"elWObot"- A Diesel-Electric Autonomous Sensor Controlled Service-Robot for Orchards and Vineyards

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Abstract

"elWObot", a cooperative research project, aims to develop an electrical driven, autonomous service-robot for vineyards and orchards. Maintenance operations are plant protection (precision spraying) and mulching. Future expansion can be yield mapping, soil preparation or picking up harvester boxes.

The vehicle is driven by two small automotive diesel engines, which supply the energy for four independent steered wheels with electrical hub motors. This construction gives a better controllability and possible energy conservation. It can carry a payload up to 1.5t. This corresponds for example to a sprayer plus 1000 liters of chemical spray.

The sprayer itself is also electrical driven and has the possibility to control the output of chemicals in different heights. In combination with a leaf wall scanning system, a reduction of chemicals can be achieved.

For the autonomous navigation of the robot a combination of different sensors and a low-cost GPS is used. The main sensor for navigation is a laser range scanner. This scanner gives back range information only in one flat layer. Thus, obstacles in the row might be missed. To overcome this problem additionally 3D-Time of Flight cameras and ultrasonic multi reflectance sensors are applied. Moreover, these sensors can detect the leaf wall area and hand over this information to the sprayer system. To improve the position information of the robot, odometric vehicle data is combined with an IMU (Inertial Measurement Unit) and GPS.
Sensors and actuators are all connected over Ethernet, using the TCP/IP protocol. This makes the development and debugging of the system more comfortable. For software development Robot Operating System (ROS) an open source framework especially for robotics is applied. ROS also supplies the 3D simulation environment Gazebo, in order to simulate the robots and sensors behavior.

Keywords

Service-robot, 3D-imaging, diesel-electric vehicle, precision sprayer, leaf wall detection, Robotic Operating System ROS, orchard, vineyard.

1 INTRODUCTION

Reduced availability of human workers and international competitions in viniculture and orchards, leads to new automation technologies for maintaining processes. These technologies can reduce costs as well as environmental impacts.

Autonomous ground vehicles in orchards or vineyards have been shown by other research teams before [4, 7]. But usually existing vehicles like tractors or small cars are applied and modified [9, 11]. The authors aim to build a completely new modular vehicle, with four individual steered wheels and integrated electric hub motors [5]. Modularity gives more flexibility for different row structures and working tasks. Electric drives means no oil for hydraulic, which results in less environmental pollution. This also applies to the electric driven sprayer.

In the last decades, progress on the technical development of plant protection machinery for orchards and vineyards has primarily been achieved by optimizing blowers, airflow and nozzles for drift reduction. Nowadays, innovations are also aimed on reducing work load, reducing power demand and achieving a higher application quality. Using an autonomous platform for spraying not only could improve labour efficiency, but also operational safety [6]. Reducing power demand while concurrently improving application quality is aim of the sprayer construction.

Information technologies and sensors are increasingly gaining importance in horticulture. Unmanned autonomous field robots [14] use several sensors for navigation and obstacle avoidance [8] like laser range scanners [3], 3D Time of Flight cameras [12] or GPS. To handle this distributed system with sensors and actuators, the open source software framework ROS [13] (Robot Operating System) is applied. ROS also supplies the 3D simulation environment Gazebo in order to simulate robots and sensors behaviour. Gazebo plugins have been generated for different sensors like a colour camera, 2D laser scanner Sick LMS511, 3D laser scanner Nippon FX-8, IMU and GPS. The plugin for the wheel drives includes PID controllers, which brings the simulation as close as possible to the reality. In Gazebo tested and optimised algorithms for navigation can be directly adapted to the hardware (robot). Thus, development time is strongly reduced.

2 TECHNOLOGIES

2.1 Vehicle Concept

The vehicle has an installed power of 60 kW provided by two automotive diesel engines, at which 30 kW can be used for the drive train and 30 kW for working processes.
It will carry a payload of up to 1500 kg. The chassis is based on a modular electric drive system with four single wheels with integrated electric hub motors and independent steering.

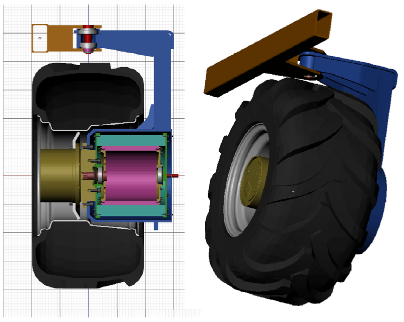
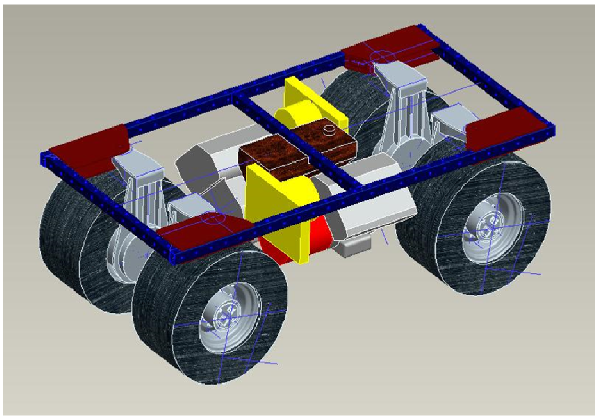


Figure 1: Setup of single wheel drive

The four permanently excited synchronous machines (PSM) have each an installed power of 7 kW and are air-cooled. They are integrated within the rim as hub motors. The generators are directly connected with the diesel engines and can deliver each up to 30 kW electrical power. The generators are water cooled.

The modular and scalable concept makes it possible to adapt the vehicle to the different requirements in orchards and vineyards. Electric drives have been chosen for better controllability and possible energy conservation



Prototyp vehicle orcharding
Realization of a platform strategy

dimensions (l x w x h):
2600 mm x 1300 mm x 930 mm

drive train:	*30 kW*
Working elements:	*30 kW*

Electrical single wheel drives,
Individually steerable

voltage 600 V DC

Figure 2: Layout of the vehicle

2.2 Plant Protection Equipment

With plant protection in vineyards, the foliage density hinders spray penetration to target surfaces with insufficient wetting of all parts of the plants. Numerous tests showed that, depending on the manufacturer, blower type and even sprayer adjustment, power consumption as well as application quality differs widely [2, 10]. At the Institute of Viticultural Engineering in Geisenheim, a new type of sprayer for vineyards and orchards therefor is being constructed. Optimizing the air distribution and speed, the number, position, orientation and type of the nozzles, should lead to a better spray deposit on the plant surface and a better energy efficiency of the whole spraying system.

To reduce power consumption, the new sprayer has 8 blowers, one for each nozzle, and two pumps, all of which are electrically driven. Using frequency converters allows the adaption of the air flow by regulating the rotation speed, according to the height and depth of the rows, considering cross wind effects as well. In addition, pressure control of the spraying system also works with rotation speed control of the pumps, thus avoiding pressure regulating with a waste gate. Compared to reference spraying machinery, test results showed considerably less power demand, simultaneously gaining application quality.

To achieve a better efficiency, the new blower-nozzle-units are developed using a computational fluid dynamics (CFD) software. With the requirements for orchard sprayers, simulation showed a radial fan with forward-curved blades as best solution. To achieve a homogeneous flow, air deflectors are necessary (Fig. 3). Based on this knowledge, a test carrier was constructed using standard components (Fig 4), machine control is provided via CAN Interface.

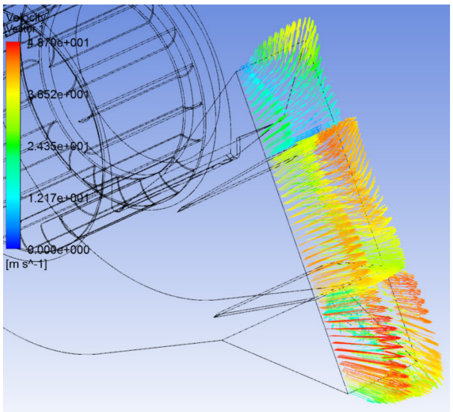


Figure 3: Simulation of the air distribution

Figure 4: Test Sprayer

First field tests with the sprayer showed promising results. Integration of the gap detection system, which prevents each single nozzle from spraying when a gap in the foliage appears, will be the next step. The adaption of the sprayer to the robot and further field test will be performed.

2.3 Sensors & System components

The autonomous driven ground vehicle needs to sense its environment for navigation and obstacle avoidance. Therefore a couple of sensors with different tasks are applied. In our case e.g. a standard laser range finder from Sick gives back the main information for the navigation task. It also can detect obstacles, but only restricted. Thus, a Time of Flight camera, a 3D laser range finder or a multi reflectance ultrasonic sensor can be a good addition to overcome this problem. The table below shows applied sensors and their role for elWObot.

Sensor	Type of Measurement	Detection Range	Tasks and Options
Sick LMS511 1x 	Laser Range Finder Time Of Flight	Field of View: 190° Angular Res.: 1.66° Max. Distance: 80m	- Navigation - Obstacle Detection
Nippon Signal FX8 1x 	3D Laser Range Finder Time Of Flight	Resolution: 65 x 40 Field of View: 50° x 60° Max. Distance: 12m	- Obstacle Detection - Leaf Wall Detection - Navigation
Mesa SR4500 2x 	3D Time Of Flight Camera	Resolution: 176 x 144 Field of View: 69° x 55° Max. Distance: 9m	- Obstacle Detection - Leaf Wall Detection - Navigation

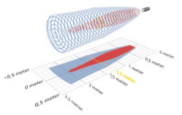
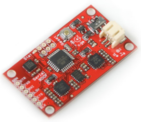
Microsonic wms-340 4x 	Ultrasonic Range Finder	Max. Distance: 5m 	- Obstacle Detection - Leaf Wall Detection
IMU Razor 9DOF 1x 	Inertial Measurement Unit	ITG-3200-triple-axis digital-output gyroscope. ADXL345-13-bit resolution, ±16g, triple-axis accelerometer. HMC5883L-triple-axis, digital magnetometer.	- Decline Detection - Calculate Absolute Position - Velocity
Navilock NEO 6P 1x 	GPS-Receiver	Positioning accuracy: GPS: 2.5 m SBAS: 2.0 m SBAS + PPP: < 1 m (2D, R50) SBAS + PPP: < 2 m (3D, R50)	- Calculate Absolute Position - Velocity
Levelone FCS-122 	Network Web-Cam	Resolution: 1280 x 800 Framerate : 10fps	- Documentation - Surveillance
Incremental Encoder 4x	Wheel Position	---	- Velocity - Calculate Absolute Position - Odometry
Rotary Sensor 4x	Absolut Wheel Angle	---	- Calculate Absolute Position - Odometry

Table 1: Applied sensors on elWObot

One important requirement to the system architecture is flexibility. This is achieved by using Ethernet as bus system and TCP/IP as protocol. A Gigabit Switch is the central unit of the architecture and connects all sensors and actuators to an industrial PC. Devices without an Ethernet interface e.g. GPS-Receiver (RS232) or the motor-controller (CAN), uses an adapter for converting the data transport in both directions. A benefit of this architecture is modularity and the possibility to connect to every device over the standard PC Ethernet interface. Remote access is established via a Wireless LAN Access Point. Thus, the vehicle can be controlled and sensor data can be read out from external without running the PC on the robot. Next Figure shows the system architecture in principle:

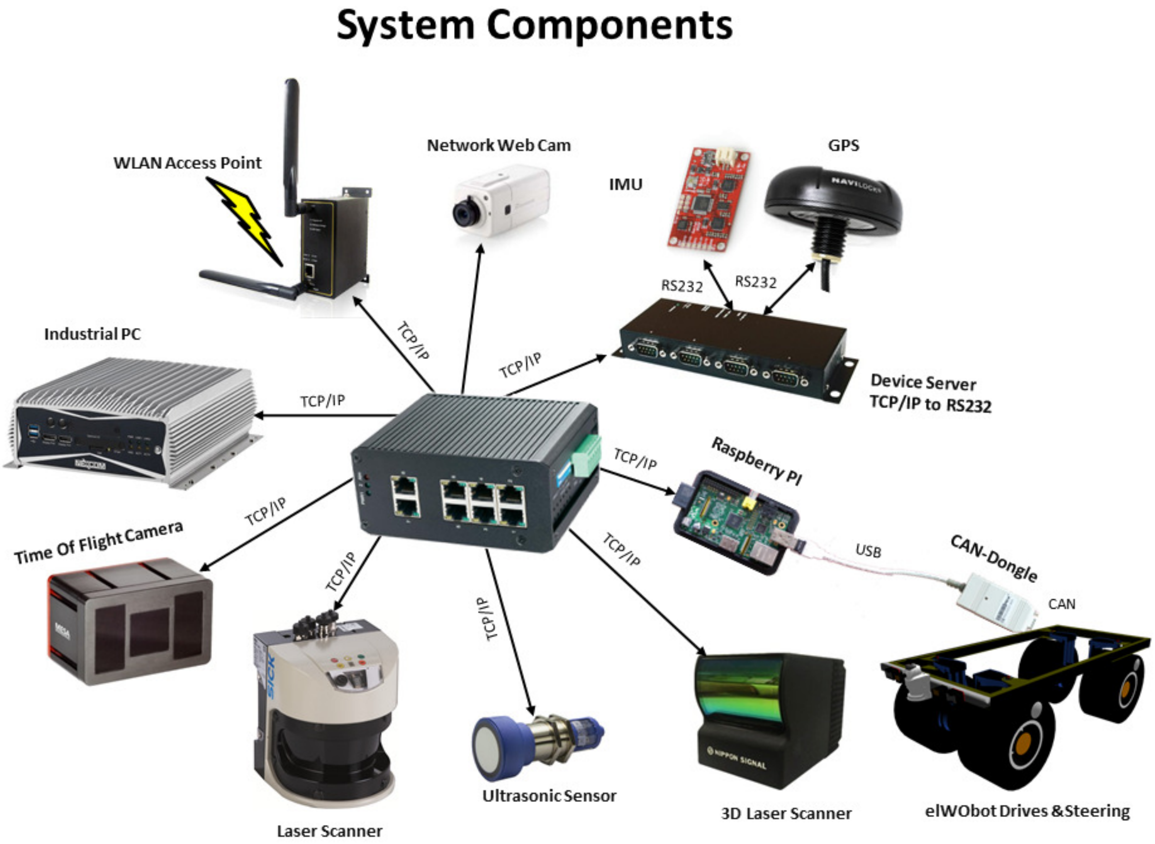


Figure 5: System components

The open source framework ROS (Robot Operating System) has been chosen for integrating device drivers and navigation algorithms. Like shown in Figure 5, the whole system is divided in many devices (sensors & actuators), which distribute data and receive commands. Every sensor and actuator has its own "intelligent" and exchanges data. The main task of ROS is the management of this exchange. Figure 6 shows "Messages" (rectangle frame) and "Nodes" (elliptic frame). Every node describes a program running in its own process. The exchange of the data between the processes is established over "sockets" with so called messages.
The task of the "toolbox node" (Fig. 6) is, to evaluate the sensor data and to send drive commands (/cmd_twist) to the motor controller. So, it plays a central role, and almost all other nodes are connected directly to it.

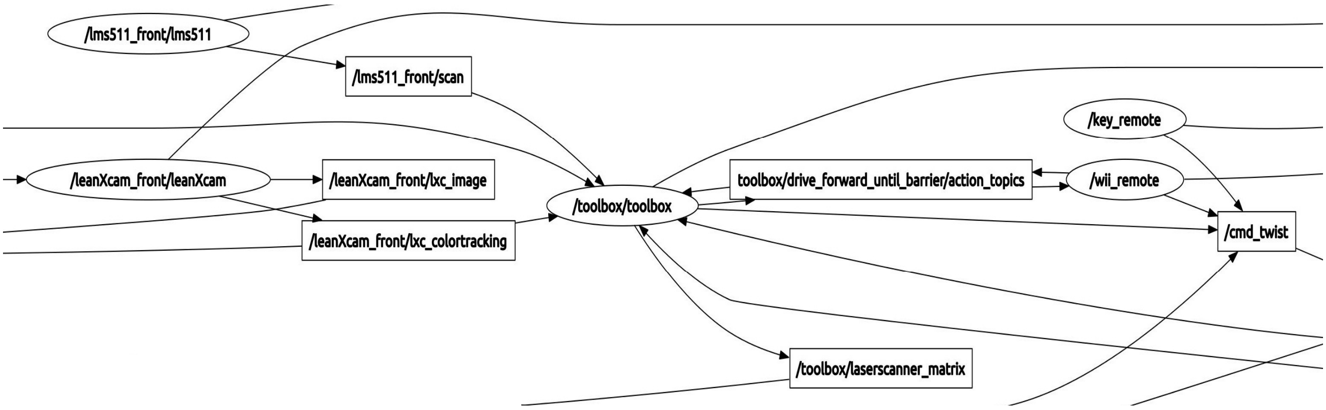


Figure 6: ROS: data exchange between nodes (elliptic frames)

3 TEST AND SIMULATION ENVIROMENTS

Because outdoor measurements are not possible in all seasons and every test drive in an orchard or vineyard needs a time-consuming preparation, an additional indoor simulation and test platform was build. This platform is sufficient for testing system architecture, dynamic behaviour of the sensors and first navigation algorithms. In Figure 3 the Fraunhofer robot platform Volksbot RT 4 is shown. GPS, the industrial switch, the WLAN-access point and the industrial PC are exactly the same which later on will be installed on elWObot. So, almost all software modules can be reused.

Figure 5: Simulation and test platform VolksBot

ROS supports a lot of helpful tools like RViz (sensor data visualization), SMACH (state machine) or Gazebo, a 3D simulation environment. The combination of Gazebo and Rviz is a very powerful tool for the development of navigation algorithms. Generated simulation data can be visualized and verified in RViz.

Maize is plant in a row structure like vineyards and orchards, thus for writing and testing first navigation algorithms in Gazebo, a model of the VolksBot and existing maize rows are applied.

Next Figure (Fig. 7) shows a model of the VolksBot with a lasers canner, a Time of Flight camera and a smart cam. The data of these sensors are visualized in RViz (on the right hand side).

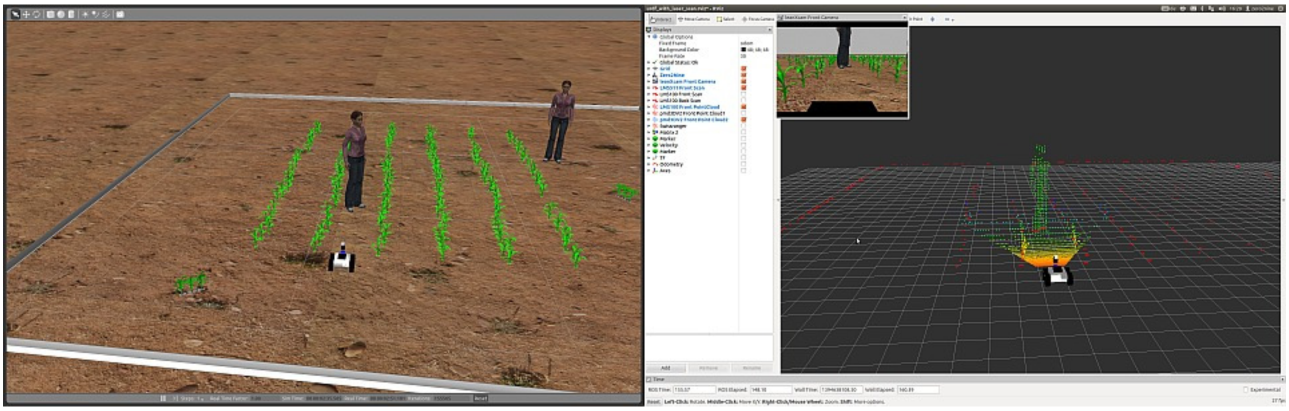


Figure 7: Gazebo and RViz

3.1 Navigation

First algorithms have been implemented and tested in the simulation and on the VolksBot platform. Finding the way in between the rows is done reactive. This means, evaluating the sensor data and control the robot directly. Another way would be to continuously generate a map, calculate the position and use this information for navigation. This leads to SLAM-algorithms (Simultaneously Localization and Mapping) and is exaggerated for this row navigation. To structure the different functions, a state machine (SMACH) is used. A pattern mode gives the ability to choose in advance, which rows should be driven through.

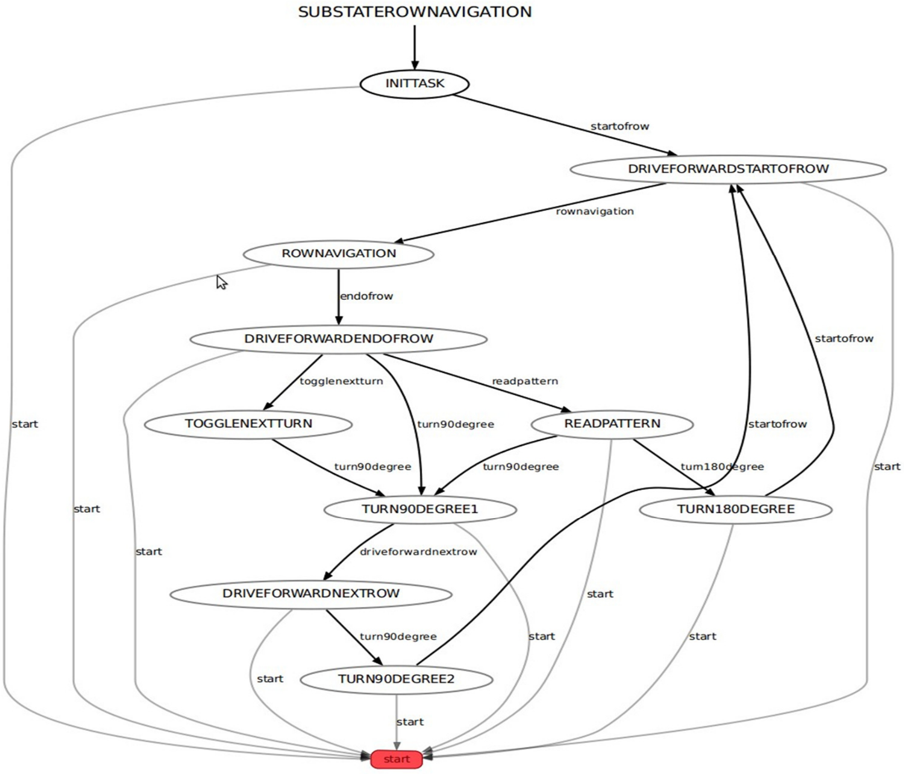


Figure 7: State machine for row navigation

A first model of elWObot is implemented in Gazebo. PID controller for the drives and the steering are applied, to have a model as close as possible to the reality. Actually, the robot is able to switch between four steering modes (Fig. 8):

- Front wheels steering
- Rear wheels steering
- Front and rear wheels steering
- Crab mode

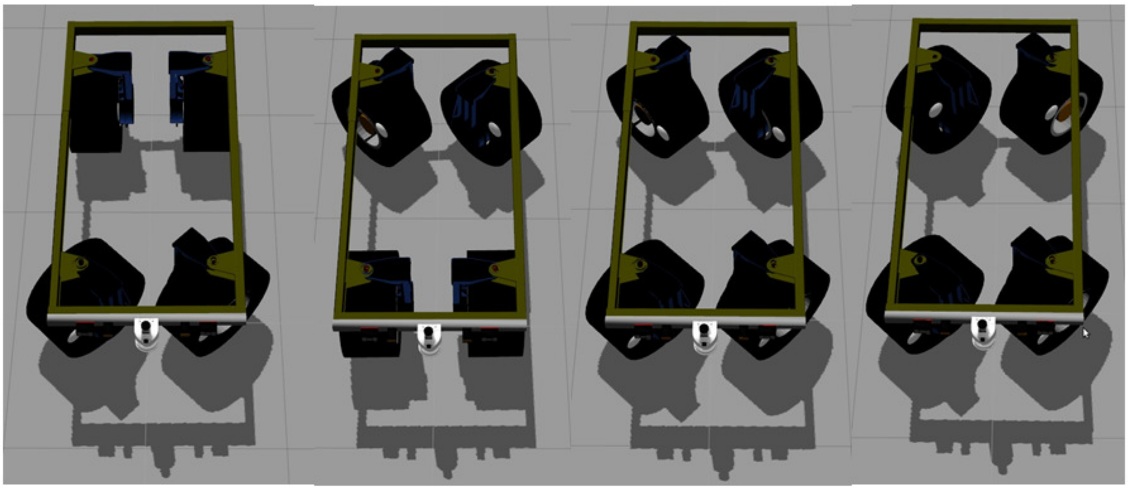


Figure 8: elWObot steering modes in Gazebo

4 OUTLOOK

First parts of elWObot have been built by the company Raussendorf and will be assembled and verified in the next stage. Sensor- and system technology has been conducted in orchards (cherry, pear and apple) mounted on a remote controlled vehicle (Caesar [1]), still without a leaf wall. This will be caught up with the elWObot prototype. Navigation algorithm developed with the help of gazebo will be adapted to the robot. Further on, sensor data from the leaf wall will be evaluated and used to control plant protection equipment.

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