Advances in Animal Biosciences: Precision Agriculture (ECPA) 2017, (2017), **8:2**, pp 848–853 © The Animal Consortium 2017
doi:10.1017/S2040470017000723

advances in animal biosciences

Modelling environment for an electrical driven selective sprayer robot in orchards

A. Linz[1†], D. Brunner[2], J. Fehrmann[3], T. Herlitzius[3], R. Keicher[2], A. Ruckelshausen[1] and H.-P. Schwarz[2]

[1]*Competence Center of Applied Agricultural Engineering COALA, University of Applied Sciences Osnabrück, Osnabrück, Germany;* [2]*Hochschule Geisenheim University, Center of Viticulture and Horticulture, Department of Technology, Geisenheim, Germany;* [3]*Technische Universität Dresden, Institute for Natural Materials Technology, Chair for Agricultural Systems and Technologies, Dresden, Germany*

Precise applying of PPP (Plant Protection Products) in orchards and vineyards requires new kinds of sprayer technologies and new methods of sensor data evaluation. In this paper a selective electrical driven sprayer, carried by the autonomous robotic platform elWObot, is introduced. A 3D-Simulation environment and the framework ROS (Robot Operating System) helps developing and testing the interaction between the sprayer and the robot. The calculated leaf wall area (LWA) and the distance from the sprayer to the leaves in the spray region, control the flow-rate and the air-assist of eight adjustable sprayers individually. First field trials showed that the adaption of the software from the simulation to the hardware worked as expected.

Keywords: 3D-Simulation, service robotic, LIDAR, selective electrical driven sprayer, orchard and vineyard

Introduction

Autonomous machinery on the field is going commercial (Ruckelshausen *et al.*, 2009; Bosch, 2016; Raussendorf, 2016) and thus new development tools are needed to adapt the robots to different events and applications. A robust framework (middleware) and a reliable simulator are requirements for developing and optimizing the software part of the robots firmware. Within the project "elWObot" (Linz *et al.*, 2014a and 2014b) ROS (Quigley *et al.*, 2009) and it's directly supported 3D-Simulator Gazebo (Koenig and Howard, 2004) is deployed. The framework ROS can be used in parallel on the machine as firmware and on the PC for the simulation. This makes the integration of the software quite simple. There are many other frameworks and simulators on the market, some of them commercial, some of them Open Source, like ROS. The free support of a huge community and the deployment of ROS in big companies like Bosch (Bosch, 2016) or BMW (Aeberhard *et al.*, 2015) led to the use of this combination of middleware and 3D-Simulation environment. Another important point is the ability of Gazebo to simulate different kinds of sensors.

Gil *et al.* (2007) showed that PPP can be reduced by 57%, using ultrasonic sensors to detect the LWA. This can be reached, because the LWA of the trees in an orchard or vineyard row can vary extremely in different heights. Since the use of LIDAR is more simple and inexpensive, and has a much higher spatial resolution than ultrasonic sensors, the laser scanner is the first choice for LWA detection. There are many works (Rosell *et al.*, 2009; Nielsen *et al.*, 2012; Rosell and Sanz, 2012; Rinaldi *et al.*, 2013; Sarri *et al.*, 2013; Tagarakis *et al.*, 2013; Bargoti *et al.*, 2015) related to geometrical characterisation of orchard canopy by using laser scanners. Most of them are calculating the sensor data offline, to generate an application map and to get a more precise information of tree biomass, growth estimation, yield prediction, water consumption estimation and health assessment (Rosell and Sanz, 2012). There are also online solutions described, deploying commercial sprayer which can adjust the dose rate in real time. (Gil *et al.*, 2007) utilized ultrasonic for sensing LWA, which is much more inaccurate than LIDAR. (Wellington *et al.*, 2012) utilized LIDAR for sensing LWA, but the "axial airblast sprayer" they used is not able to apply the optimal dose of PPP exactly to the calculated position. With the spray application and the method described in this paper, it is possible to bring out the PPP with the correct flow-rate and air-pressure to the right position (Fig. 1).

A new approach is to use a 3D-Simulation environment for the development and optimization of new algorithm and control processes (e.g. state machines), which can be directly adapted to the hardware with several spray applications in viticulture or horticulture maintenances.

Technologies

Autonomous electrical driven platform "elWObot"

The drive concept of elWObot (Fig. 2 left) is a combination of a diesel engine, a power generator and four independent

† E-mail: a.linz@hs-osnabrueck.de

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press

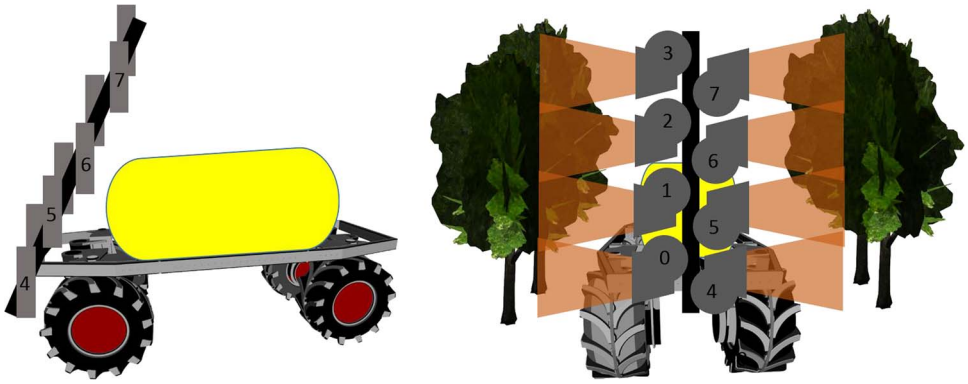


Figure 1 Concept of a robotic carrier with the spray application (left). Schematic rear view of the carrier and the spray application in an orchard (right).



Figure 2 elWObot - Electrical driven service robot for maintenance tasks in orchards and vineyards equipped with the spray application (left). Sensor fixture: a.) Horizontal laser scanner b.) 3D laser scanner c.) Vertical laser scanner d.) Webcam (right).

electrical driven wheels. This enables a very precise operation of the vehicle and allows several steering modes, like front wheel steering, rear wheel steering, four wheels steering, crab mode steering and turning on a point. Each wheel has an installed power of about 7 kW. This is needed to carry an overall load of up to 3.5t (robot + spray application + 1000 litre of chemicals). The base control of the platform is integrated in the PLC (Programmable Logical Controller) of the 8 frequency converters (4 x wheels + 4 x steering), and can be operated by an industrial radio-control connected to a CAN bus interface. The main navigation concept is based on two sensors, a 2D laser scanner and a 3D laser scanner. The horizontally mounted 2D scanner (Fig. 2 right, a.) with a maximum range of 80 m is responsible for recognizing the row, the end of the row and obstacles in the sight of its scan level. The 3D scanner (Fig. 2 right, b.) has a shorter range (about 9 m), scans horizontal and vertical distances and is installed to detect obstacles in the front of the robot. An additional low cost GPS and an IMU (Inertial Measurement Unit) is fused with the odometry data and generates position information for the U-turn at the end of the row. All sensors are connected to the main navigation unit via an Ethernet connection. Furthermore the navigation unit exchanges data with the PLC of the robot as well as with the spray application using the CAN bus interface.

Selective electrical driven sprayer

To achieve a high energetic efficiency in combination with the possibility to take into account not only (2D) LWA but also (3D) TRV (Tree Row Volume) (Sutton and Unrath, 1984) measurements for precise PPP application, a completely electrically driven sprayer module is developed. Two electric pumps provide arbitrarily adjustable flow rate and pressure combinations. Eight nozzles (four per side) are electrically switchable and one electrical blower per nozzle provides an individually adjustable air stream (Fig. 1 and Fig. 2 left). The concept of using electrical drives, electrically driven ball valves and electrically switchable nozzles in combination with the CAN bus capable PLC, allows sensitive control with respect to five domains:

1. General process control: depending on the signal from the navigation module the sprayer can adapt its settings to the current general situation, like activating the induction hopper for mixing PPP with water, driving to the field, moving or turning in headland, spraying, pause or emergency stop and internal cleaning of the whole system.
2. While spraying, flow rate and system nozzle pressure can be adapted to the required measure deduced from current LWA.
3. Blower air stream and also nozzle pressure can be adapted to be adequate to the current TRV

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press

(3rd dimension). So leaves within a very thick canopy may be reached by a stronger air stream, but energy isn't wasted using a reduced air stream in thinner parts of the canopy. This also helps reducing drift as water drops aren't shot through beyond the canopy.
4. The selectively switchable nozzles allow a very quick reaction to gaps within different height of the canopy. Depending on the canopy structure this can significantly reduce PPP consumption and drift.
5. If canopy structure or local plant health state require particularly intensive PPP application the sprayer module controller can send a CAN bus signal to the elWObot carrier vehicle to reduce forward velocity.

Basic technology components of the sprayer are 8 electrical blower with 0.5 kW, 2 electrical pumps with 2 kW (max. 4 MPa) and 8 switchable nozzles. Each blower and each pump is controlled by its own frequency converter.

Methods

3D-Simulation environment

Gazebo is an Open Source 3D-Simulation environment build on the physical engine ODE (Open Dynamic Engine) for simulating rigid body dynamics. The 3D rendering of the scenes is performed by OGRE (Object-Oriented Graphics Rendering engine), which supports the hardware acceleration of most graphic cards. ROS provides an interface to Gazebo and a XML description language (URDF) to describe the models in the simulated world. The URDF model is also used by ROS to transform all points and sensor data to the right position and orientation. Rviz is another important ROS tool. It gives the ability to visualize many kinds of data, like sensor data, position data, maps, markers etc. The source of the data can be provided from a real sensor as well as from a simulated sensor. This altogether forms a practical and helpful development environment for new robotic applications.

Principles of the "Spraycontrol"

The electrical driven sprayer is controlling the dose of PPP by varying the flow-rate and the air-pressure. Thus, there are parameters needed for every spray region individually. In this case there are 8 spray regions roughly defined in a rectangle with "sampleDistance", defining the distance in the drive direction and "sprayerLevel", defining the heights of the LWA (Fig. 3 right). The parameter "row_width" is needed, because the scanner is also looking into the next row, and this data should not be included. The markers in Fig. 3 (left) do not define the real application area of PPP, it is only a rough representation used for showing if the sprayer in this region is switched on or off.

To generate data for the 8 spray regions a vertical installed laser scanner in the front of elWObot is deployed (Fig. 2 right, c. and Fig. 4 right, c.). The distance range of the scanner is between 0,02 m and 50 m, the angular range is 270 degrees with a resolution of 0.5 degrees. The sample rate amounts 50 Hz (1/0.02 s) and limits the "sampleDistance", which depends also on the robots velocity. A minimum of one scan have to be within a "sampleDistance". For example, if the velocity of elWObot is 1.6 m/s (6 km/h) and the sample distance is defined with 0.15 m, the robot spends 0.094 s, thus the scanner samples 4 times (Fig. 5).

The position of the scan is different to the position of the sprayer. So, the switch position and the position of the spray levels must be calculated by a transformation, which can directly obtained from the URDF model (Fig. 6 left).

Furthermore, a setup file gives the ability to adapt parameters for different application scenarios (Fig. 6 right). A simple decision algorithm used for the first tests, checks if there is any hit in the spray region and if the distance of this hit is smaller than the "row_width". If this is true the sprayer will be switched on, otherwise it will be switched off.

Simulation test scenarios

The world for the first test in the simulation was generated with primitive objects, like a wall and a cube (Fig. 7).

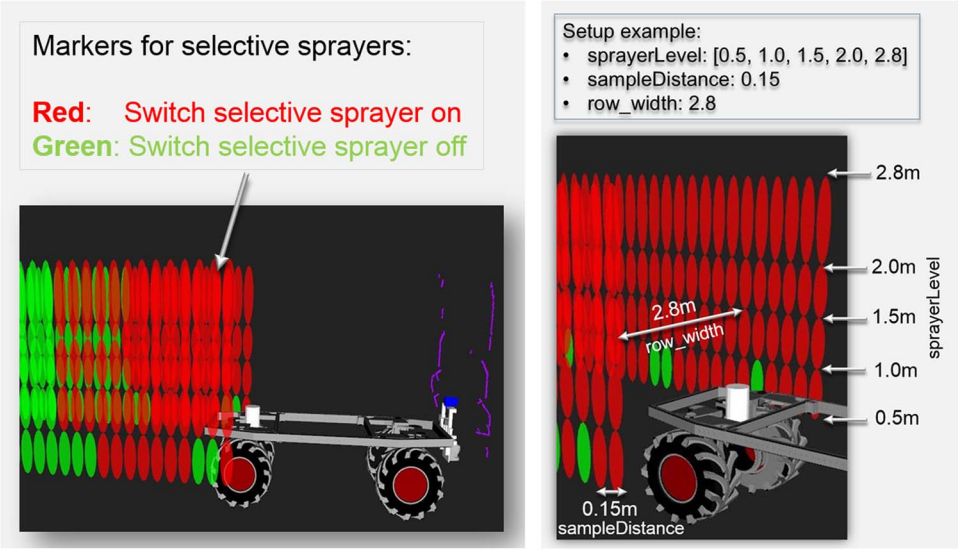


Figure 3 Spray markers in Rviz (left). Setup example for LWA regions (right).

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press



Figure 4 elWObot in the simulation environment Gazebo (left). Sensor fixture (simulation): a.) Horizontal laser scanner b.) 3D laser scanner c.) Vertical laser scanner d.) Webcam (right).

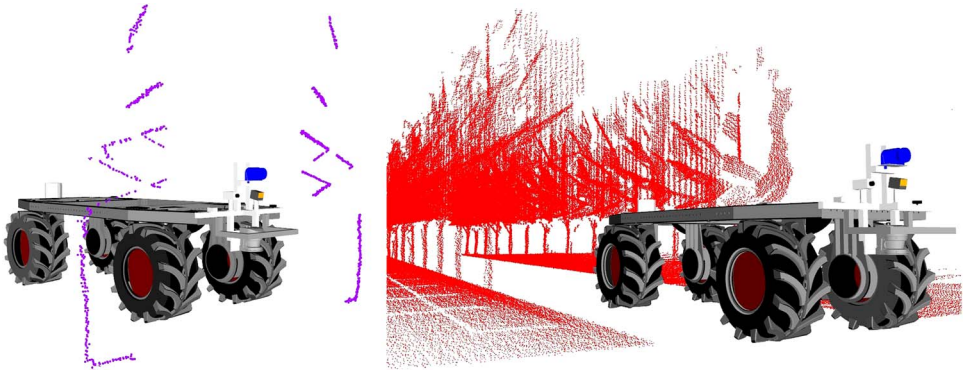


Figure 5 One laser scan in a simulated row of trees (left), Assembled laser scans (point cloud) while driving forward in a simulated row of trees (right).

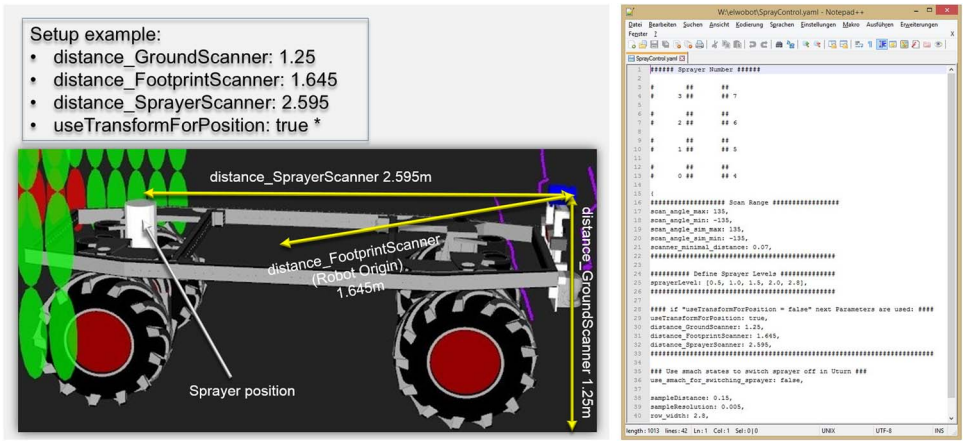


Figure 6 Transformation of the scan data (left) Setup file for "Spraycontrol" algorithm (right).

This was helpful to verify, if the "Spraycontrol" triggers at the right position.

The world in Fig. 8 has been generated to develop the autonomous navigation of elWObot (Linz *et al.*, 2014b). There are four rows with some missing trees. This is based on a real scenario, where old or sick trees have been removed. The simulation with elWObot was in a fully autonomous mode. The sprayer stops spraying at the end of the row, and starts again at entering the next row (Fig. 8 right).

Field tests without the spray application

Next step is to verify the software with real sensor data from an orchard. ROS supplies recording data in a so called "rosbag". This data includes timestamps and can be played back to the system. Fig. 9 shows a test field with young trees on the left side and older trees on the right side, thus the sprayer should bring out less PPP on the left side. By running the software with the collected data, the result is looking promising (Fig. 9 right).

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press

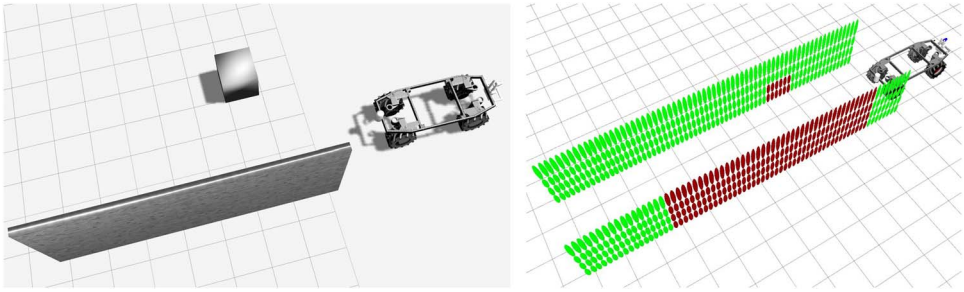


Figure 7 World in Gazebo with primitive objects (left) Output of "Spraycontrol" algorithm in Rviz (right).

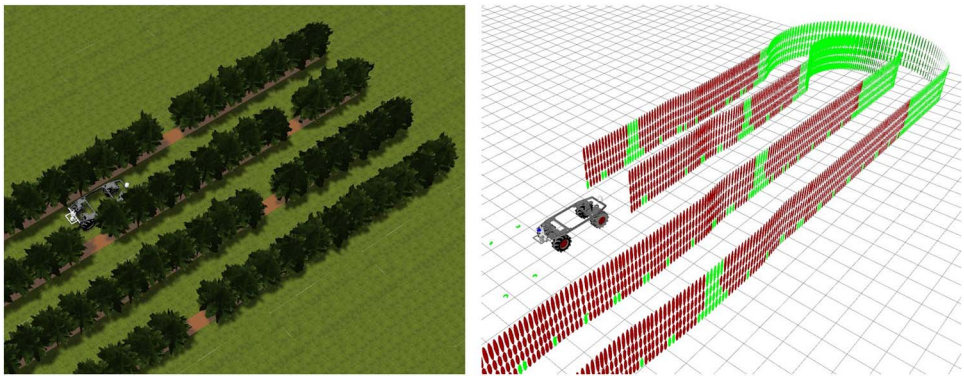


Figure 8 World in Gazebo with tree rows and removed trees (left) Output of "Spraycontrol" algorithm in Rviz (right).

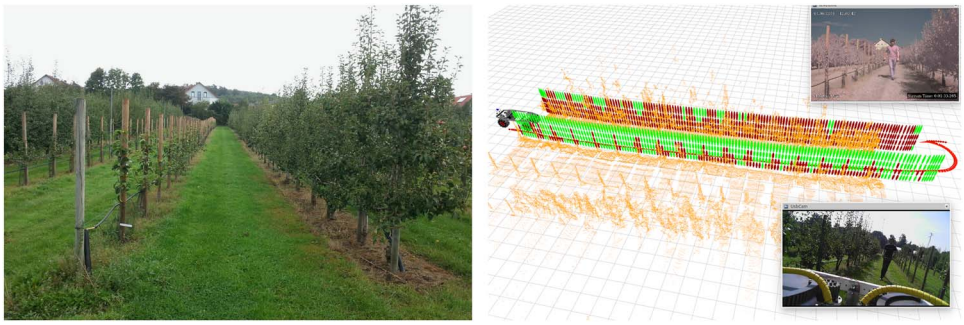


Figure 9 Test field with younger trees on the left side and older trees on the right side (left) Output of "Spraycontrol" algorithm in Rviz (right).

Conclusions

The modelling environment combination of ROS and Gazebo represents a helpful toolchain for developing new robot concepts including the simulation of the most important sensors. Simulation can be done before any hardware is existing. Furthermore real sensor data from the field can be used to verify and optimize the software. The same software can afterwards directly be implemented on the robot. The robot sprayer combination gives some advantages over the classical tractor trailer solution. The sprayer and the robot can interact and control each other. For example, an obstacle stops the robot and the robot turns off the sprayer. The other way round, the sprayer detects no leave wall, stops spraying, and give the information to the robot to increase the velocity.

First field tests with the robot sprayer combination have been conducted on an orchard near Dresden. Water was used for spraying and additionally one bright light for each sprayer indicated if the nozzle was switched on or off. The results showed, that the software implementation from the simulation to the hardware (elWObot) worked as expected. The sprayers switched off at the gaps in the row, at the end of the row and in the U-Turn. Next step will be to verify the quality of the spray result and to compare it with the simulation data. This will help to optimize the model and the method.

Acknowledgements

The project elWObot is supported by funds of the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support program.

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press

References

Aeberhard M, Kühbeck T, Seidl B, Friedl M, Thomas J and Scheickl O 2015. Automated Driving with ROS at BMW. ROSCon 2015, Hamburg, Germany.

Bargoti S, Underwood JP, Nieto JI and Sukkarieh S 2015. A Pipeline for Trunk Localisation Using LiDAR in Trellis Structured Orchards, Ed. Springer International Publishing, pp. 455–468.

Bosch 2016. DeepFieldRobotics. https://www.deepfield-robotics.com (retrieved November 2016).

Gil E, Escolà A, Rosell JR, Planas S and Val L 2007. Variable rate application of plant protection products in vineyard using ultrasonic sensors. Crop Protection 26 (8), 1287–1297.

Koenig N and Howard A 2004. Design and use paradigms for gazebo, an open-source multi-robot simulator. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No.04CH37566), Sendai, Japan, pp. 2149–2154.

Linz A, Brunner D, Fehrman J, Grimsel M, Herlitzius T, Keicher R, *et al.* 2014a. "elWObot"- A Diesel-Electric Autonomous Sensor Controlled Service-Robot for Orchards and Vineyards. In: Proceedings 4th International Conference on Machine Control and Guidance, March 18–20 Braunschweig, Germany.

Linz A, Hertzberg J, Ruckelshausen A and Wunder E 2014b. Autonomous Service Robots For Orchards And Vineyards: 3D Simulation Environment Of Multi Sensor-Based Navigation And Applications. In Proceedings of the 12th International Conference on Precision Agriculture, July 20–23, Sacramento, CA, USA.

Nielsen M, Slaughter DC, Gliever C and Upadhyaya S 2012. Orchard and tree mapping and description using stereo vision and lidar. SPC-03 IV International Workshop on Computer Image Analysis in Agriculture.

Quigley M, Conley K, Gerkey B, Faust J, Foote T, Leibs J, *et al.* 2009. ROS: an open-source Robot Operating System. ICRA workshop on open source software.

Raussendorf 2016. Obstroboter Caesar. http://www.raussendorf.de/obstroboter.html (retrieved November 2016).

Rinaldi M, Llorens J and Gil E 2013. Electronic characterization of the phenological stages of grapevine using a LIDAR sensor. In: Precision Agriculture '13, Proceedings of the 9th European Conference on Precision Agriculutre, JV Stafford (Ed), July 7–11, Lleida, Spain, Wageningen Academic Publishers, Wageningen, pp. 603–609.

Rosell J and Sanz R 2012. A review of methods and applications of the geometric characterization of tree crops in agricultural activities. Computers and Electronics in Agriculture 81, 124–141.

Rosell JR, Sanz R, Llorens J, Arnó J, Escolà A, Ribes-Dasi M, *et al.* 2009. A tractor-mounted scanning LIDAR for the non-destructive measurement of vegetative volume and surface area of tree-row plantations. A comparison with conventional destructive measurements. Biosystems Engineering 102 (2), 128–134.

Ruckelshausen A, Biber P, Dorna M, Gremmes H., Klose R, Linz A, *et al.* 2009. BoniRob – an autonomous field robot platform for individual plant phenotyping. In: Precision Agriculture '09, Proceedings of the 7th European Conference on Precision Agriculture, Wageningen, The Netherlands, Wageningen Academic Publishers, pp. 317–318.

Sarri D, Lisci R, Rimediotti M and Vieri M 2013. The RHEA-project robot for tree crops pesticide application. In Poster Proceedings of the 9th European Conference on Precision Agriculutre, July 7–11, Lleida, Spain.

Sutton TB and Unrath CR 1984. Evaluation of the Tree-Row-Volume Concept with Density Adjustments in Relation to Spray Deposits in Apple Orchards. Plant Disease 68, 480–484.

Tagarakis A, Liakos V, Chatzinikos T, Koundouras S, Fountas S and Gemtos T 2013. Using laser scanner to map pruning wood in vineyards. In: Precision Agriculture '13, Proceedings of the 9th European Conference on Precision Agriculutre, JV Stafford (Ed), July 7–11, Lleida, Spain, Wageningen Academic Publishers, Wageningen, pp. 633–638.

Wellington CJ, Campoy L, Khot L and Ehsani R 2012. Orchard Tree Modeling for Advanced Sprayer Control and Automatic Tree Inventory. 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vilamoura, Algeria.

https://doi.org/10.1017/S2040470017000723 Published online by Cambridge University Press