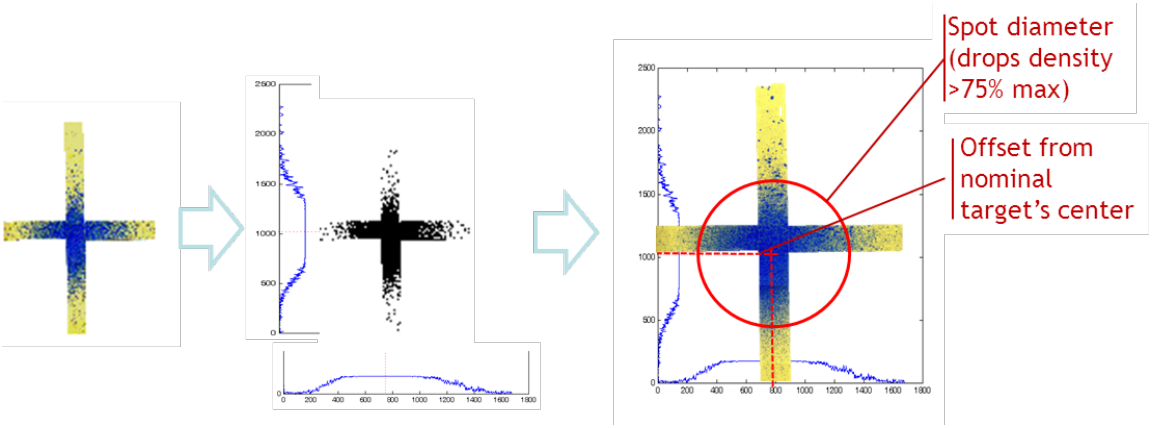
homogeneity of spray deposit on foliage improved by three sub-sprayings from different angles (3x 0.5 s, total spraying time 1.5 s)

mean spot diameter ≅ 15 cm

1.5 s spraying time equivalent to AR = 380 L/ha_{canopy_area}

http://www.crops-robots.eu/media

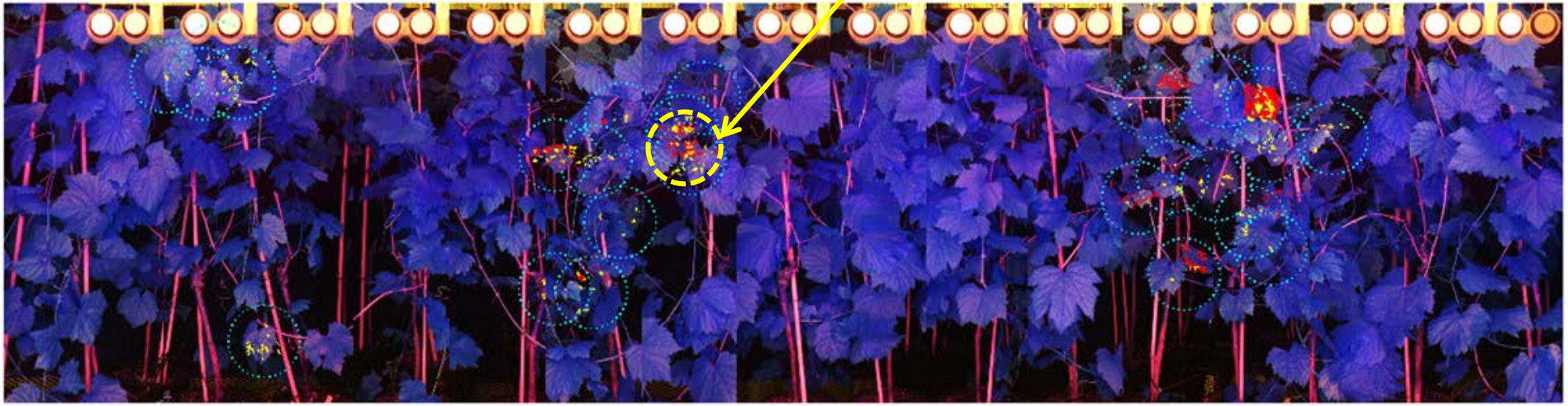
overall precision spraying inaccuracies lower 3 cm (or less if considered the fuzziness of spot size)



CROPS validation experiments: one example of results

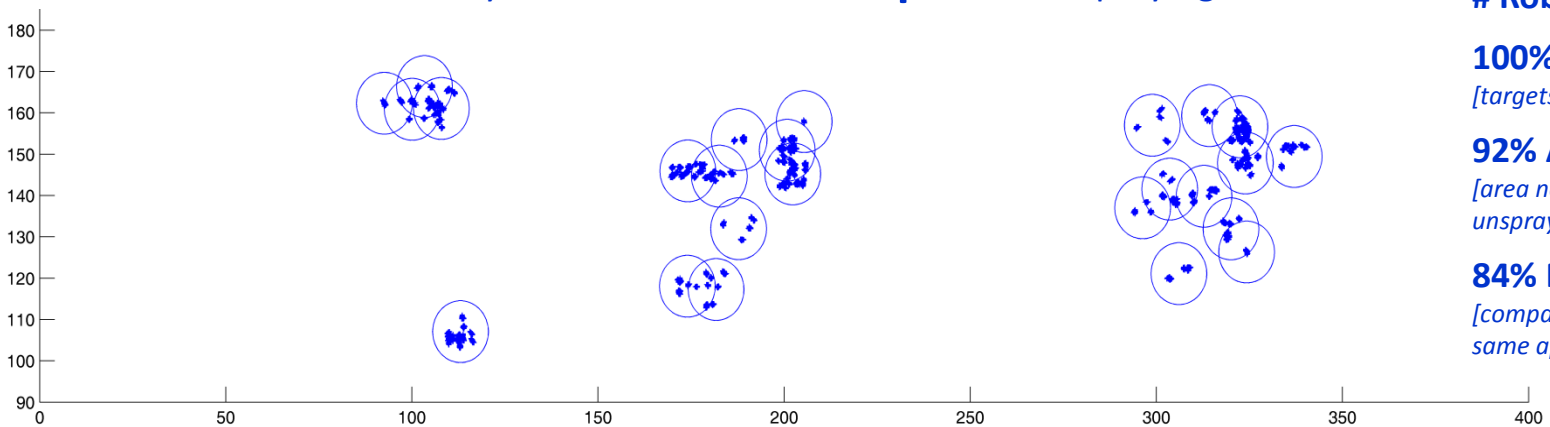
Objective : automatic detection and autonomous selective spraying of grapevine canopy areas exhibiting symptoms of Powdery Mildew

Results for the whole plot



One example of results: robot vs reference

Disease foci automatically detected and **robot operated** sprayings



 # Robot spray spots: 25

100% Disease sprayed
[targets actually sprayed]

92% Avoid spray excess
[area not to be sprayed actually left unsprayed]

84% Pesticide reduction
[compared to homogeneous spraying at same application rate]

CROPS platform was able :

- to treat 85-100% of the targets (depending on the disease stage)
- to remarkably reduce pesticide use compared to conventional homogeneous treatments (always reached about 90% of the maximal reduction, i.e. sprayed area strictly necessary to treat all the foci)

CROPS dissemination material

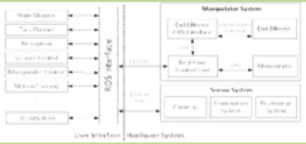
Presentations, papers, videos and dissemination at www.crops-robots.eu

Clever Robots for Crops

CROPS high tech robots are developed for site-specific spraying and selective harvesting of high-value crops such as greenhouse vegetables, fruits in orchards and grapes for premium wines. A CROPS robot is able to detect the fruit, sense its ripeness, then move to grasp and gently detach only the ripe fruit. With intelligent crop protection the canopy sprayer can detect contours of trees in an orchard and only spray on the plant, or to selectively and precisely target the pesticide only on detected diseases foci in grapevines. Attention is paid to reliable detection and classification of objects and obstacles for safe autonomous navigation in plantations and forests.

Hardware and Software architecture

CROPS robots use ROS (Robotic Operating System) as middleware. The supervisory control system and the high-level software architecture have been developed and tested within a framework of high modularity and configurability of hard- and software.

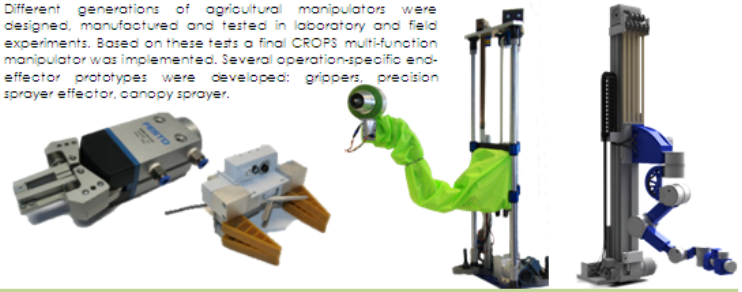


Sensing

The design and implementation of the sensory systems for CROPS includes multispectral imaging for detection, classification and localisation of products to be harvested and of crops diseases to be sprayed; imaging and fluorescence sensing for fruit ripeness evaluation; LIDAR for canopy sensing and thermal infrared for human detection in forestry.

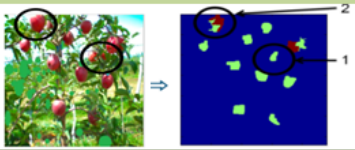
Manipulators and end-effectors

Different generations of agricultural manipulators were designed, manufactured and tested in laboratory and field experiments. Based on these tests a final CROPS multi-function manipulator was implemented. Several operation-specific end-effector prototypes were developed: grippers, precision sprayer effector, canopy sprayer.



Intelligent sensor fusion and learning algorithms

Adaptive sensor fusion algorithm was implemented and tested for apples and sweet pepper. A fuzzy grasp affordance manifold based on learning from human demonstration was developed. A learning framework was demonstrated to learn features for classification of forestry objects.



www.crops-robots.eu

Sweet pepper harvesting

A number of modules for hardware (sensors, grippers) and software (e.g. algorithms for sweet-pepper fruit localization) were built and tested for sweet pepper harvesting in greenhouse production. The CROPS manipulator, a carrier platform, a gripper and a sensing system were integrated into a complete system and successfully tested and demonstrated to growers in a laboratory setting and in a commercial greenhouse.

Apples and grapes harvesting

Based on discussions with grapes and apples growers, to maximize visibility and reachability of the fruits, the 'fruit-wall' growing system was adopted. CROPS manipulator, grippers, sensors and software architecture have been tested. All the modules have been integrated into a mobile platform system, which was successfully tested during fruit harvest in laboratory and in orchard conditions.

Precision spraying

A canopy optimised sprayer was designed as a trailed sprayer with a three hydraulic driven arms and tested in orchard experiments to optimally spray the canopy according to tree shape and foliage volume with significant reduction of pesticide use. Selective, close precision spraying was focused on targeting pesticides on disease foci detected by means of optical sensing. CROPS manipulator equipped with waterproof case, disease sensors and precision spraying end-effector were integrated in an intelligent precision spraying robot for viticulture. The robot was successfully tested in a greenhouse environment and the attained a pesticide reduction above 80% compared to current homogenous crop treatment technique

Forestry

For forestry applications a sensory system for detection and classification of trees and obstacles has been defined and evaluated in field test. A ground bearing capacity sensor for propulsion of forest machines has been specified together with a human detection system for safe navigation in forests environment and operations in plantations and tree harvesting

Lessons learned

There is a long list of lessons learned and some relevant success in autonomous crop management demonstrated in the field, such as:

- cooperation of multiple systems is a key issue for complex task in agricultural environment
- modular, reconfigurable, multifunction platforms is feasible and strategic for cost/benefit sustainability
- optimizing crop environment /workspace is a key issue to boost performance and cost/benefit ratio (e.g.CROPS apple harvest was successful also because addressing crops architecture)
- robotics advances can contribute in reducing production costs of high-value crops, by extending working time and production timeliness and avoiding repetitive, intensive manual operations
- but also can contribute in disclosing new high-precision operations in crop management and in favoring high-educated jobs in agriculture and services
- robotics modules (hw, sw,) and concepts ready for transfer/vision to advanced Ag Machinery to which manufactures could pay attention