International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July
Ref: C0223

LIDAR-based control of automated orchard sprayer

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Abstract

For efficient orchard spraying a sprayer with continuously moving geometry of its spraying arms was developed. Spraying arms were continuously adapting to shape and density of a tree canopy. To realize proper movements spraying arms were equipped with hydraulic cylinders and position sensors. The sprayer itself was equipped with a velocity sensor to automatically cease spraying when the tractor stopped. Tree canopy was measured with 2D LIDAR mounted on the sprayer. Scans were positioned perpendicularly to driving direction. In this way data of canopy height and its horizontal distance from the sprayer (for the side closer to LIDAR) were obtained. Sampling frequency of LIDAR was 50 Hz so during spraying consecutive scanned planes were only a few centimeters apart. Based on LIDAR measurements with very high spatial resolution and accuracy, the canopy at a given position along the row was characterized by determining its contour. From simplified contour the required nozzle positions and inclinations for each spraying arm were calculated. At the same time LIDAR measurements were used to estimate canopy density on the basis of a number of detected targets – received reflections of a laser beam inside a specific region of interest. Both results were used to control electromagnetic valves for hydraulic cylinders and pesticide spraying. Considering such spraying as a time-dependent process, each scan was saved in a local database with a time stamp and current driving velocity. At a given location the appropriate scan was taken from the database for further processing based on a traveled distance from the point where measurements were taken. This was done to take into account the distance between LIDAR and the spraying arms causing some time offset dependent on sprayer velocity. Regulation and control were realized in LabVIEW programming language. The sprayer was equipped with a computer which was in interaction with sprayer hardware via digital and analog National Instruments cDAQ modules. LabVIEW was found to be very suitable for a given purpose because different tasks can be divided into independent subprograms which run similarly as the data flow goes. Finally the sprayer was tested in real orchard conditions. Spray quality was estimated by spray coverage detected with water-sensitive papers mounted on trees. Results showed greatly improved coverage. This means that with our sprayer significant pesticide savings can be achieved.

Keywords: plant protection, variable geometry, canopy detection, LabVIEW

1 Introduction

For profitable production of fruits in orchards under intensive cultivation, fruits and trees are treated with pesticides many times per year (Downey et al. 2011). To reduce pesticide costs and harmful environmental effects, spraying must be performed in an effective way so that pesticide losses are minimized. The losses are strongly linked to spray drift (Centner et al. 2014) which for air-assisted orchard sprayers generally depends on weather conditions, nozzle selection, pressure, air speed etc.

However, even when all these factors are optimally set the drift can occur because of sprayer design which does not take into account the varying canopy properties of a row of trees (Cross et al. 2001). In that manner the influential factors can be divided into the ones affecting spraying at a system level (weather, pressure etc.) and the others affecting it locally (e.g., canopy characteristics). In the past, improvements were mainly done by researching the systemic factors whereas recently the overall technological advancement enabled significant technological development in intensive orchards based on improved knowledge of local factors. For this, two new segments were introduced into spraying process: sensing and control. They must be automated and performed in real-time. Typically, various sensors such as ultrasonic sensors, cameras or LIDAR were used to measure canopy properties in orchards (or vineyards), which were later correlated with the corresponding (necessary) amount of pesticides (Gil et al. 2007, Llorens et al. 2011, Sanz et al. 2013). Sprayer controls were consequently limited to flow rate variations, individual nozzle activation and velocity of assisting air.

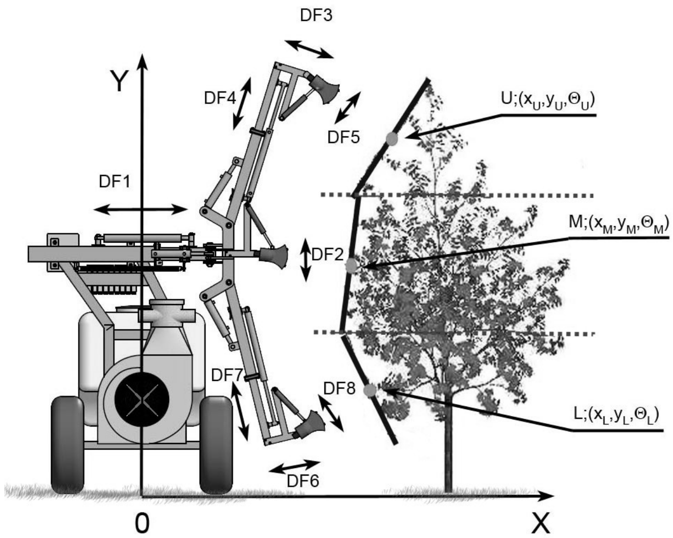

Figure 1: Canopy adapted spraying based on LIDAR data

In addition to this, our approach shown in the present paper and Figure 1 was based on the fact that drift can be also reduced by spraying directly towards the canopy (Hočevar et al. 2010). For this purpose a sprayer with variable geometry was used. To automate the spraying process LIDAR was used to continuously measure a canopy of orchard trees. Obtained data were processed with LabVIEW and results were used to automatically adjust positions of the spraying arms. This was done by controling electromagnetic valves of hydraulic cylinders of the spraying arms.

2 Materials and methods

2.1 Sprayer

Figure 1 shows a simplified schematic rear view of the trailed air-assisted orchard sprayer used in our work. It has three hydaulically moveable spraying arms which enable 8 degrees of freedom (DF). A detailed description of the sprayer can be found in Hočevar et al. 2010. For our purposes it is enough to mention that each arm covers one height segment of a tree canopy (L – lower, M – middle, U – upper) and that the spraying arms are positioned in a 2D Cartesian coordinate system moving with the sprayer. Canopy shape was continuously measured with LIDAR SICK LMS 111 (SICK AG Waldkirch, Reute, Germany) which was connected to a computer (Intel Core i5-3570, SSD) mounted on the sprayer (Figure 2).

LIDAR data were processed in a LabVIEW environment (National Instruments Corporation, Austin, TX, USA) which was also used to interface with I/O signals. For this, National Instruments (NI) C-modules with analog inputs (NI 9205) and digital outputs (NI 9476) were used, mounted inside a NI cDAQ-9174 chassis. Digital outputs were used to operate electromagnetic valves for hydraulics and spraying. LIDAR was mounted on the sprayer 2 m

from the ground and 2.4 m ahead of the spraying arms. It has a view of 270° but due to the one-sided experimental sprayer design, only data from one side of the sprayer were used. Its measuring plane was perpendicular to the row and the tractor-sprayer axis. Acquisition rate was 50 Hz and angular resolution was 0.5°. Distance-dependent diameter of a LIDAR laser beam is the distance [mm] x 0.015 rad + 8 mm (ref: SICK, 2012) so at a distance of 3 m (which is more than half of the inter-row distance plus canopy thickness), its measuring point has a diameter of 53 mm while vertical distance between them is approx. 2.6 cm.
The operating system of the computer on the sprayer was Windows XP. With average loop times under 1 ms this was a suitable solution in terms of reliability/cost/convenience. However, LabVIEW programs used for automated operation of the sprayer were written in a way that enabled their simultaneous and independent execution on all computer cores.

Figure 2: Orchard sprayer with LIDAR (1), computer (2), electronics (3), electromagnetic valves (4), spraying arms and air ducts (5), tank (6) and radial fan (7)

2.2 Experiments

The experiments were done in the research orchard of Brdo pri Lukovici (46°10'N, 14°40'E, the Agricultural Institute of Slovenia). The measurements were performed on spindle trained apple trees on cultivar 'Breaburn' grafted on M.9 rootstock at 1.5 m spacing and 3.5 m inter-row distance. The trees were fully foliated, their average height was 3 m (max. 3.5 m). Spraying was done with water. The sprayer was equipped with TeeJet hollow cone nozzles TXA80 01VK and 02VK (orange and yellow, 0.68 l/min and 1.40 l/min at 10 bar, respectively). All experiments were conducted at pressure 10 bar.
Spray coverage was observed by water sensitive papers (WSP). The size of WSPs was 76x26 mm. They were placed on four random apple trees along the row used for the experiments. WSPs were attached to leaves in pairs so that one WSP faced the sprayer and the other was turned away from it in order to observe spray coverage on both sides of leaves. According to the typical geometry of the tree canopy they were placed with regard to tree height (upper, middle and bottom position), depth (front, middle and back position) and side (left, right position). At the end of each spraying experiment WSPs were collected and quantitatively evaluated. Analytical methods used for their evaluation were based on computer-aided visualization of their scanned images. WSPs were scanned with resolution of 1200 DPI. Spraying of trees was done at five different regimes:
1) sprayer with adapting spraying arms, nozzles open all the time,
2) sprayer with adapting spraying arms, nozzles open according to row density (method 1),
3) sprayer with adapting spraying arms, nozzles open according to row density (method 2),
4) comparison with a classic sprayer,
5) sprayer with adapting spraying arms, nozzles open all the time (no. 1 repeated).
Differences between methods 1 and 2 were in density limits set for nozzle opening and in nozzle combinations. The first method used both orange and yellow nozzles while the second method preferably used orange nozzles with lower volumetric flow rate. The classic

sprayer used for comparison was a commercially available air-assisted trailed sprayer with a 800 mm axial fan (sprayer type Zupan 1100L, Slovenia, with pump Annovi/Reverberi AR904, Italy). Its working parameters were set according to the best orchard practice. It was set so that it sprayed only one side of the row. Sprayer velocity during all experiments in the second phase was 1 m/s. Weather conditions during spraying were dry and hot (30°C) with wind velocities under 1 km/h.

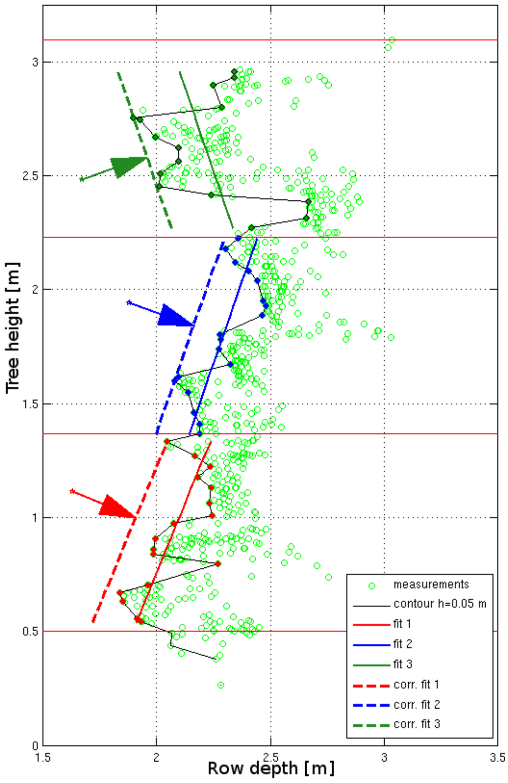

Figure 3: Positioning of spraying arms based on LIDAR data

During spraying LIDAR measures its distance from the canopy at its momentary position along the row. As can be seen in Figure 3, from measured points (green circles) a contour for the nearest side a tree is determined (black line). The contour is then approximated with linear segments (red, blue and green solid lines). Their number corresponds to a number of spraying arms (3) so that each segment represents one third of tree height (indicated by thin horizontal red lines). To prevent collision of spraying arms with a tree structure, fitted linear segments were moved in paralel to the nearest canopy point within the range (red, blue and green dashed lines). Further on, position of spraying nozzles (placed at the end of spraying arms) was determined in such way that each nozzle was normally directed to the corresponding linear segment at a distance where (considering its spray angle) it covered its whole width.

Finnaly, calculated positions were smoothed (filtered with a low-pass filter) to facilitate movement of spraying arms (Figure 4). Such approach was possible because of the high speed of data acquisition, processing and control algorithms. In Figure 5 it is shown that after the smoothing, movements of arms are mostly within centimeter range (red). It is also important that the initial peaks representing movements larger than 0.1 m were completely eliminated. The positioning algorithm is described in detail in Osterman et al. 2013.

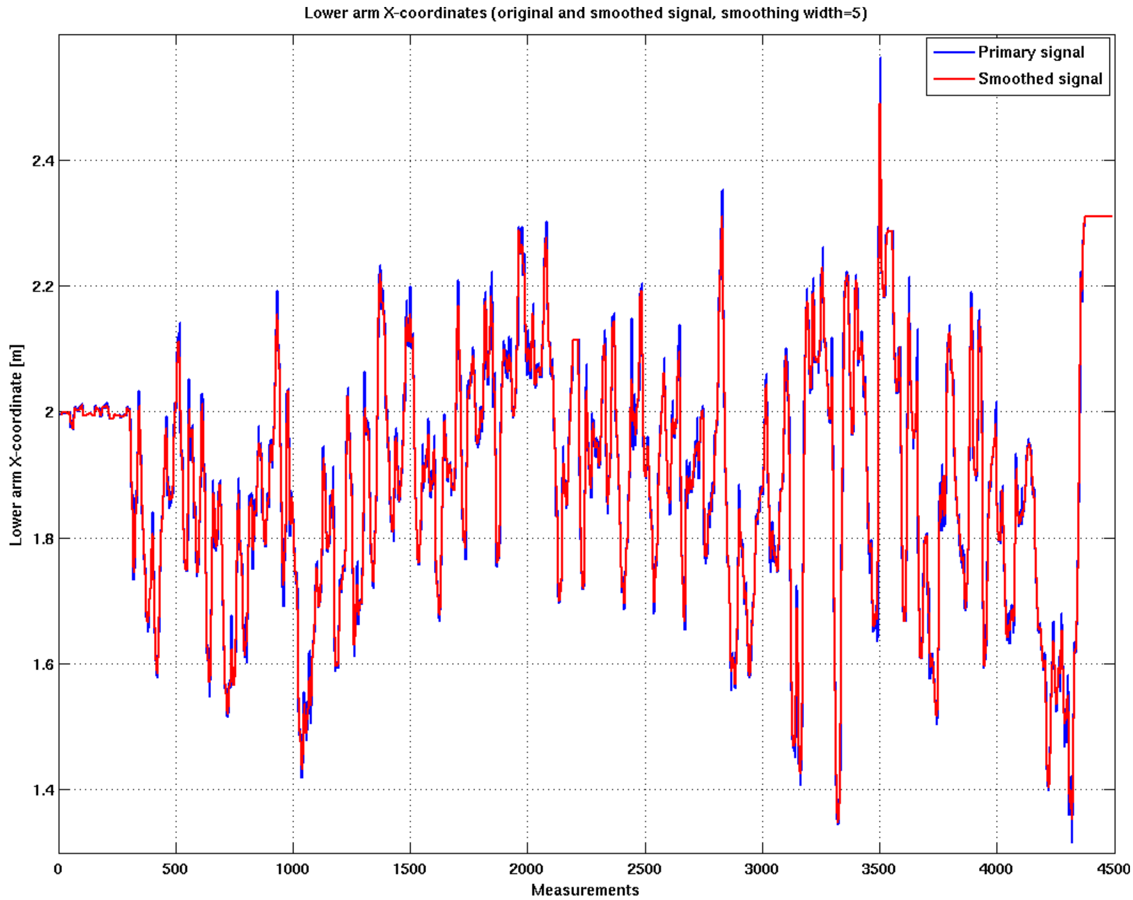

Figure 4: Original and smoothed arm positions

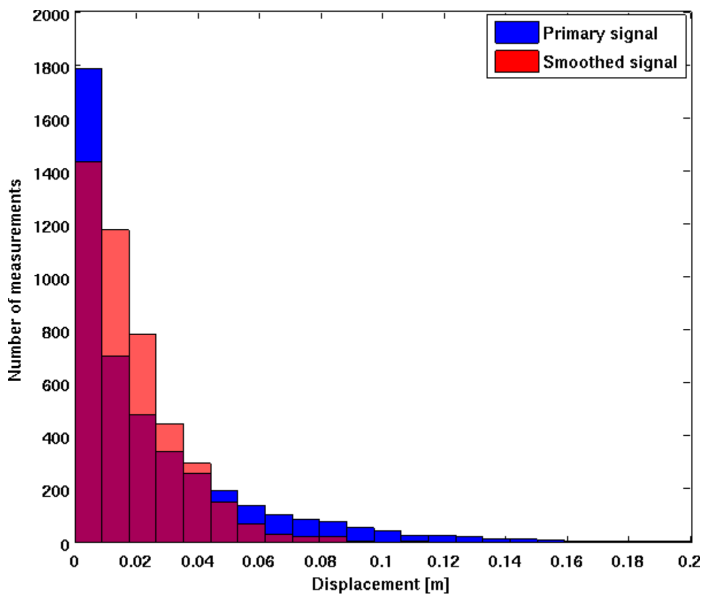

Figure 5: Comparison of arm displacements before and after smoothing

3 Results and discussion

Figure 6 shows normalized mean coverage with regard to canopy position as seen in the spraying direction. Values were normalized by the values of the experiment no. 4 which means referential spraying with the "classic" sprayer. Better coverage than this is indicated by values greater than 1. As expected, the highest coverage was obtained for experiments 1 and 5 when nozzles were opened all the time.

Experiments 2 and 3 showed smaller increases because some nozzles were closed part of the time when the canopy was thinner. It is also important that for experiments 1 and 5 coverage of the back and middle canopy section was increased which indicates better penetration of the spray. As far as drift is concerned, this behavior is undesirable, because more spray escapes through the canopy (Walklate et al. 2011). However, it can be reduced by diminishing the velocity of assisting air flow. The differences in coverage between the experiments 1 and 5 (which were of the same kind) are mainly attributed to turbulence, positioning of WSPs and changes in driving velocity.

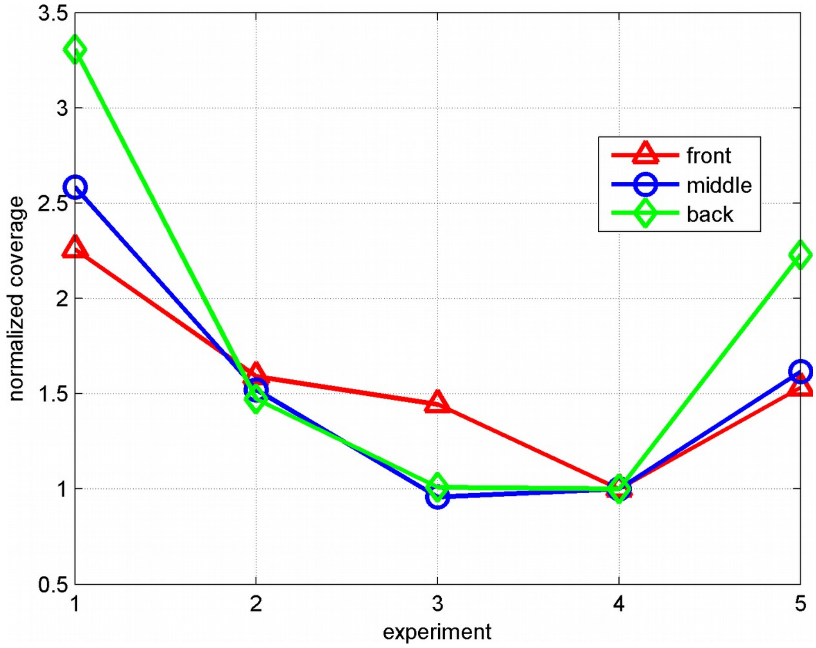

Figure 6: Spraying results (normalized by experiment no. 4)

In Figure 7 similar diagrams can be observed. They show the same data weighted by actual (measured on site) consumption of spray. As the driving velocity (approx. 4.5 km/h) was dependent on the driver of the tractor, some variations occurred which were taken into account by knowing the actual spray consumption. The results show that with a new sprayer, coverage was increased in all cases, ranging from approx. 50% to more than 400%. From these results, pesticide savings from 33% to more than 75% can be expected.

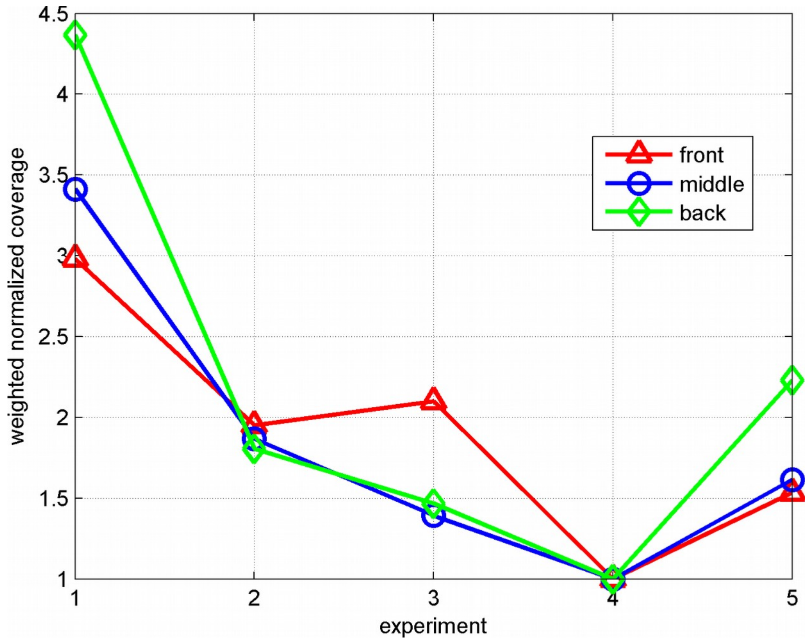

Figure 7: Spraying results (normalized by exp. no. 4 and weighted by actual spray consumption)

4 Conclusions

The paper shows how an experimental orchard sprayer with a variable geometry of spraying arms was automated on the basis of continuous canopy measurements. During spraying, measurements were simultaneously done with LIDAR. On the basis of these measurements, positons of spraying arms were hydraulically adapted to canopy shape. LIDAR data, positioning and other sprayer controls were processed in LabVIEW programming environment on a PC mounted on the sprayer. Spraying experiments in real orchard environment performed with water sensitive papers showed significantly better coverage when compared to existing sprayers. On average, the coverage was increased from about 50% to more than 400% depending on the spraying scenario. This confirmed the efficiency of the canopy adapted spraying based on a variable-geometry-sprayer approach.

5 Acknowledgements

This work was funded by the EU as a part of the 7 FP research project CROPS (grant agreement number 246252).

6 References

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